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RETHINK ROBOTICS - FINDING A MARKET

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Professors Micah Siegel (Stanford University) and Fred Gibbons (Stanford University) guided the development of this case using the CasePublisher service as the basis for class discussion rather than to illustrate either effective or ineffective handling of a business situation.

Introduction

Since 1980, millions of manufacturing jobs have been outsourced to reduce labor costs in order to maintain competitiveness in the evolving global market for products. [1] While reducing cost, this has reduced the number of middle-income jobs in developed nations. Furthermore, outsourcing has created problems for firms that now operate in politically and/or economically unstable regions. [2] Rethink Robotics hopes that its automated manufacturing robot, Baxter, will enable domestic firms to competitively insource manufacturing jobs and thus improve efficiency.

Rethink Robotics was founded by Rodney Brooks in 2008 to build a low-cost, adaptive manufacturing robot. The original name, Heartland Robotics, reflects the company's ambitions to combat outsourcing. [3] In a 2012 press release, Brooks stated, "Rethink Robotics…will do for manufacturing workers what the PC did for office workers — increase their productivity by giving them direct access to technological tools." [4] Their distinctive robotic workforce is marketed as simpler, safer, smarter, and cheaper than traditional industrial robots. [5]

Rethink Robotics has received many awards and recognition. The company was listed in BostInno's "50 on Fire," MIT Technology Review's "10 Breakthrough Technologies 2013," and named an Edison Awards finalist. [6, 7] As of June 2012, Rethink Robotics had raised $74 million in VC funding. [8, Exhibit 1] Rethink Robotics is a member of RBR50, a list of leading global robotics companies selected by The Robotics Business Review editorial team for its "innovation, groundbreaking application, commercial success and commercial potential". RBR50 members range from small private companies such as Rethink Robotics to large public firms such as ABB Robotics and KUKA Robotics. These company's robots are designed for many applications, ranging from industrial use to education and research. [9] The basic goal of these robots is to simplify work while reducing workload and improving efficiency.

Industry Overview

US Manufacturing

According to reports by Boston Consulting Group, the US is heading to regain its status as a global industrial powerhouse. Decreasing energy costs, increasing labor costs abroad, and since idle US port capacity can be used for increasing exports have started to revitalize the US manufacturing industry. By 2015, the US is expected to have a 5% to 25% cost advantage in manufactured goods exports compared to Germany, Japan, the UK, and other countries.

In particular, the cost disadvantage relative to China will decrease. Additionally, the US will be less dependent on China for its imports. In 2010, the cost of producing a dollar's worth of goods in a Chinese factory was on average 12% less than in the US; by 2015, that cost gap is expected to drop to 7%. [10]

DEMAND FOR ROBOTICS

There is an increasing demand for both industrial and service robotics. Three factors are driving the current robot sales trend: the recovering auto sector, wage inflation overseas, and an expansion in robot capabilities. The ongoing recovery of car manufacturers, such as General Motors and Ford, who have continuously demanded for industrial robots, has significantly boosted the sales of the four largest robot makers (KUKA, ABB, Fanuc and Yaskawa). Fierce wage inflation in China is reducing the appeal for US companies to manufacture their products there. Finally, a vast expansion in the number of functions robots can perform (and thus, jobs they can replace at competitive costs) is stimulating the market. Additionally, there are markets for industrial robots in welding, machining, medical devices, clean rooms, as well as other industries. [11]

WORLDWIDE MARKETS

The prevalence of operational industrial robots worldwide has increased dramatically since 1998. [Exhibit 10] According to the International Federation of Robotics (IFR) study of World Robotics conducted in 2012, there were at least 1.15 million operational industrial robots by the end of 2011. This number is expected to increase by over 36% to 1.58 million by the end of 2015. [12]

The major manufacturing markets are the US, China, Japan, South Korea and Germany. However, demand from emerging economies is increasing with Brazil, India, Russia, and Indonesia emerging as new manufacturing hubs. According to Global Industrial Robotics Market Forecast & Opportunities, global revenues from these robots are expected to cross $37 billion by 2018. [13]

China is expected to lead demand for industrial robots in the next five years. [13] Kuka AG's CEO Till Reuter reports that "China alone bought 15,000 robots last year, and we expect that number to rise to about 20,000 this year". [14] Rising wages and demands for faster production are convincing Chinese manufacturers to invest in more robots to maintain their competitive advantage as global manufacturing exporter. China is expected to pass South Korea and Japan to become the largest industrial robot market in 2013. [15]

North America

North America is becoming a hub for industrial robotics. Statistics from the Robotic Industries Association (RIA), the industry's trade group, show that a total of 22,598 robots valued at a total of $1.48 billion were sold to companies in North America in 2012, exceeding 2011's record of 19,337 robots. Compared to 2011, North American unit sales were up 17%, while profits were up 27%. The fourth quarter of 2012 was the strongest quarter ever recorded by the RIA (the association began reporting data in 1984) with 6,235 robots sold to North American companies. The RIA estimates that some 225,000 robots are now used in United States factories, placing the country second only to Japan in industrial robot deployment. In North America, the majority of robots are used in the automotive industry. The number of robots sold to automotive OEMs has increased by 47% since 2011, while the number of robots sold to automotive component suppliers has increased by 21%. [16]

Applications

The industrial robotics sector, which has reached maturity over the last half century, primarily consists of immobile single-task robots. These robots have few human interactions and perform simple, repetitive tasks. In fact, there is often a safety barrier to keep human proximity at a minimum. The robots often perform hazardous tasks and are themselves potential hazards to nearby humans. Despite the fact that the market for robotics installations in small-to-medium-sized businesses exceeds that for large enterprises, smaller manufacturers have largely missed out on the benefits of robotic industrial automation. [17] The top 5 applications for industrial robots have been in handling operations (38%), welding (29%), assembly (10%), dispensing (4%), and processing (2%). [18]

Experts in the field of manufacturing, including Georgia Tech robotics professor Henrik Christensen, insist that building robots for small and medium-sized manufacturing companies "*is a fantastic opportunity...There are many tasks that don't require the speed and precision of today's industrial robots, and these tasks are begging to be automated*". [19]

Employee Displacement

In the manufacturing sector, the average hourly cost for a US factory worker is $23.32, compared to $1.36/hour in China and $25.80/hour in Germany. [4, Exhibit 2] Purchasing Baxter with a three-year warranty (and no extra add-ons) costs $27,000. Given this sale price, an eight hour work day, and 260 working days per year over three years, Baxter costs an average of only $4.32/hour. [11] Of course, robots can operate continuously without major breaks, therefore, the cost per hour can drop even further.

As a result, Baxter is very cost competitive, even with the cost of labor in China. Since Baxter can be operated anywhere, this means that for the same task production in the US is competitive with China - maybe even more so if benefits in transportation, energy cost, political/economic stability, and other macroeconomic factors are taken into consideration.

Brooks asserts that this will shift jobs back to the developed world if American and European manufacturers bring sufficient production back home through strategic worker supplementation rather than by replacement. [19] Study data demonstrates that when automation replaced manufacturing workers, general output improved, new markets were created, and downstream jobs were generated. [Exhibit 11] According to Professor Seth Teller, a robotics researcher at MIT, Baxter and other robots have the potential to create jobs in new industries that have not yet been envisioned. [15] Increased incorporation of technical innovations, including robots, has shifted labor demands to fewer, more highly skilled manufacturing jobs that are difficult to outsource. [20] Thus, industrial robots represent a unique opportunity to shift the current industry and bolster the US economy by preventing certain types of offshoring. [21]

Although integrating Baxter into certain manufacturing processes has shown promise for first world manufacturing processes, many still remain concerned that manufacturing jobs will fall overall. This thinking is bolstered by the fact that manufacturing has shed nearly 6 million jobs since 2000. [15] However, it is unclear how large a role industrial robots have played in this. As of April 2013, the unemployment rate for the manufacturing sector in the US was 6.4%, lower than the US national average of 7.1%. However, analysts do not expect job growth to return to pre-recession levels until 2017. [22]

Illah Nourbakhsh, head of the Robotics Masters Program in The Robotics Institute at Carnegie Mellon University, claims that without serious discourse and explicit policy changes, the current path will lead to an ever more polarized economic world, with robotic technologies replacing the middle class. Although robots may never acquire the ability to outperform humans at complex tasks, even mediocre robots could pose a threat to human employment due to significant financial benefits offered by robots. [23]

History of Rethink Robotics

Robotics pioneer Rodney Brooks founded Rethink Robotics in 2008. Originally named Heartland Robotics, the company's interests were to reduce offshoring in manufacturing labor and to increase the number of US jobs. The company aimed to provide affordable, intelligent robots for small and medium-sized businesses in the US.

Mission Statement

Rethink Robotics's mission is to produce a generation of intelligent industrial robots that can automate processes to improve manufacturing productivity, and maintain cost at the same time. These products are designed to be user-friendly, easy to use for people lacking prior robotics experience, affordable, and safe to operate. [26]

Baxter was the first robot that was created which satisfied Rethink Robotics' mission statement. In Brooks' words, "*Just as businesses had to completely rethink ways to use computers when the PC was first introduced, they will want to take advantage of opportunities created by this new class of robot. With our robots, businesses will have be able to rethink manufacturing, rethink automation, and rethink outsourcing.*" [27]

Milestones/Chronology

• **2008, July:** Heartland Robotics founded in Boston

• **2009, September:** Received $12 million initial Series A funding from Bezos Expeditions and Charles River Ventures [28]

• **2010, June:** Hired Scott Eckert to serve as CEO

• **2010, November:** Received $20 million Series B funding from Highland Capital Partners, Sigma Partners, Bezos Expeditions and Charles River Ventures [28]

• **2011, January:** Left Cambridge and moved to Boston

• **2012, June:** Renamed Rethink Robotics [29]; Received $30 million Series C funding by Highland Capital Partners, Sigma Partners, Bezos Expeditions, Charles River Ventures and Draper Fish Jurvetson (DFJ) [28]

• **2012, September:** Unveiled Baxter [30]

• **2012, October:** Preordered Baxter shipments began [31]

• **2013, April:** Launched Baxter Research Robot for labs and research

- **2013, May:** Named as top 5 CNBC Disruptors [112]
- **2013, 19th May:** Made to the Top 12 Innovators in Massachusetts list [117]

MANAGEMENT

CEO: SCOTT ECKERT

Scott Eckert was hired on June 4, 2010 as the CEO for then-Heartland Robotics, Inc. He was co-founder, president, and CEO of Motion Computing, the leading provider of tablet PCs for vertical markets. Prior to Motion Computing, Eckert was an executive at Dell, Inc, where was known for his disruptive contributions as chief architect and general manager of Dell's worldwide Internet strategy. Eckert was also Managing Director for Dell's Home and Small Business Division in the UK and Ireland. He holds a BA in Quantitative Economics from Stanford University and an MBA from Harvard Business School. [32, 33]

FOUNDER/CTO/CHAIRMAN: RODNEY BROOKS

Rodney Brooks is the founder of Rethink Robotics and co-founded iRobot (maker of Roomba and PackBot). Brooks was a professor of Robotics at MIT where he directed the MIT Computer Science and Artificial Intelligence Laboratory from 2003 to 2007. He has developed the behavior-based approach that served as the technical basis for Rethink Robotics's robots. Brooks holds a degree in pure mathematics from the Flinders University of South Australia and received a PhD in Computer Science from Stanford University in 1981. [19, 34 , 35, 36]

VP MARKETING & PRODUCT: MITCH ROSENBERG

Before joining the company in 2012, Rosenberg was VP of Marketing & Product Management at Kiva Systems, a robotics company focusing on automating warehouse material handling and order fulfillment. Under his direction, PR placements for Kiva robots increased by 500%. Kiva was featured in popular periodicals such as The Wall Street Journal, Forbes, Fortune, Bloomberg/Business Week, Bloomberg TV, Fox Business News, and Der Spiegel. Rosenberg has also held senior marketing positions at PictureTel, Kurzweil Computer Products, and Automatix. He holds BS and MS degrees in Electrical Engineering from MIT and an MBA from Boston University. [40]

VP Sales: Jason Barton

Barton most recently served as COO at EnergyHub, a cloud-based software platform host for managing energy usage in homes and small businesses. Barton's past roles include VP of Global Sales & Marketing at Segway, sales leader at Palm, and leadership of UK sales and marketing for Precor Inc. Barton holds a BA Honors degree from the University of Wales. [33]

VP Product Development: Elaine Chen

Chen previously served as VP of Engineering & Product Development at Zeo, Inc., a startup in the consumer health and wellness sector. She has also served as VP Product Management at Zeemote, Inc. and as VP of Engineering at SensAble Technologies. Chen earned her BSME and MSME degrees from MIT. [33]

VP Manufacturing and Operations: Jim Daly

Daly was previously VP of Operations at consumer startups Zeemote and Tea Forte, Director of Manufacturing Operations for Handspring (later acquired by Palm), and Manufacturing Director of Solectron's Complex Systems Division. [33] Given his emphasis on low-cost manufacturing for Baxter, Daly was said to be hired even before a basic design sketch existed. [40] He holds a BS in Industrial Engineering from Worcester Polytechnic Institute and an MBA from Santa Clara University. [33]

Board Advisor: Steve Jurvetson

Jurvetson is a managing director at the venture capital firm Draper Fisher Jurvetson. He serves on the board of several companies including SpaceX and Tesla Motors. Previously, Jurvetson held senior marketing positions at NeXT Computer and then at Apple. He holds BSEE, MSEE, and MBA degrees from Stanford University. [110]

Technology

Products

Since its inception, Rethink Robotics's goal has been to build a two-armed robot with a head to sit at the assembly line and assist workers. [39] Its goal is to mimic humans and perform the same work with better efficiency. The goal implies workforce supplementation rather than replacement, aiming to increase production for companies in an affordable manner.

Baxter's prototype's design initially comprised of just a single joint powered by two gearboxes salvaged from power drills. It then progressed to a more humanoid design, including arms with four degrees of freedom (DOF). Next came the inclusion of an arm with 6 DOF, similar to the popular robot arm of the 1980s, PUMA (Programmable Universal Machine for Assembly). After an internal debate, Rethink Robotics's engineers decided that a seventh DOF was necessary to better emulate the range of motion of the human arm. A team of 30 mechanical and controls engineers completed the first two-armed prototype in late 2011, followed by a second-generation design in early 2012.

Baxter

Rethink Robotics introduced its flagship product, Baxter, in June 2012. Through this two-armed robot, Rethink Robotics aimed to improve manufacturing capabilities for the 300,000 small businesses operating in the US. [40, 41, 42] Baxter can adapt to its environment and realize specific tasks without the need for complex programming and costly integration. Furthermore, Baxter is fully scalable, requiring only software upgrades to expand its capabilities. Baxter's low price provides a compelling alternative to low-cost offshoring for manufacturers of all sizes. [40] Additionally, new Baxter robots can be fully functioning within an hour of installation. [40] Once plugged into an ordinary power outlet, a person with no robotics experience can teach Baxter a new task by simply moving its arms around and following prompts on its user-friendly interface. [39]

Rethink Robotics says Baxter will become faster and smarter over time, due to continuous software updates and its ability to adapt to its environment. For example, it can automatically adapt to changes in position and lighting and to differently-shaped objects. [19] This represents a fundamental advantage of robotics integration into assembly lines and material handing: Most factory equipment is at its peak the first day, when the equipment is new, then slowly degrades over time. Baxter's robots instead become smarter over time, peaking long after installation. Well-known media sources have called Baxter everything from “A Robot with a Reassuring Touch” (New York Times) to “Better Than Human” (Wired). Baxter has also been named one of TIME magazine’s top inventions of 2012, and featured on 60 Minutes, The Wall Street Journal, The New York Times, and Wired. [43] Exhibits 5, 10, and 11 list its features and specifications.

Humanoid Robots

The most striking difference between Baxter and most other industrial robots on the market is its humanoid form factor. Even the name Baxter, as opposed to other companies' offerings like KUKA’s KR 1000 ‘Titan’, FANUC Robotics’ M-430iA, Adept’s Quattro s650, and Motoman’s SDA10 (also dual-armed), highlights Rethink Robotics's push for differentiation in this field. Baxter's facial expressions help human co-workers judge Baxter's intentions without needing to consult technical materials. For example, Baxter informs co-workers what it is about to do by looking in the direction where it will move its arm next. If a worker comes too close to Baxter, the robot's face exhibits a concerned expression. Baxter can even inform workers if it is confused or not working with facial cues. [Exhibit 7] Baxter is also programmed to apply human-like common sense to its environment. For example, if Baxter drops an object, it knows to get another before trying to finish its task. [40]

Training

According to Rethink Robotics, Baxter is easily trainable, even by employees with little or no robotics experience. Unlike traditional robots that require sophisticated software programming, Baxter can be trained by demonstration, just as one would teach a person. A non-technical factory worker can train Baxter to perform a specific task in less than 30 minutes. Because of its versatility and quick learning, Baxter can easily move from task to task over the course of a day, week, or month, much like a human employee. This flexibility is especially important for contract manufacturers that need to quickly adjust to demands.

Cost

Baxter was designed to be affordable for small to mid-sized manufacturers, companies that aren't normally able to afford robots. Priced at $22,000, Baxter is barely a tenth of some automated production-line systems and includes a year of software updates, warranty, and no required integration. Assuming the robot operates around the clock six days a week, Baxter's price works out to be less than a dollar per hour over the course of three years. However, with eight hour work days and 260 working days per year, Baxter costs an average of $4.32/hour. This undercuts most country's current going rates for industrial employee compensation. Brooks hopes Baxter's low cost and flexibility will allow companies to incorporate robotics into their home markets for some of the assembly work currently being done in areas with lower labor costs. [45] To achieve this critical price point, Rethink Robotics designed the robot from scratch, incorporating a plastic exterior and specially engineered parts and materials to keep costs low while retaining functionality. [46]

Software

At its core, Baxter uses the open-source Robot Operating System (ROS) that was originally developed in 2007 at Stanford's Artificial Intelligence Laboratory. Rethink Robotics recently released version 1.1 of the software with an extensible SDK. The SDK has basic building blocks like perception, object identification, face and gesture recognition, motion understanding, stereo vision with depth perception, control arm trajectory planning, and grasping. Rethink Robotics hopes these building blocks will enable faster customization for different applications and domains. The hope is that robot application development will go viral the same way software apps did for smartphones, eventually allowing Baxter to offer a diverse application offering. [40]

In contrast to Rethink Robotics's approach to software, traditional robots, such as those offered by iRobot (co-founded by Brooks), have closed system software. While iRobot's CEO Colin Angle argues that open software is not helping robotics from a business point of view, Rethink Robotics is betting that the best way to succeed is by getting others to "hack" Baxter. [43] Rethink Robotics is aiming for Baxter to be a platform that anyone can use to improve on existing applications or develop completely new ones. In April 2013, the company announced a version of Baxter designed for researchers, a step that will encourage development of innovative software applications. [40]

Moreover, the concept of an open SDK and an Apple-inspired app store will be enabled across Rethink Robotics's entire product line. The SDK enables users to train the robot and share their programs with other Baxter owners. The 'killer app' for robotics may not be an app at all, but instead the app store itself. Rethink Robotics has already made available libraries for low level tasks, such as joint control and positioning. [49, 50]

To receive feedback quicker from their customers, Rethink Robotics's software development business model involves rapid product release and development cycles similar to the Lean Startup Methodology. [Exhibit 6] This model emphasizes releasing a "minimum viable product" to early adopters to encourage swift validation. Adjustments are made based on customer feedback, and are then rapidly released again, helping to achieve optimal "product market fit". [47] Rethink Robotics plans to aggressively protect and develop its software-based intellectual property. However, hardware advances for the Baxter platform will come from both in-house and third party developers. Baxter hardware sales started on October 1, 2012, but were shipped with beta software. The finalized software was not released until January 1, 2013.

Safety

Most industrial robots move rapidly and occupy floor space. They are often caged to minimize the risk of injuring nearby workers. They make precise yet rigid movements that are needed for certain tasks. Baxter, however, has limited speed, lower weight, and moves with adaptable hesitation to allow for changes in its environment. Contrary to popular beliefs, these factors do result in reduced efficiency, but a safer design that allows for direct worker integration. [39, 41] Further safety enhancements include the use of sonar in its head to detect nearby objects. If Baxter spots a human in the vicinity, it slows down its current task. Also, instead of having motors drive gears that operate its joints directly, Baxter's gears drive a spring that moves the joint. This gives the robot's movements a degree of elasticity, which coupled with force sensors, provides a feedback mechanism much like the human body's haptic feedback system. For instance, if someone gets in the way of its arm, Baxter will sense that force and slow down or stop. [41] This system is comparable to the longstanding use of elevator doors sensors to prevent premature door closure. To summarize, Baxter includes three complementary safety systems:

1. **Passive Safety System:** Baxter is designed to be inherently safe. It has no sharp edges or mechanical pinch points. Surfaces that could potentially cause harm upon impact are equipped with protective padding, and every joint is designed to be compliant.

2. **Active Safety System:** Baxter contains sensors and software protocols that enhance safety. Sensors detect people within contact distance and trigger the robot to slow down to safer operational speeds. This makes it easier for people to avoid inadvertent contact, and reduces impact force in the event of unintended collision.

3. **Interface To Third-Party Safety Components:** In addition to Baxter's built-in safety system, customers can augment it with external safety components. Baxter's data ports interface with third-party safety devices such as safety mats and light curtains. [43]

User-friendliness

Programming a traditional robot requires technical personnel to write code or run the robot through its paces by pushing buttons on a handheld control box. This process is time-consuming and requires personnel have technical programming and robotics experience. Baxter, on the other hand, does not rely on custom programming to perform new tasks. Instead, it has workers move its arms to emulate the task at hand while following prompts on its user interface. [19] Five cameras provide guidance, allowing Baxter to adjust automatically if items turn up in different positions or if it drops something. [40] All these factors enable even non-technical workers to train and retrain Baxter on the line.

For example, to show Baxter how to take an object out of a box and then put it on a conveyor belt, a worker would grab the robot by the "wrist" to get its attention. Baxter will stop what it's doing and look at the worker to indicate attention to training. Moving the arm over to the box and using buttons and a knob on the arm to navigate a series of menus on the LCD tells the robot to use its computer vision to locate the object. Finally, moving the arm over to the conveyor and pushing a few more buttons will let Baxter know where to drop the object off. Baxter will then acknowledge successful training by nodding its “head”. Pressing the “play” button tells Baxter to begin executing the task on its own.

Rethink Robotics offers two interchangeable end-effectors (appendages) that enable Baxter to work with a wide range of objects. This modular attachment method enables the customer to change end-effectors in minutes. Rethink Robotics is developing additional end-effectors, and will make specifications available for third parties interested in developing their own. [45] Thus user customization won't be limited to software apps, but will include hardware as well.

MOBILITY

While Baxter can be bolted to a table or other stable surface, Rethink Robotics offers an optional rolling mobile pedestal with industrial grade casters for manufacturers who want to move it quickly and safely between workstations. The mobile pedestal offers two adjustable heights and is designed to fit through standard doorways. It includes cable management to prevent cable clutter and keep the workplace safe. [43] Safety, yet good mobility is powerful combination and a force to be reckoned with.

COST EFFICIENCY

Baxter achieves a low price point through advanced technology and product differentiation. Baxter’s arms contain a mechanism called a series elastic actuator, in which the motor and gearbox drive a spring, which in turn drives the joint. The spring makes the actuator more pliable and lets the device measure forces. Real-time monitoring of forces on each joint allows the robot to react to force appropriately and safely. This feedback is employed when moving the robot's limbs for training. The series elastic actuators also act as filters that help reduce friction and backlash in low-cost gearboxes. Additionally, they can act as shock absorbers if the robot experiences accidental impact. David Lewis, senior mechanical engineer at Rethink Robotics, explains that having good force control enables Baxter to perform actions such as picking up parts or pushing buttons that normally require precise and expensive position control components. [19]

CUSTOMIZATION

Baxter's software and user interface enable a variety of tasks to be easily programmed. Some examples of tasks Baxter can perform include: [43]

- Pick parts from structured locations and load a line with them
- Press-fit plastic parts into place
- Load and unload paint racks
- Apply adhesive beads and wipe off excess adhesive
- Use a scale to weigh parts
- Use precision
- Operate visual quality inspection stations
- Operate heat and seal, and welding and stamping machines [48]

BAXTER RESEARCH ROBOT

In April 2013, Rethink Robotics announced the launch of the Baxter Research Robot, also priced at $22,000. Compared to the original model, the Baxter Research Robot designed specifically for academic and corporate R&D. It leverages the same hardware and characteristics of the original Baxter robot while providing an open source SDK that will allow researchers to focus on specific goals, including human-robot interaction, collaborative robotics, planning, manipulation, control, and perception in all applications. Additionally, the Baxter Research Robot runs on ROS, the global Robot Operating System standard, which gives researchers the ability to share innovations and build on each other's work and know-how. The Baxter Research Robot is recommended by the National Robotics Initiative (NRI) as a research platform suitable for funding proposals. [40, 48] Exhibit 12 lists its specifications.

The research version of this robot is aimed at providing access for research labs and academics with fully functional humanoid robots that can be used to program new applications. Several notable universities including Tufts, MIT, and Worcester Polytechnic Institute are currently using the research robots. [41]

INTELLECTUAL PROPERTY

Rethink Robotics currently holds just two patents: one for a dual-motor series elastic actuator and one for a ultrasonic motion detector. [49, 52] However, iRobot, founded by Brooks, holds many patents related to robot technology. [44] Also, Rethink Robotics has an exclusive license on the 1995 Gill Pratt/Matt Williamson Series Elastic Actuators (SEA) Patent, which protects Rethink Robotics in the short-term against competitors from using the technology present in the compliance concept. Brooks has stated that Rethink Robotics has "several key patents in the pipeline." [46]

Financing

Rethink Robotics has raised $74 million from multiple venture capital firms through three rounds of fundraising. The participating VC firms include Charles River Ventures, Bezos Expeditions, BrooksLab, Highland Capital Partners, Sigma Partners, and Draper Fisher Jurvetson. [Exhibit 1] Both Charles River Ventures and Bezos Expeditions have invested in every funding round. [70]

TIMELINE OF INVESTMENTS:

Products

1. **August 21, 2009:** Rethink Robotics received $12 million in Series A funding

Rethink secured $7 million in Series A–1 funding, led by Charles River Ventures. The new funding came less than a year after the company closed Series A funding of $5 million from Bezos Expeiditions and BrooksLab, LLC, leading to a total of $12 milliion. This funding was intended to develop the product, build the company and launch the product to market. [115]

2. **November 30, 2010:** Rethink Robotics received $20 million in Series B funding

Existing Series B backers Charles River Ventures and Bezos Expeditions were joined by new investors Sigma Partners and Highland Capital Partners. Paul Maeder, co-founder of Highland Capital Partners, joined the company's board of directors.

3. **June 19, 2012:** Rethink Robotics received $30 million in Series C funding.

Sigma Partners led the round along with new investor Draper Fisher Jurvetson and past investors Charles River Ventures, Highland Capital Partners, and Bezos Expeditions. The new funds were used to launch the company's new robot product, begin development of next generation product lines, expand sales, marketing, and services operations and increase hiring. [71, 116]

Rethink Corporate Strategy

PRODUCT DIFFERENTIATION

Industrial robots have a reputation of being dirty, dull, and dangerous. Rethink Robotics emphasizes the "dull" tasks; a strategy that relinquishes a sizable portion of the market but avoids direct competition from the established automotive robotics industry. Baxter falls under the "co-bots" category: robots designed to work alongside humans with quick programming for simple, repetitive manufacturing tasks. Baxter is designed to perform "human class, human scale tasks in a human environment;" therefore, if the robot malfunctions it can be replaced by a person without disrupting the process. Rethink Robotics's differentiation strategy focuses on versatility in handling a wide range of simple tasks, complete system availability, easy programmability, increased adaptability, multi-tiered safety measures, low cost, and regular software updates. [72]

MANUFACTURING

Made in America - Rethink Robotics's goal is to help revitalize American manufacturing with innovative automation technologies that will increase production while reducing the incentive for low-cost offshoring. Its robots are designed and manufactured in the United States, are made from 75% American-sourced components, and assembled within driving distance of its headquarters in Boston, MA. Baxter uses mostly plastic and off-the-shelf components, and no in-house manufacturing. This is necessary to accomplish the low price-point. [73, 74].

Rethink Offshoring - Brooks' emphasis on American manufacturing developed when his iRobot company experienced increased shipping costs due to rising oil prices, highlighting the complications of the global supply chain. Brooks also recalls visiting his native Australia and finding an ad for a Roomba knockoff made by a Chinese manufacturer that had likely skimmed the intellectual property from iRobot's own contractors. Brooks conceived the original Heartland Robotics as an attempt to change the economics of manufacturing. [75]

Rethink Robotics insists that its flagship robot, Baxter, improves the ability of manufacturers in developed nations to compete with third world nations by giving small- and medium-sized firms an opportunity to bring the manufacturing process back in-house. Baxter has potential to lower labor and integration costs, quicken supply chains, and bolster intellectual property protection. [76,77] The robot's ease of use and user-friendliness is one example of how Baxter can reduce labor costs. Non-technical employees can train Baxter by moving his arms to emulate the required motions.

Rethink Robotics CEO, Scott Eckert, explains that employing Baxter could help small and medium-sized manufacturers such as Vanguard win more bids against Chinese rivals. He explains, "*That keeps those companies and those jobs in the US. This is the customer set that has seen the least benefit from robotic technology so far*". [77]

MARKETING

Product Positioning - Europe recently funded an SME (Small- and Medium-sized Enterprise) public-private consortium to determine the need to augment skills and increase productivity of factory workers via robotic assistants. Rethink Robotics aims to address this large market and position Baxter to become widely adopted as an affordable manufacturing platform for companies in the developed world. [78] The focus on creating an intuitive user experience at an affordable price represents a stark contrast to the traditional industrial robot sector. SME requires "low volume, flexible automation solutions that can be easily changed to meet shifting demand... SME needs systems that are easy to set up and reconfigure, programmable to non-technologists, and able to work safely without a dedicated space or specialized equipment". [74] Aiming to meet these criteria, Rethink Robotics is positioning Baxter as a complement to existing industrial robots, rather than as direct competition.

Distribution Channel - Rethink Robotics's products go to market mainly through services provided by their distributor partner network of seven US companies. Among them, ON-Exia is the sole regional distributor with its sales region covering Eastern Pennsylvania, Southern New Jersey, Delaware, Maryland, Washington, DC, and Northern Virginia [109]. MSI Tec is the sole distributor for Colorado, Arizona, Utah, New Mexico, Wyoming, southern Nevada, and southern California [110].

To place an order, one simply requests a quote on the company's website for the Baxter robot. Upon specifying their preference (manufacturing or research-based) and completing the online form, the customer is contacted by a Rethink Robotics representative.

Pricing - Both at a price tag of $22,000, Baxter and its research counterpart each cost less than most other industrial robots. Other leading competitive products are available from Universal Robots ($33,000), ABB ($42,000), and Motoman ($54,000). Add-ons like a mobile pedestal, an electric parallel gripper, and vacuum cup gripper are sold separately, for $1,500 to $2,000 each. When completely optioned-out, including a full warranty and all add-ons, the sale price of one Baxter unit is $32,000.

Support - All Baxter robots come with a one-year/2,100-hour warranty covering parts and labor as well as product upgrades and phone support. This service can be extended to 2 years/4,200 hours for $3,000 or 3 years/6,300 hours for $5,000. On-site support is available through Rethink Robotics's service partners within 48 hours of a service request. Certified technicians will arrive on-site and be able to complete repairs within two hours. One can contact a company representative by submitting an online form on the Rethink Robotics website. [81]

Promotion - Rethink Robotics communicates with customers to foster product awareness and likelihood of purchasing products through both personal and non-personal vehicles. Rethink Robotics and their distribution partners organize events to demonstrate Baxter to potential buyers. They also attend robotics-related conferences and showcases.

Customers can easily access a regional distributor and contact a representative through an online tool. [81] Moreover, Rethink Robotics actively advertises in precisely targeted media vehicles such as Facebook and Twitter. [75] In terms of public relations, Rethink Robotics and its distribution partners primarily market Baxter through demonstrations at tech-related events such as conferences and trade shows. CEO Brooks has appeared with Baxter on Technology, Entertainment, and Design (TED) talks promoting both Baxter and robots in general.

CHALLENGES

Perception - Selling Baxter's idea may be a challenge for Rethink Robotics. Not everyone is convinced that the rise of co-bots will be a rapid one, mostly because of a perception that they are slower than humans. “It's an interesting concept, but for now the models are too slow and not strong enough,” says Hans de Koning, president of Flexicell, a company that installs industrial robots for the food-packaging industry. [82] Rethink Robotics faces the challenge of convincing business owners that Baxter can boost productivity through efficiency. Similar companies such as Kiva Systems have experienced success in explaining this in terms of real-world profits expectations for business, rather than typical robotics success parameters that are more appreciated by engineers. While Baxter performs a limited number of tasks now, as Rethink Robotics continues to upgrade their robots, especially its software, Baxter’s will become more versatile and valuable. At that point, Brooks predicts that Baxter will “sell like hotcakes”. [83]

Cost - As the complexity of the robot increases, the task of keeping engineering and fabrication costs down becomes more difficult. Rethink Robotics engineers found creative ways to work with less expensive components, often designing parts out of cheap, yet functional materials. By working closely with local manufacturers, they were able to get the necessary parts economically without compromising quality.

Rethink Robotics has also cut costs by utilizing software to enhance physical properties. By giving Baxter the ability to autonomously compensate for its own mechanical irregularities, as well as changes in its environment, Rethink Robotics was able to use cheaper components. [83] The result of these design choices is that Baxter will be profitable even at fairly low volume. Rethink Robotics claims that Baxter will not be a loss leader because it requires an unspecified but small volume to be profitable. In contrast, robots primarily used in home settings, such as the Roomba robot, require millions of sales to be profitable. [84] As Baxter obtains more upgrades and features, these strategies may become less effective.

Competitors

Rethink Robotics faces competition from both established companies, such as those who cater to the automobile manufacturing industry, as well as smaller, newer companies. Its primary competitors include ABB, Universal Robots, Stäubli, KUKA, FANUC, Yaskawa, and Kiva Systems. Additionally, Rethink Robotics also needs to compete with over 1,000 smaller, private robotics developers worldwide. Robotics is a healthy source of research in academics and a growing commercial industry, making competition intense. Selected financial data for Rethink Robotics's competitors is provided in Exhibit 13. [53, 54] A concise overview of key competitors is given below.

ABB Group

ABB Group, a multinational corporation headquartered in Zurich, Switzerland, is a leading supplier of industrial robots and modular manufacturing systems and services. In 2011, ABB Group reported a global revenue of $40 billion and was ranked 43rd in Forbes' 2010 rankings. ABB Group's key targeting markets include automotive, plastics, metal fabrication, foundry, electronics, machine tools, pharmaceutical, and F&B industries. Under the ROSETTA project, which is funded by the European Community's Seventh Framework Programme, ABB Group produced a dual-arm Frida concept robot designed for high-precision assembly applications. ABB has installed more than 200,000 robots worldwide and operates in about 100 countries. [50] In 2012, ABB earned $39 billion in net revenue, 29% in gross margin, and 10% in operating margin. [Exhibit 13]

Universal Robots

Universal Robots (UR), founded in 2005 in Denmark, launched the UR5 robot in 2009, claiming an average payback time of between six and eight months. Revenues were €0.5 million (US $0.65 million) in 2009, and climbed to between €2.4 and €6.5 million (US $3.1 to $8.4 million) in 2011. Currently, UR has an unfenced assembly line robot priced at around $34,000. [53, Exhibit 3]

UR is similar to Rethink Robotics in that it is relatively far along in developing a low-cost, user-friendly robot. Many of the large industrial robot makers have been working on lightweight and human-friendly arms. However, they are not typically low-cost and user-friendly, and lack plug and play features. Other startups similar to Universal and Rethink are not nearly as far along. [51]

UR currently builds over 100 robots a month, 25 to 30% of which are for customers in the US for 2013. [49] Its customers include Fortune 500 companies, as well as small business owners, allowing UR to serve the full spectrum of companies. UR's robots are continuously upgraded and once purchased a steady stream of software upgrades will give users access to all of the latest features. With this approach, UR future-proofs customer purchases. [56, 57, 58, 59]

KUKA

KUKA is the leading European supplier of industrial robotics, commanding a 7% market share. The company produces larger-scale automation systems that require skilled operators. KUKA has traditionally served the automotive industry. However, KUKA is increasingly gaining customers from other industries, including medical technology, solar, and aerospace. KUKA is committed to increasing its market share through investing heavily in R&D. They are currently targeting customers in the United States as well as Brazil, Russia, India, and China.

KUKA is divided into three business segments: laboratories, systems, and robotics. The laboratories team handles the company's R&D in conjunction with customers, institutes, and universities. The systems team handles the automated systems that incorporate KUKA robots, such as setting up supply lines in a factory. Finally, the Robotics team develops a variety of robots, including foundry, ARC-welding, palelizing, press-to-press, shelf-mounted, cleanroom, SCARA, jet, stainless steel, ATEX-compliant, high-accuracy, and heavy duty.

In 2012, KUKA earned €1,739.2 million (US $2,260 million) in revenue. The company operates at a roughly 20% gross margin, and invests heavily in R&D and sales. In 2012, KUKA spent €119.7 million (US $155 million) on selling expenses and €42.6 million (US $55 million) on R&D. KUKA has a 6% operating margin. KUKA's 2012 income statement is provided in Exhibit 13. [55, 61, 62]

FANUC Robotics

FANUC Robotics America is a leading supplier for automated systems. The company is divided into Robotics, Software, Controls, and Peripherals. FANUC sells several industrial robots that serve a variety of applications, including assembly, packing/palletizing, machine tending/part transfer, material removal, welding, and painting. The diversity of their robots skills allows FANUC to operate in a wide range of industries, from Aerospace and Defense to Alternative Energy, Automotive, Composite, Consumer Goods, Distribution Centers, Education, Electronics/Clean Room, Fabricate Metal, Food & Beverage, Foundry, Glass, Medical Device, Off Road Vehicle, Paper & Printing, Pharmaceutical, Plastics, and Wood.

FANUC's Software division focuses on Controller Software, PC Software, Simulation Software, and Computer Vision Software. By offering a complete set of software applications to complement its products, FANUC makes it easy to integrate its robots into manufacturing company's supply lines. The Controls and Peripherals divisions develop products to control and extend the capability of robots and supply lines.

In 2012, FANUC earned ¥538.5 billion (US $87.6 billion) in Net Revenue. Its gross margin was 51%, and its operating margin was 41%. [63, 64] FANUC's Group Income Statement is provided in Exhibit 13.

Yaskawa Motoman

Yaskawa Motoman is an American subsidiary of the Japanese company Yaskawa Electric Corporation. Yaskawa Motoman produces robotic automation for industry and robotic applications, including arc welding, assembly, clean room, coating, dispensing, material cutting (laser, plasma, waterjet), materials handling, materials removal, and spot welding. Since its founding in August 1989, Yaskawa Motoman has grown to become the second largest robotics company in the Americas, with more than 35,000 robots installed. [65] In 2012, Yaskawa earned $3 billion worldwide and $433 million in the Americas in revenue. [66] In 2012, Yaskawa earned ¥307.1 billion in net revenue, with a 26% gross margin, and a 5% operating income. [Exhibit 13]

KAWADA INDUSTRIES

YKAWADA Industries is a long-established Japanese company with a robotics division involved in aeronautical, mechanical, control, and electrical engineering fields and their associated industries. The robotics division was initiated with a design-build contract by the University of Tokyo of the Humanoid Robot H6, and then developed a variety of humanoid robots.

The most recent development HRP-4 is a life-size "platform for research and development of working humanoid robots" developed in collaboration with the National Institute of Advanced Industrial Science and Technology (AIST). The HRP-4 is externally designed with the "slim athlete" model in mind to make it more appealing to humans. The robot is a "co-robot", which works alongside humans and assists or replaces human operations or behavior. Kawada claims to have spent significant engineering and business resources to drive down the cost of the HRP-4. Despite such efforts, the robot costs $300,000, and is not specifically geared toward manufacturing. [67, 68]

OTHERS

There are several other companies that have directly competing technologies to Rethink Robotics. Adept Technology offers a variety of SCARA, 6-axis, and Parallel robots for manufacturing. Known for their WAM-Arm cable-driven product, Barrett Technology produces a robot with a fully compliant arm with 7 DOF for a price of $85,000 to $100,000. Founded by Meka Robotics, Redwood Robotics specializes in robotics for flexible manufacturing. While more expensive, these robots focus on high-precision operations that Baxter is unable to perform, such as assembling electronics boards. [19] Whether or not this poses a great threat to Baxter remains to be seen.

POTENTIAL MARKETS

Until recently, robots have been employed by a few major manufacturers in a handful of industries, predominantly automotive. Furthermore, they have generally only been used in limited roles. [Exhibit 12] In contrast, Baxter's flexibility and low cost enables it to fit into a wider range of roles in which automation has not yet taken off. The potentials are limitless. Rethink Robotics currently targets six markets with Baxter: rubber and plastics, academic and corporate R&D, transportation, metal fabrication, consumer goods, and food processing. [95] However, in a March 2013 interview, VP of Marketing & Product Management Mitch Rosenberg admitted that there are only "a couple of applications for Baxter right now." CEO Eckert remains optimistic about Baxter's future usage opportunities, and with the flexibility of application-based customized use, he believes users "are going to do all sorts of stuff we haven't envisioned." [93]

RUBBER AND PLASTICS

Baxter is able to withstand the heat, noise, noxious odors, night shifts, and monotony that are present in the rubber and plastics industry. This industry has almost 6,000 businesses generating a combined annual revenue of $90 billion in the US alone. [105] Baxter's ability to be retrained quickly can accommodate frequent line turnover. [95] Jobs in the rubber industry are mechanical and repetitive. Using Baxter would boost it's efficiency.

ACADEMIC AND CORPORATE R&D

Introduced in April 2013, Baxter Research Robot is a new addition to the world of corporate and academic robotics research. Similar in hardware to the original Baxter, the Research Robot makes use of an open source SDK allowing researchers to create custom functions for a wide array of manufacturing applications. The global Robot Operating System (ROS) standard gives researchers the ability to share innovations and build on others' work. The

Baxter Research Robot is recommended by the NRI as a research platform suitable for funding proposals. [102]

AUTOMOTIVE AND TRANSPORTATION EQUIPMENT

The car and transportation industry may find new applications for Baxter-like robots. Unlike traditional robots used by equipment manufacturers, Baxter does not require a safety cage. In this industry, Baxter can perform the tasks of comparatively expensive human labor and will likely have a much higher return on invest than in other industries. In the collaborative report by researchers at top US universities including Georgia Tech, MIT, Stanford and Carnegie Mellon, they predict that robots will become "as ubiquitous over the next decades as computer technology is today." [113] On the road, robot drivers 15 years from now will be able to drive anywhere humans can, and will be safer than humans with limited road experience. They will also be able to learn to navigate in extreme weather and other atypical situations. Thus mobility is managed.

METAL FABRICATION

The metal fabrication market requires repetitive tasks for each processed good. Although the industry does have some major players, there are a considerable amount of smaller companies. According to the EPA's report on the industry in 1995, a "typical" shop employs 15 to 20 people and generates $800,000 to $1 million in annual gross revenues. Around this time, around 95% of metal finishing companies had less than 100 employees and nearly 50% had less than 10. [97]

Similar to the plastics industry, the metal fabrication industry involves jobs with heat, noise, night shifts, monotony, sharp part edges, and other unfriendly working conditions that Baxter can withstand but are undesirable to many human workers. Baxter can perform some of the more monotonous tasks in metal fabrication such as [95]

- Tending press breaks, welding machines and stamping machines
- Operating machines that perform grinding, polishing and other finishing operations
- Performing various inspection tasks that use machines, jigs, and coordinate measuring machines (CMMs)
- Feeding raw materials and semi-finished assemblies to machines via conveyor
- Unloading lines

However, Baxter is currently limited by its lifting capacity.

CONSUMER GOODS

Baxter is capable of being programmed to perform a variety of the simpler jobs for the consumer goods industry. These include [111]:

- Loading and unloading lines
- Performing product inspections (or interface with existing inspection equipment)
- Identifying and removing defective items from the line
- Transfering parts from line to line
- Putting caps onto jars
- Cleaning
- Packaging
- Squeezing and crimping tubes
- Packing products into retail blister packaging
- Operating heat-and-seal machines
- Packing products into boxes, thermoformed trays or cases

FOOD PROCESSING

Another potential industry from which Baxter could benefit is food processing. The United States food manufacturing industry employs over a million workers and generates billions of dollars in revenues. There are many large international companies in this industry, which accounted for about 36% of all jobs in 2006, but there are also a significant number of smaller firms that might be willing to implement a Baxter-driven process. 89% of establishments employ fewer than 100 workers. [96] Total employment in this industry is 1.5 million workers. In 2006, the baked goods processing industry alone was $49 billion, so there is large potential for revenue if this market was targeted. [96]

Some of the major issues facing the industry are safety, energy costs, and rising commodity prices. [96] Although not all of these issues could be fixed through automation, smaller establishments could possibly improve food safety by decreasing the amount of human-food interaction in the packaging pipeline. Another important ever-growing trend in the food processing industry is the increasing consumer demand for organic, natural and healthy foods. Along with this desire for more health conscious food is the desire for heightened awareness for processed foods that are sensitive to those with food allergies, like peanuts and gluten, which may make more highly specialized food processing plants more desirable in the future. This health and allergy trend would also be helped by Rethink's products, which could guarantee sterility which might otherwise be impossible when human influence the food production process. With the IP50 rating Baxter is allowed to work around packaged, but not raw, foods, and also in chilled, though not frozen, environments. [95] Baxter is capable of performing tasks such as loading lines, performing inspections, removing defective items, putting caps onto jars, squeezing and crimping tube or packing finished containers into cartons. [95]

HEALTHCARE

There has been a lot of interest in introducing robots to this sector. The healthcare service industry, resistant to price declines due to labor costs, may use improved robotic human-interaction automation to increase productivity and reduce those costs. [94] Although the demand for care robots might not play to Baxter's current strengths (e.g. providing care for an elderly patient requires a more dynamic robot), Baxter could potentially improve efficiency in menial jobs in this field and thus improve working standards.

SERVICE JOBS

Although not listed as a potential market currently by Rethink Robotics, Baxter has potential for jobs such as waiting tables. Eckert says, “it's not a target market, but it's something that's pretty repeatable... There are simple repeatable service tasks that Baxter could do over time.” Although not a target market for Rethink, the use of robotics in restaurants or grocery stores could potentially be a huge, previously-untapped market. [93] In the United States, 20% of jobs are in retail and service. [93] Targeting this market would not only make Baxter, and subsequently Rethink Robotics, a household name, but would play to Rethink's strengths as a producer of human-like robots. It's a seemingly simple task but requires intricate planning. But work would be the same. To take orders.

CURRENT CUSTOMERS & EARLY ADOPTERS

By January 2013, Rethink, which unveiled Baxter to wide attention in the media in September 2012, had not sold any robots. However, it confirmed that it had over 3000 inquiries from numerous of manufacturers [100], including artisanal breweries that wanted to see if the robot could box bottles. “Most folks are treating it as a totally new category that they should roll out in small numbers,” says Mitch Rosenberg, VP of marketing. [74] Since January, Rethink released Baxter for academic research and received validation of the original Baxter's functionality from some private sector companies. In March, Rosenberg mentioned that Rethink had “several dozen” Baxters currently in the hands of customers. However, Rethink engineer Mike Fair stated that Rethink was ”...surprised by the types of companies buying Baxter". Rethink expected to see many "mom and pop operations that didn't think they could afford robots" purchasing Baxter, but instead, saw a lot of interest from big companies. [90]

More than 500 units of Baxter robots are being produced and sold in 2013. [51]

RESEARCH INSTITUTIONS AND LABS

Researchers at Worcester Polytechnic Institute (WPI), MIT, and Tufts are among those with the Baxter Research Robot. MIT's Marine Robotics Group is utilizing Baxter to scan a large number of people and objects with a Kinect-like camera to collect a large library of scanned items. They hope that Baxter will save graduate students from the tedium of repeatedly scanning objects, allowing them to focus on more involved research. [85] Tufts is planning on using Baxter for user interface design, human factors, machine perception, and education. In particular, Baxter is "well-suited for education because of the intrinsic safety of its series-elastic actuators and its relative portability... Robots like Baxter can serve as entertainers, and programming entertainment tasks could be effective educational and research experiences." [85] As for WPI, WPI plans to use Baxter to modernize an existing industrial robotics course that introduces students to robotics within manufacturing systems. In that course, Baxter will be incorporated as an example of a current manufacturing robotic technology. [85] Students and educationists alike will benefit from Baxter's assistance.

Additionally, Baxter will be used as an enabling technology for future proposals, including National Science Foundation's NRI and Catalyzing Advances in Undergraduate STEM Education program. Furthermore, Baxter will also be used by undergraduate and graduate students in the research on understanding novel grippers, studying human-robot interaction, incorporating touch sensing, and making Baxter mobile. [87]

RODON GROUP

Rodon Group, a plastic injection molding factory in Pennsylvania, has long relied on automation to produce parts "cheaper than China" and is among the first plastics processors to deploy Baxter. [85] A sister company to K'nex, Rodon Group uses Baxter for tedious jobs such as snapping plastic parts together and pack building block toys. "Unlike a human worker, Baxter could be set up to pack toys for hours on end, even overnight," says Lowell Allen, SVP of Rodon Group Manufacturing. "There's another dozen jobs here we haven't thought of that we could use Baxter for. We're looking at adapting him to pick out defective parts form an assortment of parts, perhaps down the road, with Rethink's help." In the future, other tasks Baxter could be responsible for include separating parts by color, assisting larger servo robots in various manufacturing tasks and even assembling multi-part objects, freeing up humans to do more complex and interesting tasks. [88]

Rodon also helped Rethink engineers focus on end-use applications in a factory, by sending people to Boston early in the process, Allen said. Rodon is a good candidate for using Baxter to put parts in boxes, because many of the company's beam robots currently use end-of-arm tooling that can adjusts in size, once it removes parts, to package them very precisely. [92]

NYPRO

Compared to the Wittman Battenfel robots on many of the Netstal and Roboshot machines in its Class A molding room, the Rethink robot in Nypro's plant will be nowhere near as fast or as precise. However, different types of drive mechanisms are used to slash costs below what press-side robots cost. Thus, the Rethink robots serve a different purpose than the robots typically found in molding shops where robots must respond very exactly every time to split-second molding cycles. For example, they could possibly fit into a custom assembly area. [89,90]

VANGUARD PLASTICS

Another potential adopter is Vanguard Plastics. As a company with a extremely repetitive human part of its manufacturing process and $6 million in revenues, Vanguard is a good potential client for Rethink Robotics. After the plastic materials are created, a worker making $9 an hour, stacks the items, then flicks a plastic bag over the stacks. [92] Chris Budnick, President of Vanguard Plastics, believes that plastics will be a big early market for Baxter. “It's ideal for that robot because the payloads are fairly light and the production rates are fast, but not way too fast.” [92] He plans to test Baxter and says if Baxter meets requirements so that he can eliminate one temporary worker (thus earning back his investment in a single year) he will buy Rethink’s robot if the cost can be worked into the budget for the coming year. [74]

Vanguard Plastics already has 24 conventional robots. While extremely fast and precise, these robots take up to a day to program. They are also very sensitive to misalignment, which can cause them to completely fail at their task. Due to their hazardous nature, these robots must also be separated from human workers by protective fencing. [103]

Future Trends

Rethink Robotics plans to release new hardware platforms in 2013. Concurrently, the company will further develop its software offerings. The long term goal is to expand the applications of Baxter into new areas, such as health care and elderly care. [106]

Rethink Robotics prioritizes robot usability and accessibility by non-technologists as well as designing a robot with human-like features, easier operability, and safer human interactions. Strategists foresee positive trends in robotics over the coming years: increased autonomy including the ability to make situational judgments, improved environmental sensitivity to the robot's surroundings, and easier integration with human co-workers. [107]

The state of robotics technology parallels computer technology of the late 1970s. Just like early computers, industrial robots are expensive and bulky. The PC revolution truly kicked-off when standardized platforms were offered which could be expanded and upgraded to fit user specific needs. Similarly, Rethink is offering “future potential” through the promise of frequent software upgrades and an open source SDK, which will improve and even expand Baxter's repertoire. Fast-paced development is anticipated in the robotics industry, mostly driven by small firms such as Rethink Robotics who provide unconventional robotic solutions.

Rethink Robotics's innovative spirit and ambitious goals has been well received by the industry. Reputable manufacturing companies have validated Baxter's usefulness and others are in various stages of acquiring their own co-bots. Baxter's success will be measured by its wide adoption by domestic firms.

According to a report by a leading roboticist, by 2030 robots will be everywhere: the gym, the operating room, the deep sea, and outer space. [113] The report predicts that robots will become “as ubiquitous over the next decades as computer technology is today.” Robotic systems have been part of manufacturing since the industrial revolution began. Now they are becoming more independent. Examples include the Kiva shelving robots in Amazon's big warehouse operations, or Baxter, the humanoid robot that can be customized for various manufacturing and research needs. As a result, US manufacturing has the potential to expand. Robot researchers contend it will be cheaper to use robots for some jobs domestically that are outsourced to other countries today. But questions remain: are we ready to embrace such revolutionary change? With a dearth of jobs, high unemployment and recessionary conditions, will these new robots ever be openly accepted in the workplace?

Discussion Questions

1. What business is Rethink Robotics in? Who are its customers? Evaluate the success of the current business model.
2. What are the competitive forces operating in this business ecosystem? Who are Rethink Robotics's competitors, and what are their respective business models?
3. How does Rethink Robotics maintain competitive advantage against fast followers? How can Rethink Robotics protect itself against competition?
4. Does Rethink Robotics Have a Patent Portfolio?
5. What is the overall market environment for products and services like those offered by Rethink Robotics? Are there non-traditional markets that could be more disruptive and available than those currently targeted?
6. Is the current product line a good fit for the target market? Would it be considered a disruptive technology? What should be the new product development priorities?
7. What is their marketing strategy? What market are they targeting and how?
8. Does Rethink Robotics have the right team to achieve its goals?
9. What should be the funding strategy of Rethink Robotics?
10. With reference to the bizjournal article, a research robot for colleges and labs has been released. How successful do you think this could be?
11. Is Rethink Robotics's goal of "making American Factories competitive again" in line with its business plan? Does automation conflict with its goal of preventing American job losses?
12. Will humans ever embrace the idea of such incredulous change? How will working-society react to the idea of being replaced by robots? What will the job scene look like in, say, 2050? Will human force be replaced by robots?
13. What is the production cost of Baxter robot? (While this is not explicitly stated on the datasheets we may try to estimate the cost by the BOM list and Baxter's selling price).
14. What next?

EXHIBITS

Table of Exhibits

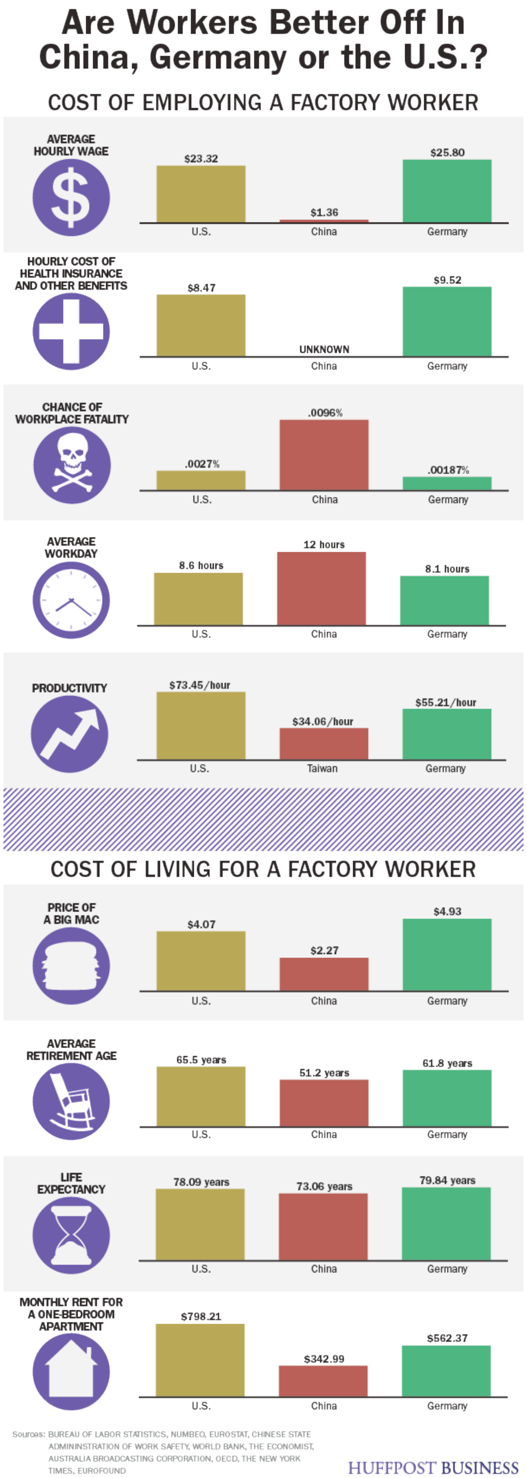
EXHIBIT 1: VC FUNDING TIMELINE

DATE	INVESTOR		ROUND	INVESTOR TYPE
Dec. 2008	Charles River Ventures		A	Venture Capital
Dec. 2008	Bezos Expeditions, LLC		A	Venture Capital
Dec. 2008	BrooksLab, LLC		A	
	TOTAL ROUND A	**$12,000,000**		
Sep. 2009	Bezos Expeditions, LLC		A	Venture Capital
Sep. 2009	Charles River Ventures		A	Venture Capital
	TOTAL ROUND A	**$12,000,000**		
Nov. 2010	Highland Capital Partners, LLC.		B	Venture Capital
Nov. 2010	Sigma Partners		B	Venture Capital
Nov. 2010	Charles River Ventures		B	Venture Capital
Nov. 2010	Bezos Expeditions, LLC		B	Venture Capital
	TOTAL ROUND B	**$20,000,000**		
Jun. 2012	Sigma Partners		C	Venture Capital
Jun. 2012	Draper Fisher Jurvetson		C	Venture Capital
Jun. 2012	Charles River Ventures		C	Venture Capital
Jun. 2012	Highland Capital Partners, LLC.		C	Venture Capital
Jun. 2012	Bezos Expeditions, LLC		C	Venture Capital
	TOTAL ROUND C[1]	**$30,000,000**		
	TOTAL OF FUNDING SHOWN ABOVE	**$74,000,000**		

Source: http://www.privco.com/private-company/heartland-robotics

EXHIBIT 2: FACTORY SALARIES INFOGRAPHIC

Comparison of the costs of factory workers in Germany, China, and the US.



Source: http://big.assets.huffingtonpost.com/0308factoryworkers.gif

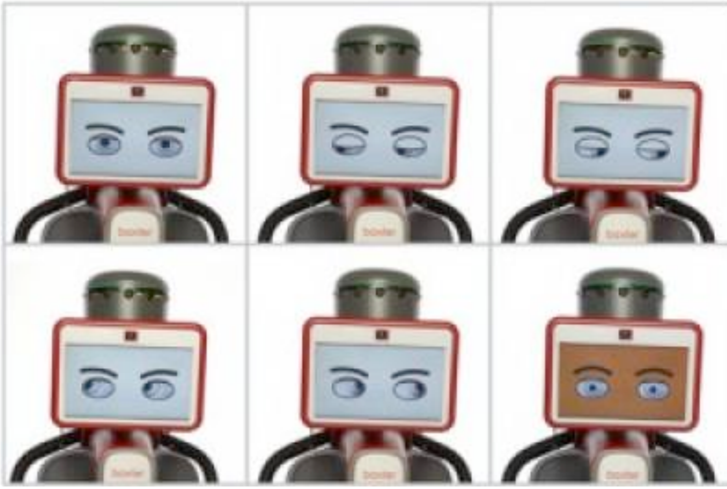
EXHIBIT 3: BAXTER VS UNIVERSAL 5

Comparison of the Rethink Robotics Baxter and Universal Robots UR5 industrial robots.

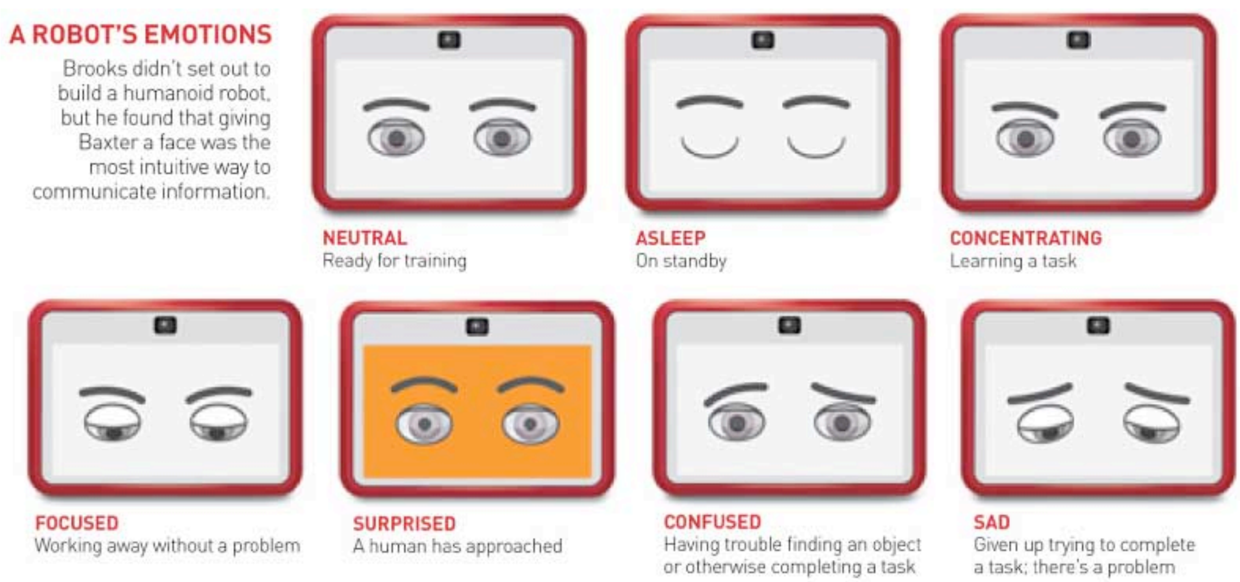
	Baxter	Universal 5
	Dual-armed	Single arm
Useful life	6,500 hours	36,000 hours
Maximum load	5 pounds	11 pounds
Vision system	Included	Add-on
Safety	Sonar & cameras	Torsion sensing
Speed	.6 meter/sec	1 meter/sec
Cost	$22,000	$34,000

Source: http://www.everything-robotic.com/

EXHIBIT 4: BAXTER'S HUMAN-LIKE EXPRESSIONS



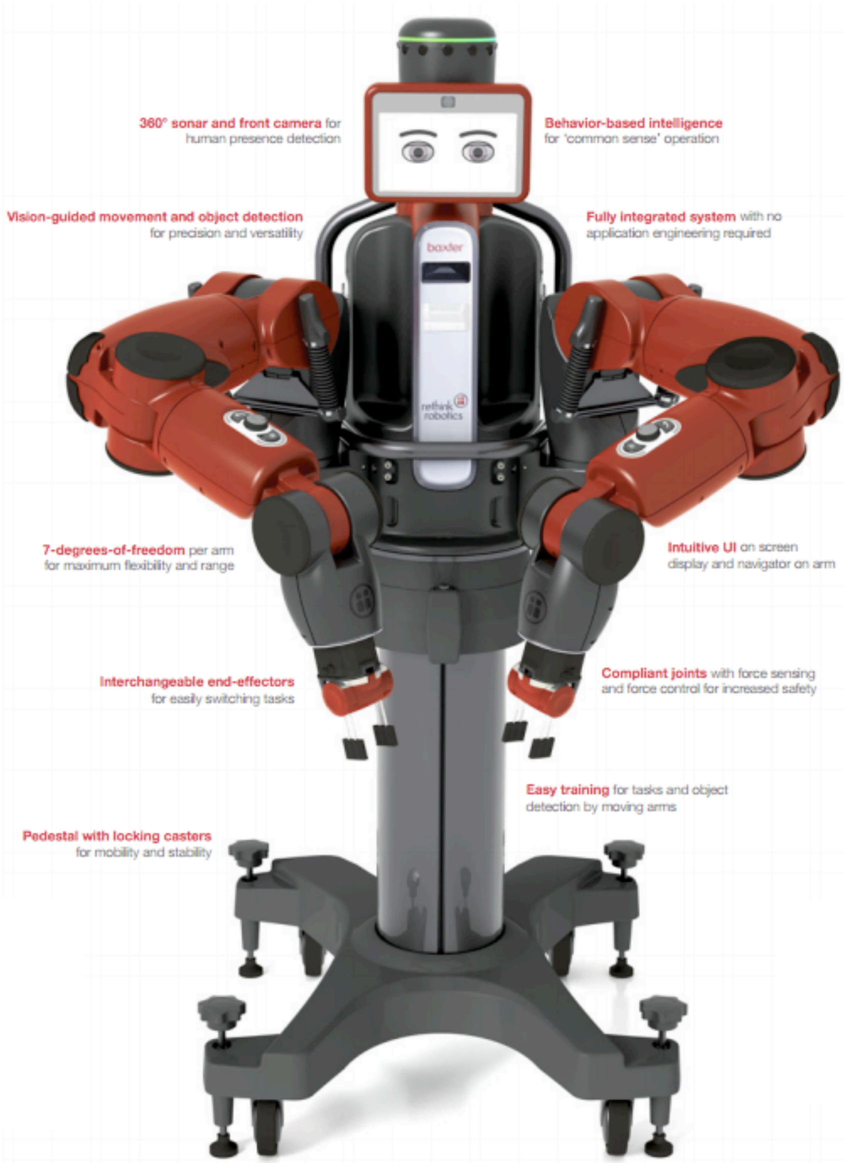
Source: http://www.roboticsbusinessreview.com/article/rethink_robotics_unpacked/P4



Source: http://www.inc.com/magazine/201210/david-h-freedman/the-rise-of-the-robotic-workforce_pagen_2.html

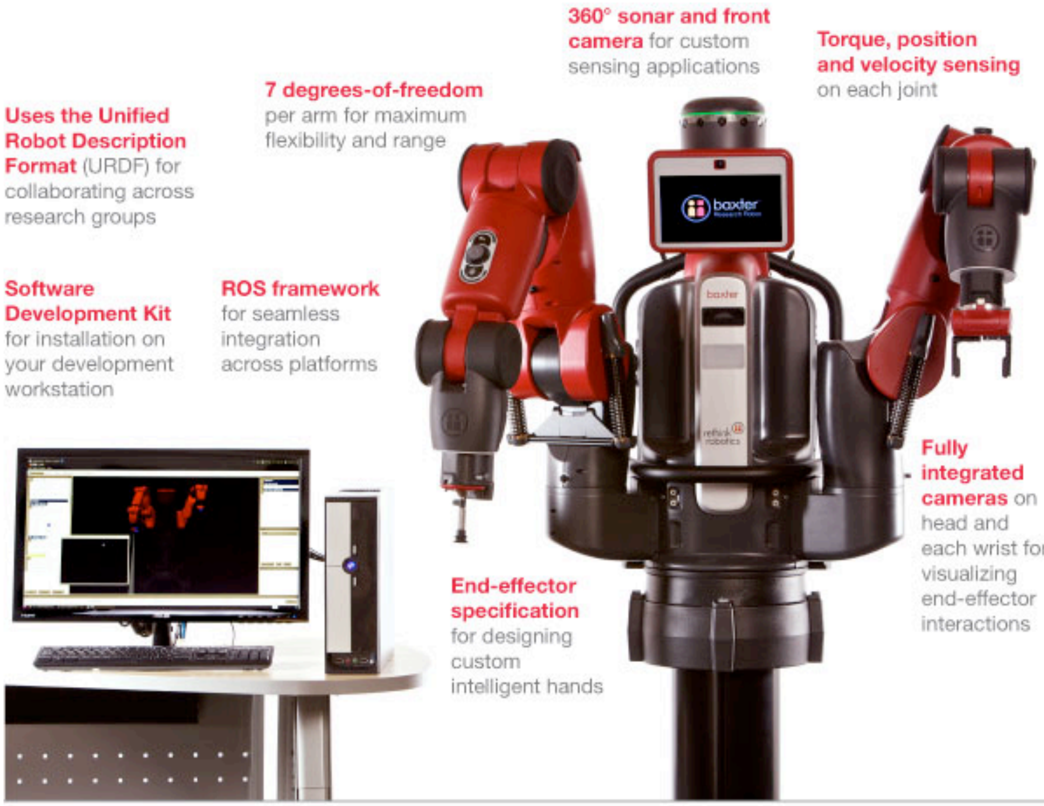
EXHIBIT 5: BAXTER'S FEATURES

Many of Baxter's features highlighted in this exhibit serve as competitive advantages.



Source (datasheet): http://www.hizook.com/files/users/3/Baxter_RethinkRobotics_datasheet.pdf

Baxter Research Robot



Baxter Research Robot – Basic Specifications

Physical

- Robot height: 3'1" without optional pedestal
- Robot height with pedestal: 5'10" - 6'3" (adjustable)
- Arm length to end-effector plate: 41"
- Torso mounting plate diameter: 13.3" (for mounting on table)
- Body weight, without pedestal: 165 lbs
- Body weight, with pedestal: 306 lbs
- Degrees of freedom: 14 (7 per arm)
- Pedestal footprint: 36"x32"

Electrical

- Supply voltage: 120 Volts Alternating Current
- Rated current: 6 Amps

Environmental

- Protection classification: IP50
- Operating temperature range: 32-104° F (0-40°C)

End Effectors

- Vacuum cup with interchangeable cups
- Electric parallel gripper with interchangeable 'fingers' and user-adjustable 'fingertips'

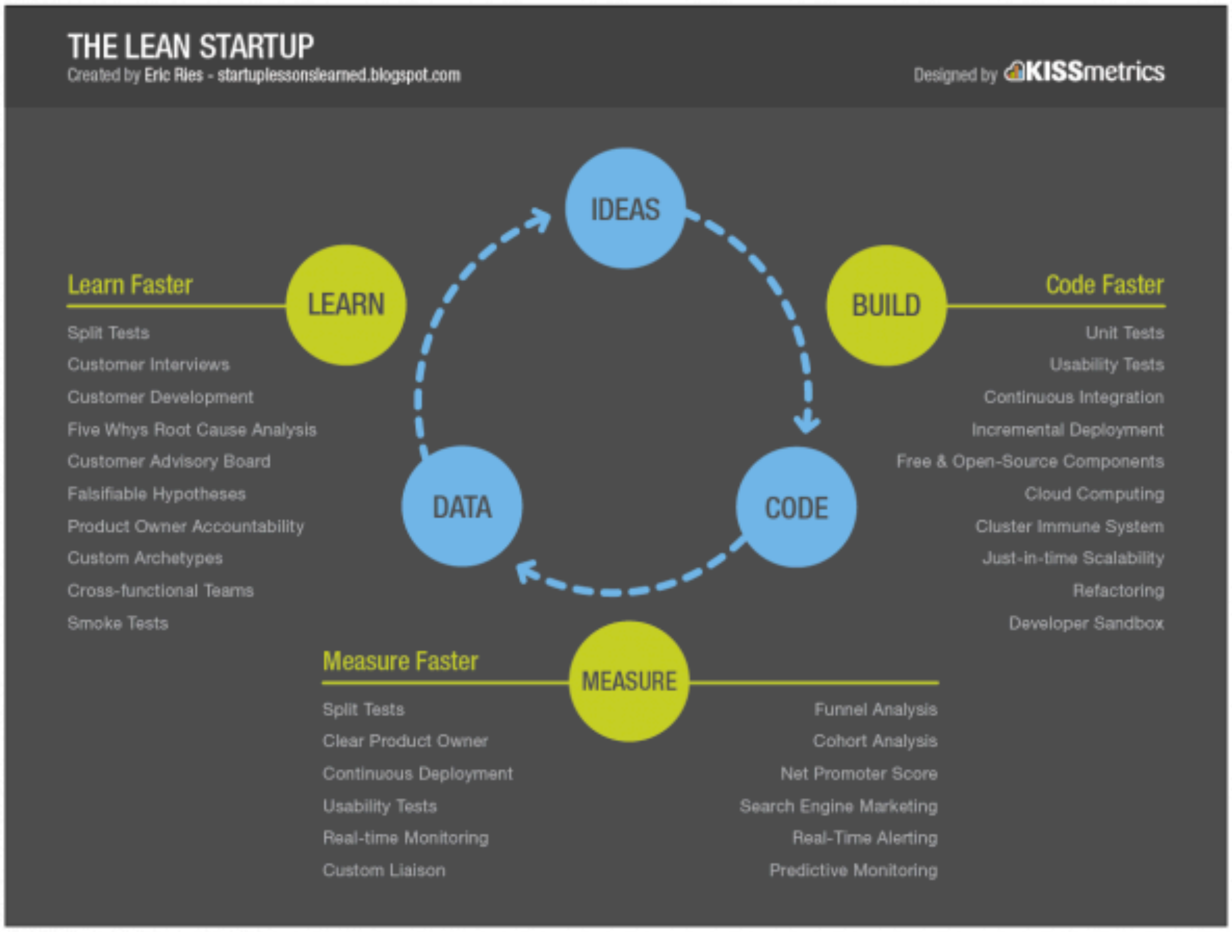
Workstation Requirements
(workstation not provided)

- Ubuntu 10.04 LTS and ROS Electric, with minimum specifications:
  - Intel i5 or above
  - 4GB memory or above
  - Min. 2GB of free disk space
  - Ethernet port

Source: http://www.rethinkrobotics.com/files/2913/6825/2843/img_baxter_research_capabilties.jpg

EXHIBIT 6: LEAN STARTUP SOFTWARE DEVELOPMENT CYCLE

Lean Startup Methodology advocates releasing a minimum viable product to early adopters for quick validation. Such a software development model is a contrast to traditional robotics.



Source: http://www.roboticsbusinessreview.com/article/rethink_robotics_unpacked/P3

EXHIBIT 7:

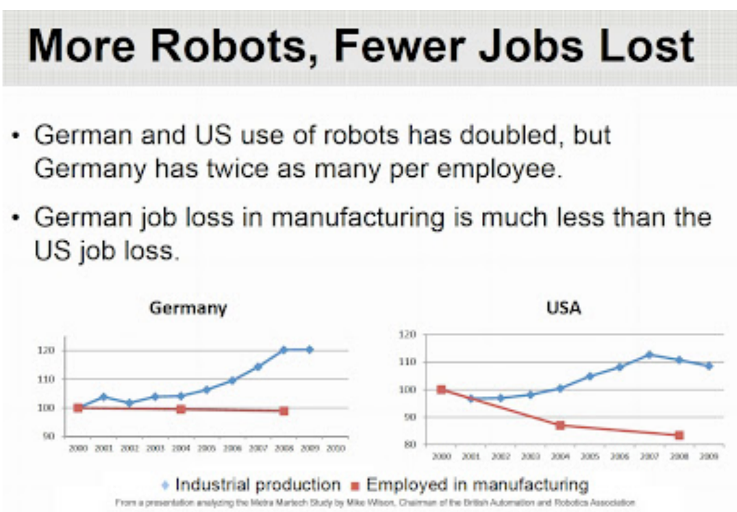
Estimated Worldwide Annual Supply of Industrial Robots (in units)

Year	Annual Supply
1998	69,000
1999	79,000
2000	99,000
2001	78,000
2002	69,000
2003	81,000
2004	97,000
2005	120,000
2006	112,000
2007	114,000
2008	113,000
2009	60,000
2010	118,000
2011	166,000

Source: http://en.wikipedia.org/wiki/Industrial_robot#cite_note-11

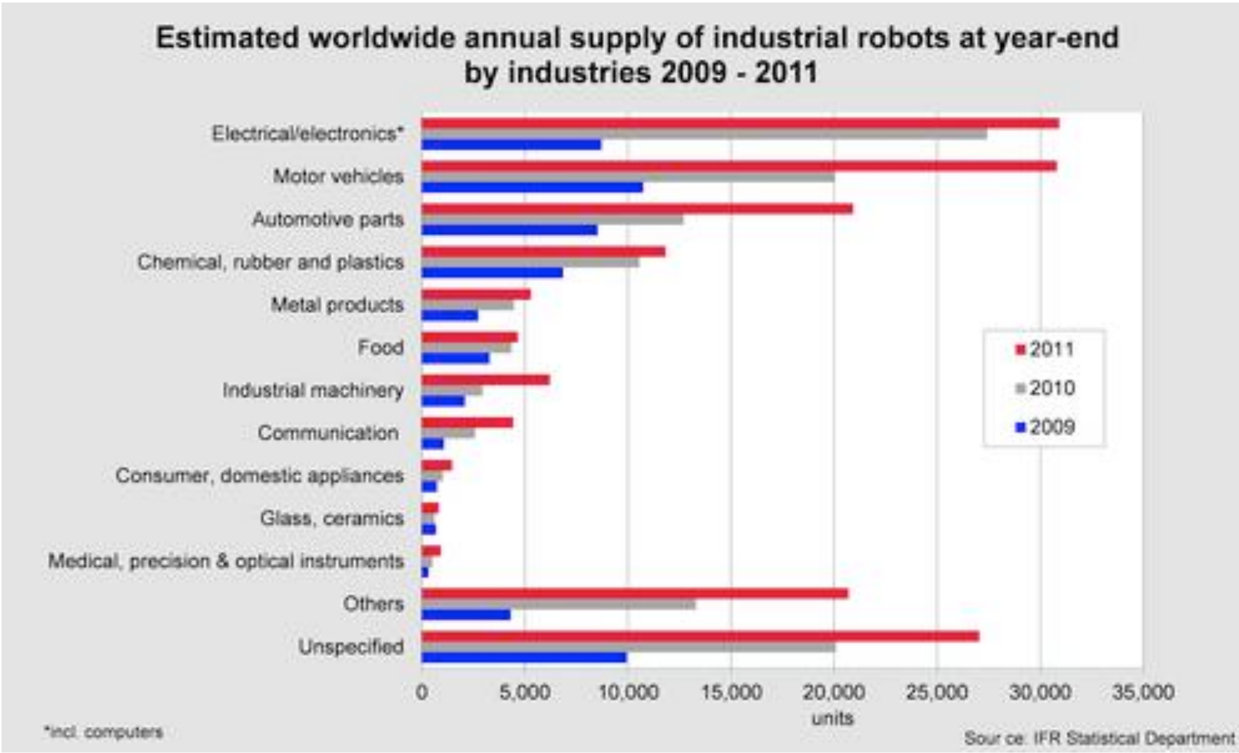
EXHIBIT 8: METRA MARTECH REPORT ON THE EFFECT OF ROBOTS ON JOB CREATION/LOSS

Metra Martech study concluded a job-creation ratio of 3.6 jobs for every robot deployed and that with more robots, fewer jobs are lost.



Source: http://www.everything-robotic.com/

EXHIBIT 9: USE OF ROBOTS IN THE RECENT PAST (BY MARKET)



Source: http://www.ifr.org/industrial-robots/statistics/

EXHIBIT 10: SPECIFICATIONS FOR BAXTER RESEARCH ROBOT

General Features	Physical Features	Electrical Features	End Effector
Price: $22,000 inclusive of a year of software updates and warranty and with zero integration required Equivalent of a worker making $4 an hour OS: Open-source Robot Operating System (ROS), (Unix-like system developed by the Stanford A.I. Lab) Requires no custom programming to perform new tasks Operating temperature range: 32-104° F (0-40°C)	Robot height with pedestal: 5'10" - 6'3" (adjustable) Arm length to end-effector plate: 41" Toros mounting plate diameter: 13.3" (for mounting on table) Body weight, with pedestal: 306 lbs Pedestal footprint: 36" x 32" 360-degree sonar and front camera Arms: 7 degrees of freedom, spring driven, able to stop if it "feels" it hits something No sharp edges, points, or other hazards that could cause an injury	Supply voltage: 120 Volts Alternating Current Rated current: 6 Amps	Vacuum cup with interchangable cups Electric parallel gripper with interchangeable "fingers" and user-adjustable "fingertips"

Source: http://www.rethinkrobotics.com/index.php/products/baxter_research/

EXHIBIT 11: BAXTER SPECIFICATIONS

General Features

- Price: $22,000, which includes a year of software updates and warranty and with zero integration required
- Equivalent of a worker making $4 an hour
- OS: Open-source Robot Operating System (ROS), (Unix-like system developed by the Stanford A.I. Lab)
- Requires no custom programming to perform new tasks
- Operating temperature range: 32-104° F (0-40°C)

Physical Features

- Robot height with pedestal: 5'10" - 6'3" (adjustable)
- Arm length to end-effector plate: 41"
- Toros mounting plate diameter: 13.3" (for mounting on table)
- Body weight, with pedestal: 306 lbs
- Pedestal footprint: 36" x 32"
- 360-degree sonar and front camera
- Arms: 7 degrees of freedom, spring driven, able to stop if it "feels" it hits something
- No sharp edges, points, or other hazards that could cause an injury

Electrical Features

- Supply voltage: 120 Volts Alternating Current
- Rated current: 6 Amps

End Effector

- Vacuum cup. Interchangeable cups.
- Electric parallel gripper with interchangeable "fingers" and user-adjustable "fingertips"

Source: http://www.rethinkrobotics.com/files/3313/6825/3525/BRR_005.10.13.pdf

Source: http://youtu.be/gXOkWuSCkRI

Source: http://www.economist.com/node/21563705

EXHIBIT 11: BAXTER RESEARCH ROBOT SPECIFICATIONS (OTHER THAN THAT OF BAXTER)

Workstation Requirements

- Ubuntu 10.04 LTS and ROS Electric, with minimum specifications:
- Intel i5 or above
- 4GB memory or above
- Min. 2GB of free disk space
- Ethernet port

Features

- Uses the Unified Robot Description Format (URDF) for collaborating across research groups
- Software Development Kit for installation on development workstation
- ROS framework for seamless integration across platforms

EXHIBIT 13: COMPETITOR INCOME STATEMENT - 2012

ABB

Consolidated Income Statements

Download XLS (20 kB)

Year ended December 31 ($ in millions, except per share data in $)	2012	2011	2010
Sales of products	32,979	31,875	26,291
Sales of services	6,357	6,115	5,298
Total revenues	**39,336**	**37,990**	**31,589**
Cost of products	(23,838)	(22,649)	(18,607)
Cost of services	(4,120)	(3,907)	(3,453)
Total cost of sales	**(27,958)**	**(26,556)**	**(22,060)**
Gross profit	**11,378**	**11,434**	**9,529**
Selling, general and administrative expenses	(5,756)	(5,373)	(4,615)
Non-order related research and development expenses	(1,464)	(1,371)	(1,082)
Other income (expense), net	(100)	(23)	(14)
Earnings before interest and taxes	**4,058**	**4,667**	**3,818**
Interest and dividend income	73	90	95
Interest and other finance expense	(293)	(207)	(173)
Income from continuing operations before taxes	**3,838**	**4,550**	**3,740**
Provision for taxes	(1,030)	(1,244)	(1,018)
Income from continuing operations, net of tax	**2,808**	**3,306**	**2,722**
Income from discontinued operations, net of tax	4	9	10
Net income	**2,812**	**3,315**	**2,732**
Net income attributable to noncontrolling interests	(108)	(147)	(171)
Net income attributable to ABB	**2,704**	**3,168**	**2,561**

Source: ABB 2012 Annual Report

KUKA

GROUP INCOME STATEMENT

of KUKA Aktiengesellschaft for the period January 1 – December 31, 2012

in € millions	Notes	2011	2012
Sales revenue	(1)	**1,435.6**	**1,739.2**
Cost of sales	(2)	-1,153.9	-1,353.3
Gross income		**281.7**	**385.9**
Selling expenses	(2)	-99.5	-119.7
Research and development costs	(2)	-37.7	-42.6
General and administrative expenses	(2)	-78.9	-98.6
Other operating income	(3)	43.0	31.8
Other operating expenses	(3)	-44.4	-54.3
Earnings from operating activities		**64.2**	**102.5**
Reconciliation to earnings before interest and taxes (EBIT)			
Financing costs included in operating results		8.4	7.3
Earnings before interest and taxes (EBIT)		**72.6**	**109.8**
Write-off of financial assets	(4)	-0.8	–
Interest income	(4)	9.9	9.6
Interest expense	(4)	-27.3	-22.4
Financial results		**-18.2**	**-12.8**
Earnings before tax		**46.0**	**89.7**
Taxes on income	(5)	-16.1	-34.1
Earning after taxes		**29.9**	**55.6**
of which: attributable to minority interests		0.1	–
of which: attributable to shareholders of KUKA AG		29.8	55.6
Earnings per share (diluted / undiluted) in €	(6)	**0.89**	**1.64**

Source: KUKA 2012 Annual Report

FANUC

(2) Consolidated Statement of Income and
Consolidated Statement of Comprehensive Income

Consolidated Statement of Income

(Millions of Yen)

	Years ended March 31 2011	2012
Net sales	446,201	538,492
Cost of sales	208,076	262,120
Gross profit	238,125	276,372
Selling, general and administrative expenses	48,368	54,538
Operating income	189,757	221,834
Non-operating income		
Interest income	1,466	1,912
Dividends income	533	651
Gain on sale of scrap	744	825
Investment profit on equity method	3,126	3,499
Miscellaneous income	1,666	1,123
Total non-operating income	7,535	8,010
Non-operating expenses		
Loss on valuation of investment securities	530	—
Foreign exchange losses	455	600
Loss on sales and retirement of noncurrent assets	478	185
Sales discount	165	142
Miscellaneous expenses	230	339
Total non-operating expenses	1,858	1,266
Ordinary income	195,434	228,578
Extraordinary loss		
Loss on adjustment for changes of accounting standard for asset retirement obligations	1,939	—
Total extraordinary losses	1,939	—
Income before income taxes and minority interests	193,495	228,578
Income taxes-current	77,319	92,831
Income taxes-deferred	△4,638	△3,695
Total income taxes	72,681	89,136
Income before minority interests	120,814	139,442
Minority interests in income	659	623
Net income	120,155	138,819

Source: FANUC 2012 Annual Report

Yaskawa

Consolidated Statements of Income and Consolidated Statements of Comprehensive Income

Yaskawa Electric Corporation and Consolidated Subsidiaries Years ended March 20, 2011 and 2012

(Millions of yen)

Consolidated Statements of Income	2011	2012
Net sales	296,847	307,111
Cost of sales	219,815	227,540
Gross profit	77,032	79,571
Selling, general and administrative expenses	64,157	64,752
Operating income	12,874	14,818
Non-operating income		
Interest income	73	62
Dividends received	270	329
Government subsidies for employment adjustment	284	152
Equity in earnings of associated companies	442	760
Foreign exchange gains	–	61
Miscellaneous income	665	399
Total non-operating income	1,735	1,764
Non-operating expenses		
Interest expenses	647	727
Foreign exchange losses	232	–
Miscellaneous expenses	301	230
Total non-operating expenses	1,180	957
Ordinary income	13,429	15,626
Extraordinary gains		
Gain on sales of fixed assets	46	24
Gain on sales of investment securities	39	8
Reversal of allowance for doubtful accounts	–	65
Gain on negative goodwill	–	1,091
Other	32	58
Total extraordinary gains	118	1,284
Extraordinary losses		
Loss on sales and disposal of fixed assets	82	112
Loss on devaluation of investment securities	1,084	170
Impairment loss	14	–
Loss on adjustment for changes of accounting standard for asset retirement obligations	–	332
Loss on step acquisitions	–	146
Other	306	759
Total extraordinary losses	1,488	1,521
Income before income taxes and minority interests	12,060	15,353
Provision for income taxes-current	4,374	4,076
Provision for income taxes-deferred	1,131	2,684
Total income taxes	5,505	6,760
Income before minority interests	–	8,592
Minority interests in income	11	160
Net income	6,544	8,432

Source: Yaskawa 2012 Annual Report

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Madison White (81)
Stephen Wu (10)
Ming Yin (3)