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The Robotics Revolution And The Path Ahead

Introduction

It is nearly impossible to read a newspaper or consult an online news source these days without coming across something about robots and robotics. Indeed, robotics is frequently mentioned as one of the foundational technologies of the 21st century in the same breath as artificial intelligence, augmented reality/virtual reality, biotechnology, and green energy. We at Navidar agree that robotics is one of the most fascinating, promising, and important emerging technologies being developed today and we wanted to explore the industry, its characteristics, and offer a peek into the future with several predictions.

Even before today's explosion of interest, robotics had long occupied a special place in our culture. We have watched robots like R2D2 and C3PO in Star Wars films, seen robots like Data in Star Trek: The Next Generation on television, and even read about robots (usually gone amok) in popular fiction since the early 1940s when books like *Liar* and *I, Robot*, were first published.

One of the major points of this report is that robotics is currently in the midst of major changes—which others, as well as we, call the Robotics Revolution—that are being driven principally by improvements in a broad range of underlying technologies that are used to create robots and that this revolution offers the promise of changing—perhaps even transforming—many facets of our existence, including how we work, do business, travel, relax, and live our daily lives.

These dramatic improvements in software, hardware, computing power, integrated circuits, "smart" materials, sensor technology, artificial intelligence, and numerous other technologies create more opportunities to deploy robots in useful applications and will enable robots to move to new use cases that could not have been imagined only a few years ago.

This trend of improvements in existing technologies and development of new technologies shows no signs of abating. In fact, investment in robotics has exploded over the past decade as traditional venture capitalists, corporate venture funds, and incubators have invested billions of dollars into the robotics field. Robotics is a hot sector today and we may well anticipate continued dramatic advances in the years ahead.

This report is divided into three primary sections and focuses principally on the United States, though we do offer commentary on global robotics developments where relevant. First, the Background & Overview section offers a very brief history of robotics and highlights the key characteristics of robots. Next, the Observations and Commentary section discusses the main growth drivers of the robotics industry and shares several observations about the industry and its interesting structure. Finally, in the Predictions Section, Navidar offers several predictions about how the industry will evolve and discusses some of the issues that the Robotics Revolution will likely create.

The Robotics Revolution is here today, and we will all have a ringside seat to watch this technological revolution unfold. Let us begin our discussion with a very brief history of the industry to set the stage for the broader messages of our report.

Section 1: Background And Overview

A Short History of Robotics: Robots Have Actually Been In Use for Decades!

Would you be surprised to learn that robots have actually been around for a long time? Well, it is true. The word "robot" is derived from the Slavic word ***robota***, which means work or job, and entered the English language over one hundred years ago in 1920, when Karel Capek, an Austro-Hungarian (we would say Czech today) playwright, first introduced the term in his science fiction play "Rossum's Universal Robots", in which robots rebel against their human creators and cause humans to become extinct. In a bit of trivia, Capek, although recognized in other ways for his literary accomplishments, never won the Nobel Prize in Literature, despite having been nominated for the honor a total of seven times.

Very little happened in the United States for a while after the term was introduced into the English language by Capek. In 1928, Japan created the first simple robot. In 1941, Isaac Asimov, another science fiction writer, created the term "robotics" in his play, *Liar*, according to the Oxford English Dictionary. It was not until twenty years later in 1961, however, that the first industrial robot, named Ultimate, was created and installed to move scalding metal pieces from a die-cast machine and stack them. Shortly thereafter, in 1961, General Motors began using robots consisting mostly of mechanical arms on its assembly lines to handle dangerous or highly repetitive tasks like screwing and welding cars on an assembly line. Thus began the long association and the beneficial use of productivity-enhancing robotics technology in the manufacturing industry in general and in the automotive industry in particular. In 1969, the famous landing on the moon actually used robotic technology to assist the astronauts with their mission. Many years later, places like MIT Labs began developing humanoid robots in 1994. And, yet, as late as 2005, 90% of all robots were still used to assemble cars in automobile factories.

If robots have been around for so long, why do Navidar and others think that we are in the midst of a Robotics Revolution? It is a fair question to ask. The answer to this question is something we mentioned earlier: the dramatic improvements in the various underlying technologies used to create robots have enabled robots to become useful for many new and different things. Robots have today expanded far beyond their initial uses of doing narrowly-defined, repetitive work to now performing tasks like helping with surgeries, operating in nuclear power plants, and assisting with warehouse logistics. As a testament to this dramatic expansion of use cases, 2020 was the first year in history that yearly orders of robots from non-automotive sectors surpassed automotive robot orders. Today, robotics is creating intelligent machines that can learn, think, do more, and help humans with a far broader range of tasks.

What Is A Robot, Anyway?

The Oxford English dictionary defines a robot as "a machine resembling a human and able to replicate certain human movements and functions automatically." By extension, we can say that robotics can be defined as the field that involves the conception, design, construction, manufacture, operation, and use of robots. So far, so good. Those are reasonable starting points. We agree that a robot is definitely a machine. For our purposes, however, the definition misses a few key elements. Let us add in some of those key additional points.

Our friends at Oxford do not say anything about the purpose of robots. We would add that the purpose of robots is to help humans in any variety of ways.

Oxford also omits any mention of what robots are designed to do. We would say that robots are intentionally designed by humans to take action and to do something, which is to accomplish a (usually physical) specified task.

Perhaps understandably, the definition says nothing about the technologies and disciplines involved in creating a robot. We cannot blame them for this likely quite intentional omission, because robotics is multi-disciplinary, highly complex, and involves a broad range of scientific, technological, and engineering disciplines.

We would note that creating a robot requires or can require knowledge of some or all of the following diverse disciplines:

- Mechanical systems and mechanical engineering
- Electrical systems and electrical engineering
- Chemical engineering
- Bioengineering
- Information science
- Computation
- Software
- Mathematics

Have we forgotten to mention any other required areas of expertise above? We probably have, actually. This gives one a sense of how multi-disciplinary and inter-disciplinary robotics really is.

Now that we have our working definition of a robot and have touched briefly on the field of robotics, let us engage in a brief robot anatomy lesson.

Robot Anatomy 101: A High-Level Introduction To Robot Anatomy

(See Exhibit 1 at the back of this report for a graphic depicting the typical robot's anatomy)

By anatomy, of course, we are referring to the basic characteristics and components of robots. Here, we want to make the key point that robots can be thought of as assemblages of numerous component technologies that together give the robot its functionality and use case. If we think of robotics as the combination of many different technologies that are organized into the form factor that we call a robot, it may help us better understand how advances—or setbacks—in one technology area can advance—or hinder—the cause of robotics more broadly.

1. Robot Programming And Control Systems

Every robot has and needs a control system to guide its actions and behavior. Indeed, all robots contain at least some level of computer programming. (Programming is basically the language—and there are hundreds of these computer programming languages—that the programmer uses to communicate with the robot.) A robot's control system—which is a computer program built into the robot—determines what, when, and how a robot performs a given task.

Until very recently, any action whatsoever that a robot was required to take had to be programmed by a human. Today, advanced robotic programming is beginning to enable robots to learn and adapt to changes in their environment and take an action or make a decision about what to do next. It is important to note that robots still do not possess general analytical abilities like humans (or, at least, not yet, but more on that later), but progress is being made each day.

2. Sensors And Robotic Perception

Sensors enable robots to sense or perceive the environment in which they are operating. Sensors are essentially information-gathering devices that allow a robot to accumulate facts about its environment (the physical space that it functions in), where it needs to go, if any obstacles lie in its path, and also to monitor its own internal status (is everything working okay in my system?).

In designing a robot that can function effectively in its environment, it is very important to select the appropriate sensors for that robot's particular use case. There is an extremely wide range of sensing and perception technology. People usually think first about vision and there are sensors such as image sensors and video cameras that capture images and act as the robot's eyes. Sensors can also include microphones that capture audio information and serve as the robot's ears. In addition, sensors can include photoresistors that detect and react to light. But sensor technology has gone far beyond these functions as well. Today, sensors can use radar (radio waves), sonar (sound), and even lidar (lasers to measure reflected light) to help robots perceive their environment and perform their designated tasks. Specialized sensors are even being designed to detect things like a person's facial expressions.

3. Mobility And Locomotion Through Actuators

Robots need to move in some way in order to complete their tasks. Movement in robotics is called locomotion. If sensors are a robot's sensory organs (sight, hearing, etc.), then a robot's locomotion is accomplished through what are termed actuators, which are the components responsible for moving the robot through its environment.

Locomotion for robots can be accomplished in a wide variety of ways. Some robots move using wheels (there are one-wheeled, two-wheeled, four-wheeled, six-wheeled, and other robot varieties). There are two-legged robots that walk. Other robots move along tracks, hop, fly (such as drones), or climb (vertical surfaces). Some robots move like flying objects; drones use propellers. Believe it or not, there are even robots that move by sailing, swimming like a fish, or slithering like a snake. As one would expect, the mobility system for a robot is normally determined by the environment in which that robot is intended to operate.

4. Manipulation Using Effectors

Robots must not only be able to perceive their environment (through sensors) and move through their environment (through actuators), but they also need to interact with and manipulate their environment, which is done through effectors or end effectors. Effectors basically enable robots to physically interact with their environment. They allow robots to manipulate objects by picking them up, moving them, gripping them (which is a great deal more complicated than one might think), modifying them in some way, or even destroying them. Effectors can operate like hands, claws, pincers, or pushers. They can also function like shovels, hammers, or chisels. Suction is another more recent means of robot manipulation. As with actuators, the type of effectors used will be closely related to the task that the robot is designed to complete.

5. The Power Source/Power Supply

Unsurprisingly, robots require a constant source of power. Today, this power source is usually a battery of some kind. Key considerations for batteries include safety, weight, replaceability, and lifecycle. A robot's power source is important not only for keeping the robot "up and running," but also because the weight, safety, and rechargeability of that power source will have a large effect on the robot's design and overall cost. In fact, the power source is often seen as a significant limiter of robotic performance because batteries can go dead after only a few hours of continuous usage. Designers are actively exploring and refining other power sources including pneumatic (compressed gas), hydraulic (liquids), chemical, and solar.

6. The Human-Robot Interface (HRI, for short)

The final component we want to mention is the human robot interface (HRI), also known as the operator interface. The HRI is basically the way that the user and the robot communicate. The HRI is important because effective communication is often important to enabling a robot to do its task correctly. Suffice it to say that a great deal of thought needs to go into the design of the HRI. The HRI must be easy to use, intuitive, and enable clear and efficient communication.

Section 2: Industry Observations And Commentary

In this section, we offer and explore the following observations about the robotics industry:

- Observation #1: There Are An Incredible Number Of Different Types of Robots
- Observation #2: No Other Technology Can Match Robotics' Diversity of Environments
- Observation #3: The Applications And Use Cases Of Robotics Are Virtually Unlimited
- Observation #4: Robot Autonomy Is the Holy Grail
- Observation #5: No Single Country Has Emerged As The Clear Robotics Leader…Yet
- Observation #6: Numerous Secular Growth Drivers Are Propelling the Robotics Industry

Before we start, one of the most remarkable things about the world of robots is their incredible breadth and variety. This breadth and variety cuts across types of robots, environments in which robots function, and applications and use cases for robots. As robots continue to get smarter, more flexible, and more efficient, their breadth and variety along all three of these dimensions will only become more pronounced and impressive.

Let's dive in and start with the first type of breadth and diversity: types of robots.

Observation #1: There Are An Incredible Number Of Different Types Of Robots

It is striking how many different types of robots exist today. These robots include, but are certainly not limited to, the following:

Industrial Robots: These robots have been in use since the earliest days of robotics. They are most commonly used in manufacturing applications and particularly in the automotive industry.

Drones/Unmanned Aerial Vehicles: These vehicles are unmanned and are used in numerous ways, but are primarily utilized for inspection and intelligence purposes, though there is much talk today about using specialized drones for delivery of packaged goods.

Collaborative Robots (Known As Cobots): Collaborative robots are engineered to operate *safely around human beings* and are designed to permit automation beyond the confines of the factory environment.

Social Robots: These robots are often contrasted with industrial robots. They are designed to interact with and communicate with people or other machines by following a set of social behaviors and rules. The hope is that these robots will allow for a broader range of applications and use cases involving people. Enormous growth is expected in this category.

Humanoid Robots/Legged Robots: A humanoid robot is a robot specifically designed to look like a human; it typically has a face, two arms, two legs, and a torso.

Autonomous Vehicles: This type of robot is clearly the rage these days and includes both trucks and cars as well as autonomous underwater vehicles.

Military Robots: These robots are used in military settings where the use of human soldiers is too dangerous, too risky, or ill-advised. These robots operate, for example, on the battlefield and have been used to identify and clear landmines.

Exoskeletons: This type of robot, often used in warehouse, logistics and construction applications, was created to physically enhance human performance, increase human strength, and reduce the risk of human injury.

As a final example of the breadth and variety of robots, note that robots exist today that vary in size from literally several millimeters to hundreds of feet long.

Observation #2: No Other Technology Can Match Robotics' Diversity Of Environments

(See Exhibit 2 at the back of this report for a small sampling of various robotic environments)

Perhaps no technology has ever been called upon to be as versatile as robots and operate in as broad a range of different environments. There may be as many different environments in which robots are called to operate as there are different types of robots.

Today, robots operate in the following sampling of incredibly different environments:

- Roads & Highways
- Earth
- Sky
- Outer space
- Ocean floor
- Households
- Hotels
- Battlefields
- Factory floors
- Warehouses
- Healthcare facilities
- Surgical centers
- Nuclear power facilities

There are today and will be tomorrow even more environments in which robots will help humans as the underlying technologies continue their seemingly inevitable advance forward.

Observation #3: The Potential Applications Of Robots Are Almost Literally Unlimited

(See Exhibit 3 at the back of this report for an overview of various robot use cases)

Robotics is clearly a very widely applicable technology with myriad and ever-expanding use cases driven by the advances and breakthroughs in various underlying technologies. As this technology frontier pushes continually outward, the ultimate limit of the applicability of robotic technology lies perhaps only in the ability of our human minds to conceive of and identify new use cases for these robots.

Below we discuss a number of the use cases for robots across a range of different industries.

Manufacturing

The manufacturing sector accounts for some $2 trillion in the United States and is a significant component of GDP. Robots have been used in the manufacturing industry since their earliest days. These robots handle, weld, screw, transfer, move, build, assemble and manipulate materials throughout the manufacturing process. These uses represent perhaps the most traditional and well-known use cases of the millions of industrial robots around the world today. In addition to working on their own, collaborative robots—cobots—have been used in manufacturing to work *alongside humans* in manufacturing plants for many years. And one suspects that the need for robots in manufacturing will increase, driven by the need to lower costs, increase productivity, improve quality, and speed product delivery.

Logistics

A wise person once told us that logistics basically addresses the issue of how to get things from one place to another place. Unsurprisingly, the logistics industry is a very large user of robots. Robots in warehouses take items off the shelves, move them across the warehouse floor, and package them, all often without human intervention. Robots are involved in picking, shipping, packing, handling, tracking and doing quality control for many logistics companies. It is estimated, for example, that Amazon uses over 350,000 robots in its warehouses to supplement the work of its human workers.

Robots—particularly flying drones—have been mentioned as a promising potential solution to a major issue in logistics, referred to as the "last mile" problem. This problem refers to the *final or last part* of the logistics process involving actually getting the packaged finished product safely, reliably, and cost-effectively delivered to the customer's doorstep. The last mile issue is one of the most important, but also one of the most difficult and costly, parts of the entire supply chain, and autonomous drones—unmanned aerial vehicles—may represent a way to significantly reduce the costs of last mile delivery.

Household And Home

What would you think of robots that can mow your lawn, clean your pool, and vacuum your floors? Well, such robots already exist today. Roomba, a robot that can vacuum your home autonomously, is perhaps the most well-known of these types of household robots.

There exists another major potential use case for social robots and that is to improve the quality of life for the lonely, elderly, and home-bound. Loneliness is a major problem—and therefore a major market opportunity and potential use case for robots—in America. In a recent national survey, 36% of respondents reported "serious loneliness"—feeling lonely "frequently" or "almost all the time or all the time". This included 61% of young people aged 18-25 and 51% of mothers with young children. While the Covid-19 pandemic did not create this issue, it has certainly exacerbated it as 43% of young adults have reported increases in loneliness since the pandemic. The future applications of an interactive, empathetic social robot in family homes with young people, nursing homes, retirement communities, and singles living alone are very exciting and may well help alleviate a significant social problem as well.

Travel And Transportation

One reads about autonomous—or self-driving—vehicles all the time. They have certainly caught the attention of the public and the investment community. (As of this writing, Tesla's market capitalization is greater than General Motors'.)

Autonomous vehicles have gotten the attention and focus of startups like Tesla and Waymo, established automotive incumbents like Ford, Volkswagen, and BMW, and ridesharing companies like Uber and Lyft. Autonomous trucking automation has received significant investment interest as well. In the first half of 2021, for example, investors placed $5.6 billion into autonomous trucking companies like TuSimple, Plus, Aurora, and Embark, surpassing the $4.2 billion invested in 2020 and establishing a record for investment in the sector. Against the backdrop of a ground and air transportation infrastructure that has not kept up with demand and regularly experiences congestion, delays, and capacity constraints—all of which exact a human and societal toll (no pun intended)—the promise of autonomous vehicles to deliver people and goods smoothly, safely, efficiently, reliably, and speedily to their destinations is remarkably appealing.

Healthcare

Healthcare is the largest sector of the United States economy, representing approximately 18% of GDP. It is also one of the most labor-intensive. Today, robots are involved in virtually every part of the healthcare industry. They assist hospital staff in a number of routine tasks such as delivering food, retrieving medicine, and aiding in patient transport. This frees up valuable nursing time for less routine but higher-value activities. In addition, robots help patients with their physical therapy and rehabilitation. Toyota's healthcare assistants, which help people regain the ability to walk, are an example. Finally, robots assist in surgeries. If you have been in a hospital lately, you have probably seen the posters throughout the building about the da Vinci surgery robot, which is utilized by surgeons to perform a range of surgeries, or the CyberKnife, which is used in cancer treatments.

Law Enforcement And Military

Robots add significant value in a range of law enforcement and military use cases. In law enforcement, robots can monitor, control, and disperse crowds, photograph potential violators of the law for later follow-up, and aid in search and rescue missions after natural disasters. The military uses robots to detect landmines in war zones, surveil enemy territory, bring injured soldiers back to camp, and carry light loads—all without endangering human soldiers. Some military robots can even fire live ammunition against enemy targets, leading some to predict that robots may one day change the nature of warfare.

Agriculture

Agriculture is a huge market in the US and accounts for nearly 6% of GDP. Like healthcare, it is also quite labor-intensive and requires a large work force. Today, robots plant seeds, apply fertilizer, water, and harvest crops, do weed control and precision spraying, and monitor and collect data on crops. As robotics continues to push its frontiers outward and generate new high-value use cases, we would expect its role in agriculture to expand and broaden.

And There Are Uses Cases In Many Other Industries …

We have touched upon a subset of the robotic applications and use cases in the industries mentioned above, but there are many other industries as well that can and do benefit from robots. This list of industries includes retail, real estate, forestry, and wildlife management as well as aerospace, oil and gas, construction, power, and utilities.

Just as more *types* of robots will be invented to meet our emerging needs and robots will be utilized in even more *environments*, so, too, will the range of *industries* benefitting from robots increase over time.

Observation #4: Robot Autonomy Is The Holy Grail: What Does It Mean?

Autonomy is an important characteristic of—and goal for—some robots. Today, many see autonomy as the ultimate goal—the Holy Grail—for robots. Autonomy essentially refers to the degree to which a robot can operate on its own, without human guidance, direction, or intervention. It is important to note that, generally speaking, the more autonomy a robot has, the more easily that robot can operate in unstructured environments—meaning environments that vary and are not controlled—which is the goal for many new robot use cases.

We can therefore categorize robots based on the degree of autonomy that they possess, ranging from 100% human-controlled robots to fully-automated robots that perform tasks without any external influence.

Three of the broad concepts around autonomy include:

1. **100% Human-Controlled Robots:** These robots operate only under human control and are *not autonomous* at all. The da Vinci robotic system for performing surgeries is an example because it is fully controlled by the surgeon in all cases.
2. **Semi-Autonomous Robots:** These robots are partially, but not fully, autonomous, so they can operate on their own under certain conditions and circumstances, but they do not operate on their own all of the time.
3. **Fully Autonomous Robots:** These robots can make decisions and operate on their own without any human direction. A Roomba vacuum cleaner that the user turns on and leaves alone to vacuum their house provides a simple example. These robots may go without any human intervention for long periods of time. Autonomous robots can be said to be the most independent.

Observation #5: No Single Country Has Emerged As The Clear Robotics Leader…Yet

One of the most striking things about the emerging robotics industry is how global it is. Perhaps this is not surprising given the broad array of different technologies, disciplines, and skill sets underlying the robotics industry.

The industry is remarkably varied and heterogeneous and has a broad range of participants:

- Established international behemoths and new domestic-focused startups
- Conglomerates (where robotics is one component of their business) and pure-play robotics companies (that are focusing solely on robotics)
- Very large companies and small companies

Can we point to an industry leader at this point? It is difficult to choose an industry leader now because the Robotics Revolution is in its early days and, as is perhaps typical of many emerging industries, we do not believe that a clear leader has emerged yet. One should also resist the temptation to anoint a single leader because, given that there are so many different underlying technologies in the robotics industry, it might be misleading to choose a single leader. Perhaps the United States could be termed an early leader in Artificial Intelligence while Japan could be termed a leader in deploying industrial robots in manufacturing. And China is making a huge strategic push in this area, as they have in other technology areas that they have identified as linchpins of their global ambitions, and may have the most momentum currently. If we were forced to anoint the frontrunners, we would probably choose China and the United States, but we would be remiss not to mention Japan, Europe, and South Korea in the same breath. Significant venture capital investment has gone into robotics startups in both the United States and China. In the 12 months ended March 2021, $6.3 billion was invested in robotics companies by venture capitalists, an approximate 50% increase from the $4.3 billion invested during the same period in the prior 12 months. Taking a longer time frame, robotics investment grew more than five times, increasing from $1 billion in 2015 to $5.4 billion in 2020. One thing is certain from these figures: the global race is on, and we should expect intense competition.

Observation #6: Numerous Secular Growth Drivers Are Propelling The Robotics Industry

(*See Exhibit 4 at the back of this report for a graphic of the robotic industry growth drivers)*

We believe that it is important to understand the growth drivers of any industry or technology. Generally speaking, a greater number of strong growth drivers bodes well for an industry, increasing the industry's long-term chances for success, growth, and proliferation.

We believe that the robotics industry, in both the United States and globally, possesses a number of very strong secular growth drivers that are enabling today's Robotics Revolution.

While each specific individual industry—ranging from manufacturing to healthcare, from transportation to logistics and beyond—has its own industry-specific growth drivers, we wanted to explore some of the general, high-level growth drivers that today are pushing the Robotics Revolution broadly forward.

We Identify The Following Long-term "Meta-drivers" Of The Robotics Revolution:

1. The Long-Term Labor Shortage
2. The Ongoing Drive to Reduce Costs
3. The Benefits of Improving Productivity and Increasing Efficiency
4. The Growth of E-Commerce
5. Increasing Global Competition In Our Flat World
6. The Never-Ending Desire Improve People's Lives

1. The Long-Term Labor Shortage

The United States is experiencing a significant labor shortage that many believe is a long-term, secular trend that will drive growth of robotics for many years. On a macro level, domestic job openings continue to far outpace the number of available workers, with nearly 5 million more open positions than people seeking work. Currently, there are 11 million job openings in the US, representing a record 1.7 job openings for each unemployed person. This shortfall has been compounded by the fact that people have recently been quitting jobs at record levels. Employee turnover has clearly become a significant problem. To compound matters, the worker shortfall is particularly severe in a number of very large industries including manufacturing, retail, and transportation.

Perhaps not surprisingly given the developments mentioned above, the cost of labor in the United States continues to rise, as it has in other countries as well. For example, in the 3rd quarter of 2021, median weekly earnings for full-time workers were 6.9% higher than they were in 4th quarter of 2019. Earnings for full-time workers in the bottom 10th of income rose a whopping 9.2%. Increases of this magnitude will surely fuel the desire to substitute robots for labor going forward.

The decline in the growth of available workers to fuel economic growth, while exacerbated in the short-term by the pandemic, is a long-term secular phenomenon driven by two key factors. First, as Baby Boomers (those people born between 1946-1964) move into retirement, the growth of the labor supply in the United States is slowing. Second, the United States population is aging. It is estimated that by 2030, 21% of the population will be 65 years of age or older. As projections extend further into the future, this percentage continues to increase. As a result of both of these forces, the abundant labor that had fueled past economic growth can no longer be counted on going forward and these trends will drive the desire to utilize robots going forward.

2. The Ongoing Drive To Reduce Costs

Robots offer the promise of reducing costs and this would be a boon to many industries. Some estimates suggest that robots—and other forms of automation—could reduce operating costs anywhere from 10-15%, which would take billions of dollars of costs out of the system and enhance margins as well. Robots do not get sick or tired; can work without breaks; do not require healthcare or benefits packages; do not get injured on the job (though they do require maintenance and repair); and do not file lawsuits against their employer. Even if the adoption of robots takes out less cost than estimated above, cost reduction still represents a powerful and attractive long-term growth driver.

3. The Benefits Of Improving Productivity And Increasing Efficiency

Robots offer the promise of improving productivity and increasing efficiency in many industries today. They have over the years proven their value in doing precisely this in the manufacturing sector, particularly in the automotive industry, as well as in the logistics industry where they have also been widely deployed. Robots can improve productivity and increase operational efficiency, particularly in many—though not yet all—of today's operations and processes that still have a significant (and increasingly costly) component of manual labor.

4. The Growth Of E-Commerce

We would be remiss if we did not mention e-commerce as an important long-term trend. The global market for e-commerce was $26.7 trillion in 2020 and is expected to grow approximately 15% annually for the next 5+ years. Online shopping seems to be something that people across the world have in common. The growth of e-commerce has been driven of course by more online shopping during the pandemic but also by the shift away from brick-and-mortar store purchases in favor of online shopping. As customers purchase more goods online and expect those goods to be delivered in only a day or two, this demand for faster shipping times has created opportunities to deploy robots in warehouses and distribution centers as a means of improving e-commerce fulfillment. Amazon, which alone uses around 350,000 autonomous robots to automate order fulfillment, has been a major driver of this trend and its actions have forced other retailers to respond in kind.

5. Increasing Global Competition In Our Flat World
We see global competition as a driver of robotics adoption in two fundamental ways. First, global competition in our increasingly "flat world" has increased significantly in virtually all industries. Competition is already intense, and it will likely only increase going forward. This competition drives faster response times and the search for technology solutions to gain a competitive advantage, which we think certainly includes robotics technology. Second, once one industry participant adopts robotics technology, their adoption will be a force to push other industry participants to adopt robots, thus accelerating adoption across the industry. The United States understands the importance of robotics and the associated technologies enabling the Robotics Revolution today, but so do our competitors. China, Japan, Europe, and Korea all have made major investments in robotics, and many have significant government-funded programs to support continued investment and progress.

6. The Never-Ending Desire To Improve People's Lives
Finally, we hope we don't sound too pollyannaish when we say that we believe that robots have always had as their guiding purpose to make people's lives better by enabling people to do things better, more precisely, and more safely. Indeed, this trend has been occurring for over six decades and the bottom line is that we believe that this trend will continue indefinitely. There are still today many unmet human needs that robots may one day be able to satisfy. Recall our discussion of social robots as a potential solution to the society-wide problem of loneliness as but one example. Unmet needs often create large market opportunities, and we expect that the entrepreneurial spirit in the United States and in other parts of the world will drive many new use cases where robots can help people improve their lives.

Section 3: Looking Into Our Crystal Ball: 8 Predictions About The Future

Predictions can be interesting for many reasons, not least because they are often an excellent way to generate thought and discussion around fascinating topics. So, in this, our final section, we engage in some forward-looking thinking. Of course, making predictions about emerging industries that are rapidly evolving is particularly challenging. It is quite true that many things concerning the future evolution of robotics are both unknown and unknowable today. As a result, any prediction we make will represent one possible scenario among a cloud of many different potential outcomes. We may be wrong. We may be off on timing. We may miss a major development that is difficult or impossible to foresee at this time. But these challenges will not stand in the way of our offering several predictions about the robotics industry, how it may evolve, and where we go from here.

Here in summary are our 8 predictions, which we will explore in greater depth below:
1. The Robotics Revolution May Take Many Years Before It Changes Our Lives Dramatically
2. Robots May Not Become Fully "Human" (Fortunately Or Unfortunately, Depending On Your Perspective) During The Lifetime Of Anyone Reading This Report
3. Artificial Intelligence Will Be The Single Most Important Technology For Robotics
4. RaaS Will Become The Dominant Business Model For The Robotics Industry
5. The Proliferation Of Robots Will Create A Large Robotics Services Industry
6. Robots Will Eventually Work Together In Groups
7. Robots Will Not Replace All Of Us, Or Even Most Of Us, But They May Replace Many Of Us
8. The Spread Of Robots Will Raise Important Public Policy Issues

Prediction #1: The Robotics Revolution Is Well Underway And Will Drive Revolutionary Change, But It May Take Years Before Our Daily Lives Change Dramatically

Navidar is clearly long-term bullish on robotics, and we do not believe it is an exaggeration to say that robots will have profound effects on many aspects of our lives. In fact, we believe that the long-term impact of robots will extend beyond our wildest imagination. But we also believe that it may take longer than many expect to realize the vision of ubiquitous robots that dramatically change the way people lead their lives. Despite the promising array of new technologies, the varied secular growth drivers, and all the impressive progress that has been made so far, we think a number of obstacles could slow the pace of adoption over the near-term and intermediate-term and thus push out the time frame for society-wide adoption.

What are some examples highlighting potential obstacles and challenges that may lie ahead?

Grasping: We would start by noting that some significant issues in robotics—like grasping—have not been fully solved yet, despite dedicated scientists and technologists having worked on them for the past 40 years. We noted earlier the importance of robots being able to interact with their environment and grasping is clearly one of the primary means by which certain robots do this. You might think that grasping is an easy problem to solve, but you would be mistaken. This seemingly simple problem is actually extraordinarily complicated. Across a range of use cases, robots today cannot match the speed and accuracy of the human hand in identifying and grasping a broad range of objects of varying shapes and sizes. And we believe that this example is important both practically and symbolically because it underscores (for the time being anyway) that there are limits to what robots can do and therefore limits to how rapidly humans will be able to deploy robots across society.

We turn now to two additional examples of potential challenges to robotics adoption.

A Short Cautionary Tale Showing That Robot Deployments Do Not Always Go As Planned

One has to be careful when extrapolating from isolated cases such as the one we are about to describe. Nevertheless, sometimes small examples can provide valuable insights, as we believe the following story does. There is a hotel in Nagasaki, Japan. The hotel is called the Henn na Hotel. (Apparently, the name translates into "Strange Hotel".) The hotel opened in 2015 with a staff of 243 robots that were to check people in, escort guests to their rooms, and help with other hotel tasks. The robots were programmed to speak both Japanese and English. Fast forward to 2019: the hotel "fired" over half of its robotic work force and decided to return to using human beings because the robots failed to reduce costs or the workload of the hotel's employees. What went wrong? It has been widely reported that the robots frequently broke down. Guests also complained that the robots could not answer basic questions. The luggage-carrying robots could not do their task correctly in many cases. And the robots created additional work for the hotel staff—rather than reducing it—because the staff were often called upon by guests to help with problems with the robots. This small example shows that the reality of robotic deployment does not always match their theoretical promise.

Operating In Unstructured Environments Is A Major New Mountain To Climb

Robots have provided major contributions by enhancing speed, efficiency, accuracy, productivity, and safety in many environments, but most of those environments have been highly structured environments. As robots continue to advance, they will need to be able to handle technical challenges related to unstructured environments. But moving from structured and unchanging environments, like warehouses and factories, to unstructured environments like offices, homes, and grocery stores represents a challenge of a much greater order of magnitude. Unstructured environments vary; they change; they may contain obstacles. In these unstructured environments, robots may well face situations that they have never experienced in the lab or have to undertake entirely new tasks that they have not been specifically programmed to perform. The truth today is that it is still very difficult to design robots that can do more than one task at a time.

Will robotics solve the challenges involved in grasping what we highlighted above? Yes, we believe that these challenges will be solved in the next decade or so. Is, however, a general solution to robots operating in most unstructured environments right around the corner? It might be, but the probabilities suggest otherwise, and we think it will likely take longer to solve the challenges presented by unstructured environments than many might expect or hope.

Prediction #2: Robots May Not Become "Fully Human" (Fortunately Or Unfortunately, Depending On Your Perspective) During The Lifetime Of Anyone Reading This Report

We love science fiction. We love the robots in Star Wars and Star Trek. We love the robots in the Terminator movies. So, we are sorry if we are disappointing the true optimists—some might say visionaries—out there when we say that we may well not see these types of robots in our lifetimes. To be clear, yes, we do already have walking robots. We also have talking robots today. But we do not have robots that any human would look at or interact with and mistake for a human being…yet.

Will we have "thinking" robots in the next 50 or so years? If by "thinking," we mean robots that use artificial intelligence to solve complex problems in forms that they have not seen exactly before? Then the answer is yes, and we have robots that use artificial intelligence to think (to some extent) today. But if by "thinking" robots we mean robots that are capable of abstract thought, that can demonstrate creativity or critical thinking and decision-making skills, then we believe that the answer is probably no.

Would we like to add a caveat to our prediction? Sure, why not. We have stated what we believe based on our knowledge today, but if, say, 20 or 30 years from now, we turn out to have been wrong about our prediction, we think it will likely be because we underestimated the speed of the advances in Artificial Intelligence capabilities in general and its use and application in robots in particular.

Prediction #3: Which Single Technology Is Going To Drive Broad Robotics Adoption?

That we are in the midst of a major change—the Robotics Revolution—driven primarily by improvements in a number of the underlying technologies used to create robotic systems seems clear. Enhancements to these "robot-enabling technologies" will drive new use cases that were previously undoable, infeasible, or unimaginable; they will accelerate robotic adoption; and they will lower the cost of these new solutions. In saying this, we recognize two things: first, that the technologies listed below interoperate and that advances in one technology may well lead to (unforeseen) advances in other disciplines; second, that our thesis begs the question of which of these technologies might turn out to be the single most important one in accelerating the society-wide adoption of robotics.

There are many potential candidates, but we have identified what we consider to be 8 of the most promising candidates. We conclude this discussion of the most important enabling technology by choosing a runner-up as well as the technology that gets our winning vote:

1. Sensor Technology
2. Control Systems and Programming
3. HRI And Improved User Interfaces
4. Integrated Circuits/Semiconductors
5. Power Supply
6. Speech Recognition
7. "Smart" Materials
8. And the Winning Technology Is … Artificial Intelligence

Candidate #1: Sensor Technology?

Sensors are important for robots because they are the means by which robots process stimuli, recognize their environment, and correctly perceive "reality". Robots (and humans for that matter) have limited ability to capture the complexity of the world around them. Improved vision, hearing, touch, and other sensors would enable robots to understand and react to their environment in broader and more flexible ways. Of the various robotic senses, vision may well be the most important of all for many robot applications. For example, enhanced vision holds particular promise for social robots who would have the ability to see and correctly interpret facial features, gestures, body language, and other physical cues given by the person with whom they are interacting. In addition, better sensing and perception will certainly prove useful for accelerating the adoption of autonomous cars and trucks, particularly by enabling them to operate safely under poor weather and other hazardous conditions. General advancements in the speed, clarity, and depth of sensors would undoubtedly advance numerous robotic use cases.

Candidate #2: Control Systems And Programming?

After our earlier points about autonomy and unstructured environments, improvements in control systems and programming clearly take on major significance. Whether through home-grown proprietary control systems or through open-source technology, scientists today continue to push the frontiers of what control systems are able to do. As robotic use cases extend to operate in unstructured environments, robots will need far more advanced control systems and planning abilities to manage and overcome the greater uncertainty and novelty of these new environments. The critical word is *uncertainty*. And control systems that enable robots to operate in a broad range of environments will open the door to exciting new use cases and richer forms of interaction with humans.

Candidate #3: Human Robot Interfaces?

What will it take for humans, particularly individuals who are not experts, to be able to interact seamlessly with robots? One part of the answer is certainly that we need to *make things easy* on the human. By "easy," we mean intuitive, clear, and simple to learn user interfaces. Although not very common today, the human robot interface of the future will be uncomplicated and will not require any special training to learn to operate adeptly. If one day, the typical human robot interface is as elegantly and intuitively designed and as easy to learn as, say, the interfaces on today's cell phones, then this would undoubtedly open up many new and valuable use cases and drive adoption of robots.

Candidate #4: Integrated Circuits/Semiconductors?
Could new chips that enable significant advancements in computational power enhance the flexibility and adaptability of robots? Undoubtedly, yes. Better integrated circuits are analogous in some ways to a person becoming more intelligent, or at any rate being able to solve problems more rapidly and efficiently. This ability is always a good thing and advancements in integrated circuits surely offer this possibility.

Candidate #5: Power Supplies?
It may seem surprising to mention something as seemingly unglamorous as power supplies as a potential candidate to dramatically accelerate robotic adoption. And, yet, battery life is a significant issue in some robotic systems because some robots cannot operate continuously for long periods of time without needing to be recharged. In addition, as noted earlier, the type and weight of the battery have an impact on the design and the overall cost of the robot and so take on added significance. A huge amount of money is being invested in developing new power sources and one day perhaps a solar cell or other power source will replace the batteries in use today. One senses that while improving the quality of the power source would have positive effects on robotic adoption, it is not likely to be the game-changing technology that dramatically accelerates adoption.

Candidate #6: Speech Recognition Technology?
Alexa™ by Amazon and Siri™ by Apple are two examples of intelligent devices that function using speech recognition technology. Anyone who has interacted with these devices can see how much improved this technology has become over time. And, yet, interpreting sound in real time is still challenging for a host of reasons, including that people speak differently, sound different based on the surrounding acoustics, pronounce words differently, and have varied accents. We have clearly come a long way from the early days of speech recognition technology and today the technology functions quite well in many cases. But there are many things that could be improved, and improved speech recognition would certainly enhance the ease of human-robot interactions, particularly in applications where robots are directly interacting with people. Our conclusion (tentative though it may be) is that improved speech recognition, while very useful in accelerating the adoption of robots, will probably not by itself be the primary driver of widespread adoption of robots.

Candidate #7: "Smart" Materials
It seems almost like science fiction when one thinks about the new and remarkable materials that are being created around the world at places like the Soft Machines Lab at Carnegie Mellon University in Pittsburgh, Pennsylvania. Imagine, for instance, a material that reacts to stimulation and is sufficiently strong and flexible to function just like a human "muscle" that it could move a robot. How about a soft material that conducts electricity and can actively change its shape in response to electrical stimuli? And what if you could combine these capabilities to create a multifunctional material that is soft and stretchable, can change its shape, conduct heat and electricity, respond to touch, is resilient to damage, and may even be able to repair itself? If you can conceive of any of these things, you would be thinking about "intelligent" or "smart" materials which are a part of the broader discipline of materials science. (We will use the term "smart materials" throughout this report.) These types of materials and others like them that can "sense", process, and react to their environments are in development today and may well be game-changers for robotic adoption in the years ahead.

Let us begin with a quick explanation of what we mean more precisely by smart materials. One useful way to think about these smart materials is as materials that can sense, process, and respond to their environment without embedded electronic devices like sensors and processing units. For example, a material that can change its shape based on electrical stimuli would be a smart material. A material that "remembers" or reverts to its original shape would be another example of a smart material. The common denominator in these examples is that the material shows an effect in one domain based on stimulation through another domain. (The range of potential domains is broad and could include thermal, electrical, chemical, and so on.)

Using Smart Materials To Create A New Paradigm—And New Use Cases—For Robots
How could smart materials create a new paradigm for robots? We start with an important observation, noted by many scientists, researchers, commentators, and observers, that will seem very obvious after you read this sentence: most robots today are made of hard materials. As many have noted, animals and people are made of hard materials *and also soft materials*, which is not true of any robot today. Quite literally, there is no known animal, including humans, made 100% of totally hard materials.

Creating softer robots using smart materials could enable us to replace the current "hard robot" paradigm by no longer thinking of robots (only or even primarily) as rigid and inflexible machines made of metal and plastic. These smart materials offer the intriguing possibility of totally transforming our idea of what robots are and how they can be used, thereby unleashing a potentially massive number of new applications and use cases—taking advantage of their newly-enabled lightness, versatility, agility, flexibility, adaptability, movement, and ability to self-repair—to operate in a far broader range of environments that would not have been previously possible. For example, we could dramatically improve gripping technology using smart materials. In addition, we could create a whole new category of surgical robots capable of operating on the human body with the flexibility and delicacy permitted by soft materials. And we could potentially create prosthetics that utilize smart materials. The possibilities are broad and endless and exciting. The exciting possibility that smart materials offer to drive robotics in exciting new directions is why we choose them as the runner-up in the race for the technology most likely to drive widespread adoption of robots.

We turn now to Artificial Intelligence as our final candidate for most influential technology.

Candidate #8: Introducing Our "Super Candidate": Artificial Intelligence (aka AI)

We will end any remaining suspense immediately: Artificial Intelligence is our winning candidate. All of the prior seven candidates deserved consideration, but Navidar predicts that AI will be the single technology most responsible for the society-wide proliferation of robots. AI has been referred to as a "foundational technology" of the 21st century and we agree wholeheartedly. AI is everywhere these days and indeed holds great promise for changing our world. AI is quietly transforming manufacturing, health care, transportation, construction, energy, and education, and it is finding its way into virtually every industry imaginable. All around the world, AI has received massive amounts of funding. An OECD report taking a multi-year perspective on the industry found that venture investment in AI companies grew from $3 billion in 2012 to a remarkable total of $75 billion in 2020, with the United States and China accounting for over 80% of that amount.

Before we discuss our main topic of interest in this section—which is the intersection of AI and robotics—we would like to explain what AI is. Let us turn to our old friend, the Oxford English dictionary which states that AI is "the theory and development of computer systems able to perform tasks normally requiring human intelligence, such as visual perception, speech recognition, decision-making, and translation between languages." That is quite a mouthful, but we would like to highlight that AI involves enabling a computer—or a robot—to do things that we typically associate with human thought and intelligence. So, the promise of AI is that it can be used to create machines that can learn and make decisions. If you think about this for a moment, you will realize that this is a remarkably powerful vision.

To avoid any confusion, let us also make a clarifying comment that we hope will avoid a potential area for misunderstanding. Robotics and AI are *not the same thing*. They are actually very different technologies. It is important to realize that not all AI is applied to robots and not all robots are enabled by AI. The reason some commentators get confused is that people often talk about AI in the context of robotics, which is to say that they are talking about the *intersection of AI and robotics. That intersection comes in the form of AI-enabled robots*. If you are a visual learner, imagine a Venn Diagram with one circle containing AI and a different circle containing Robotics. The shaded area in the middle where the two circles overlap would represent the AI-enabled robots that are the subject of this section. When we talk about AI being a key driver of robotic adoption, we are talking about AI-enabled robots, which is a small minority of most robots today.

AI certainly sounds very cool when you think about how it can be applied to robots. And it is very cool and promising. Recall from our earlier discussion that for most of their history robots have operated in structured environments that did not vary, did not change, and did not contain obstacles. We believe, therefore, that the most important capability that AI will provide to AI-enabled robots will be to allow these robots to handle, navigate, and operate effectively in unstructured environments. This could be a real game-changer.

Lest we sound naive or overly enthusiastic, we would note that AI is still an emerging technology and, alas, it is not perfect nor has it been perfected. More specifically, AI typically relies on massive data sets to "train" the robot to "think." This process can be both very time-consuming and expensive as it involves using an extensive trial-and-error approach to "teach" the robot. This robot "training" data can be very costly to obtain. In addition, this data can be incomplete. Further, if the data on which the AI-enabled robot is trained does not include everything a robot needs to be able to handle a particular situation, then that robot may not be able to operate effectively in that unstructured environment. In this sense, the expression that AI is only as good as the data it is trained on is quite accurate and this can pose significant challenges.

To be fair, we feel we should end on a positive note. The idea that one day robots using AI can interact with and function well in minimally-structured and unstructured environments—which is to say variable and changing environments, whatever they may be—on their own without any human intervention, can make decisions and resolve problems and obstacles they encounter using only their preexisting programming is sufficient to earn them our winning vote. We selected AI as our winner because robots that are able to effectively generalize to new contexts and operate autonomously in minimally-structured and unstructured environments would represent a new frontier and be remarkably flexible, valuable, and useful enhancers of our lives.

Prediction #4: RaaS Will Become The Dominant Business Model For The Robotics Industry

(See Exhibit 5 at the back of this report noting the advantages of the RaaS Business Model)

Emerging industries often find it advantageous to adopt business models that reduce barriers to customers' use of their products and services. Acquisition cost and total cost of ownership are frequently cited as significant concerns for those contemplating adopting robots. In the "standard mode," to date, industrial machinery has typically been purchased: the customer buys the equipment and owns it. Services may be bundled --or not-- for a specified time period.

<u>RaaS</u>: The Robot As A Service Model (RaaS) is a newly emerging model for robotics in which, like its cousin Software As A Service (SaaS), the seller charges the user of the robot a monthly (or annual) subscription fee that entitles the user to utilize the robot. Some robotics companies today have already adopted this model. The RaaS model has many advantages that reduce barriers to purchase and facilitate robotic adoption and deployment thereby accelerating customers' "time to benefit" from the technology, including:

- Lower upfront costs
- Reduced cash outlays by converting a potentially large capital expenditure into a smaller operating expense
- Greater flexibility and scalability to pay as additional capacity is needed
- Ongoing access to the latest technology and upgrades as they are made available
- Diminished risk of technological obsolescence
- Better scalability by allowing surge capacity if needed
- Greater control over growth by allowing measured capacity increases

Navidar believes, as others do, that the RaaS model will likely triumph for all the reasons that the SaaS model ultimately triumphed over the previously dominant perpetual license software model. We envision various flavors of RaaS, including a fixed price RaaS model in which there is an agreed-upon standard amount for the services of the robot as well as a variable RaaS model in which the user is charged either based on usage or consumption or some other agreed-upon metric.

As more robotic companies enter the public market, we would expect that they would position their businesses as recurring revenue businesses, emphasize the customer appeal of being a recurring operating expense, and report the well-known metrics of customer acquisition cost, recurring revenue per robot, and robot lifetime value as the standard metrics by which they would like their business evaluated by investors.

Prediction #5: The Proliferation Of Robots Will Create A Large Robotics Services Industry

Navidar believes that the growth and proliferation of robots will over time create a large, potentially multi-billion dollar robotics services industry. We can look to the past for analogies about what has happened with the arrival of new technologies in order to get a sense of what might happen in the robotics industry. If we look at once-new technologies like relational database management systems (RDBMS), enterprise resource planning systems (ERP), and customer relationship management systems (CRM), we see that they all created large markets for services dedicated to implementing and helping enterprises benefit from this once-new software sold by vendors like Oracle, SAP, and Salesforce.

Might we be wrong in using these analogies from the software industry to predict what might happen in the robotics industry? It is certainly possible, but we don't think so. If we think more generally about any major new technology—whether software or hardware or a combination of both—the key is to focus on what is needed to make that new technology proliferate over time and we believe that services will be an integral component of that proliferation for the robotics industry. The robotics industry will certainly need services, including many or all of the following:

- Robotic system design
- Implementing robotic solutions
- Training people to use robots (HRI quality will influence the size of this opportunity)
- Robot installation (at least for certain types of robots, particularly industrial robots)
- Robot maintenance
- Robot repair
- Robotic system interoperability

Another interesting question relates to the extent to which the robot manufacturers will dominate the robotic services market in the sense of providing the vast majority of the aftermarket services that companies will require. If this were to occur, it could certainly crowd out or minimize the incentive for third-party companies, by which we mean companies other than the manufacturers themselves, to enter the robotic services market. Surely, some portion of the services will be provided by the robot manufacturers themselves, as has been the case to date, particularly with industrial robots. Manufacturers thus far have had the incentive and the required expertise to provide these implementation, maintenance, and repair services to make their robots successful at client sites and reduce the customer's time to value from their robotic technology. This is logical and makes sense in an emerging industry. Over time, however, we think it is highly likely that new third-party services companies and system integrators will emerge to provide robotic services. We envision both newly formed companies focused purely on robotics services as well as new practice groups within existing services companies like Accenture, Cap Gemini, and Wipro providing these third-party robotics services. Some of these third-party firms will specialize in particular industries (say, logistics or healthcare), geographies (Europe or Asia), or specific robot manufacturers while others will have general robotic services practices.

We make this prediction in part because we believe that robot manufacturers will ultimately have an economic incentive to see a thriving third-party services ecosystem around the industry. As more robots are purchased and deployed, we believe that manufacturers will see the economic benefit of using trusted third-party service providers to implement, maintain, and repair their robots. This development will enable the manufacturers to continue to do what they do best—which is to manufacture robots—and thus spend less time building services capabilities within their organization to meet the growing need to service their robots.

In addition, if we look farther out in time and if we are correct *(see Prediction #6)* that robotic systems will arise—where groups of robots made either by the same manufacturer or by different manufacturers work together to accomplish a task—then this will require knowledge about multiple vendor systems and interoperability which will require companies beyond the manufacturers themselves to provide the services since one manufacturer is not likely to be able to service another manufacturer's robots. We think that there will be a real need for systems integrators to perform robot implementations, glue together different robotic systems, and resolve interoperability issues that may limit robotic adoption. The rise and presence of third-party system integrators will also enable more rapid and easier turnkey robotics solutions across different industries, geographies, and even OEMs to drive further adoption and growth.

Prediction #6: Robots Will Eventually Work Together In Robotic Systems

Could robots made by the same manufacturer one day work together successfully in groups? The answer is yes. In fact, this is happening today as teams of robots are working together as a group primarily in use cases such as manufacturing and logistics but also in other areas such as agriculture. For the most part, however, most robots today work alone rather than together in groups or systems.

Perhaps even more interestingly, could robots *made by different manufacturers* one day work together as a group of robots functioning within a broader robotic system? Distributing workloads across more than a single robot—particularly in unstructured environments—could enhance effectiveness and robustness in the sense that the failure of any single robot would not prevent the task from being completed. The idea is that the whole would be greater than the sum of the parts. Another benefit would be that using a team of robots, for example, could open up new use cases such as exploring space, handling a wide range of agricultural tasks currently done with human labor, and potentially fully automating and solving the vexing and expensive logistics "last-mile problem" referred to earlier in this report.

There are of course a number of key challenges to overcome to make this vision a reality. One challenge, perhaps solved by the robotic service companies and system integrators that we believe will arise *(see prediction #5 above)* is the current lack of standards among various robotic manufacturers. The resulting heterogeneity of these systems—and the resulting lack of interoperability—is clearly an obstacle to creating integrated teams of robots made by different manufacturers that can work together in various environments. Another key challenge is how the learning of one robot can be communicated across the entire group of robots. How can collective intelligence be gathered and communicated via instructions for each robot? Further, how do groups of robots reach collective decisions, which is termed the "consensus problem"? Just think about how hard it can be for you and 10 friends to decide where to eat dinner together and you will have insight into the consensus problem. If no single robot is "the boss," how does the group function? The answers to these questions are not totally clear today, but talented scientists and researchers are working on them and will one day find solutions.

Prediction #7: Don't Worry, Robots Will Not Replace All Of Us, Or Even Most Of Us; But Robots May Replace Many Of Us

(See Exhibit 6 at the back of this report for three views of the labor market impact of robots)

One of the most serious and unsettled issues under discussion today involves the labor market implications of broader robot adoption. People wonder what will happen to employment in general and their jobs in particular as robots proliferate throughout society. They ask whether there will be good jobs or any jobs at all left for humans? Not surprisingly, opinions vary quite dramatically. Sometimes it seems as if there are as many different opinions on this topic as there are experts.

Below, we review these different viewpoints and offer our perspective on what we think is actually most likely to happen to jobs as robots are increasing adopted throughout society.

"The Pessimistic View": Robotics will create massive displacement of workers, particularly blue-collar workers and workers with lower skill levels, which in turn will lead to widespread societal displacement of workers.
The Basic Equation Is: Jobs Lost > Jobs Created, by a long shot.

In this view, robots will eventually replace many, if not most, of the jobs in today's economy. Robots will be such an economically compelling replacement for labor across a broad swath of the economy that millions of people will lose their jobs as a result. Proponents of this view point to a 2013 study conducted by researchers Carl Frey and Michael Osborn at Oxford University. Known now as the "Oxford Study," this much-cited analysis examined over 700 occupational groupings and their susceptibility to computerization and concluded that nearly half—47%, to be precise—of all workers in America had a high probability of seeing their jobs automated over the next 20 years. Bain & Company has also looked closely and thoughtfully at this issue and concluded that by the end of the 2020's--less than a decade from now—automation could eliminate 20% to 25% of current jobs, hitting low-income and middle-income workers most severely and potentially eliminating as many as 40 million jobs.

"The Optimistic View": Robotics will eliminate some jobs and displace some workers, but adoption of robots will create more and different jobs in other areas as a result.
The Basic Equation Is: Jobs Created > Jobs Lost

This view posits that the Robotics Revolution will leave some people behind and eliminate some jobs, but it will also be a dynamic force for new job creation in the domestic economy. In this view, robots will generate additional wealth, which correlates closely with capital formation and investment which in turn will lead to significant job creation. Proponents of this view sometimes point to the manufacturing sector which has experienced significant automation and robot adoption but has nevertheless grown in overall size. In addition, proponents posit that as robotics devices proliferate, so too will the demand for professionals who understand robotics, and this will create job roles to support and maintain these robots. Furthermore, innovations in robotics will increase demand for labor in other industries and may well also create new industries that will provide employment opportunities for those whose jobs no longer exist. On a macro basis, the net effect of these changes will be more jobs created than eliminated.

"The Neutral Transformation Of Work View": Robotics will not really change much in terms of the overall levels of employment and will not harm workers in the aggregate.
The Basic Equation Is: Jobs Created = Jobs Lost

This view states that although advances in robotics will enable machines to perform mundane and time-consuming tasks efficiently and quickly, it will also allow professionals to take up more innovative job roles. In a nutshell, this view can be said to hold that robots will change the nature of many jobs, but that they will free up those workers whose jobs have been changed to do different, higher-value functions. The net effect will be that gains and losses will even out over time. Jobs will be transformed, but not necessarily lost. Note that View #3 stops short of and is a bit more conservative than View #2 above, which sees jobs created surpassing jobs lost. Instead, view #3 posits that the increased productivity generated by widespread robotics deployments will be an equalizing force that basically creates as many jobs as it eliminates. This view notes that in the past, as technology and automation have reshaped economies, workers have historically migrated from the automated industries to other parts of the economy. They cite the Industrial Revolution and Technology Revolution that clearly altered the nature of work that people did but did not create massive unemployment in the aggregate as people *moved to the industries where the new jobs* were being created. People (i.e. labor), capital (i.e. money), and other resources shifted to the growing industries. The classic example is the farmer who migrated away from the farm to work in the factory, which historically did happen on a massive scale. In a modern-day example supporting this view, some commentators believe that the growth and success of the autonomous trucking industry will augment existing capacity and will not result in workforce disruption and job elimination.

So, Where Does This Leave Us: What Does Navidar Think Is Most Likely to Happen?

Assessing the labor market impacts of robotics adoption is a complicated, nuanced question and we understand why there are such widely varying opinions on the matter. To state our prediction as clearly as possible, Navidar believes that robotic adoption will create new jobs, new job categories, and new industries, but there will also be significant worker displacement across industries and geographies. What the net effect of this will be on employment is hard to determine currently. We believe that there is a reasonable chance that *as many new jobs* will be created as lost. Less probable is that the number of new jobs created will *exceed* the number of jobs lost.

But there is a proverbial fly in the ointment, a rub, a big issue that is noteworthy. Regardless of the number of new jobs created and whether they exceed the number lost, the pain of the Robotics Revolution is *not likely to be borne equally* across groups of people, professions, industries, or geographies.

We believe that robot adoption is most likely to affect the following groups most negatively and most disproportionately:

Blue-Collar And Lower-Skilled Workers: We believe that robots will indeed displace many lower-wage and middle-wage jobs. Workers in these industries are at higher risk of job displacement and will almost certainly feel more pain since their jobs will be the first to be eliminated. Clearly, workers will be affected by what happens more broadly in the industry in which they are employed. Ultimately, the net employment effects will be based on a number of factors, including the relative strength of organized labor, affecting the industry in question.

Different Effects In Different Geographies: Navidar believes that some countries and regions may benefit greatly from robotic adoption and other countries and regions may be negatively affected by such automation *in aggregate*. In this light, we would note that some commentators have suggested that poorer nations will be more negatively affected than richer ones, though this is difficult to predict with a high degree of confidence. Ultimately, the impact on any particular country will be based (at least in part) on its economic, social, governmental, and cultural structures and their ability to accommodate and adjust to these changes.

Highly-Skilled Workers Will Likely Benefit: It is entirely possible that highly-skilled labor will become increasingly scarce and increasingly valuable as robotics technology proliferates. As a result, robotics may shift demand to more highly-skilled workers. In addition, robotic adoption appears less likely to affect those industries and those workers that rely on creativity and professional skills.

A Potential Wild Card: The Speed of Robotics Adoption: We believe that the dislocating effects of robotic adoption will be more easily handled and managed--for example, through government-sponsored and employer-led worker retraining and re-skilling programs—if the pace of robotic adoption is slower rather than faster. If the transition associated with robotic adoption takes place over a longer time frame, there will be more time to manage these worker, industry, and geographical adjustments than if the adoption happens more rapidly.

Prediction #8: The Spread Of Robots Will Raise Important Public Policy Issues

Dear Reader: Before we discuss this prediction, we have to say at the outset that nothing we write here—or anywhere else in this report—is meant to be political, to express a political viewpoint, or to endorse any political philosophy. We are investment bankers who provide M&A and capital raising services to technology and technology-enabled businesses and throughout this report we have been trying to explain, diagnose, understand, and predict what we think will happen in the Robotics Revolution in an entirely apolitical manner. We will continue to do exactly that in this section as well. So, please understand that if we say we think that something is likely to happen, that does not necessarily mean that we are glad that it will happen or that we endorse the outcome. We are just giving you our current view of how we see this emerging industry evolving.

Students of history know that no revolution—technological or otherwise—occurs in a vacuum. There is always a backdrop, be it cultural, social, political, or economic, or all of the above. The Robotics Revolution is no different. So, while thus far, we have been examining the Robotics Revolution on its own terms, it is important to note that there is a broader context for robotics that must be considered. That context is what we address in this section.

How Might The Robotics Revolution Play Out?

We believe that the advance of any new technology has the potential to create social issues—*both foreseen and unforeseen, foreseeable and unforeseeable*—that might elicit governmental reaction. Robotics is clearly moving forward at a rapid pace, and, to date, it seems that little attention has been paid to its potential impact on a number of important areas. Indeed, as use cases proliferate and robots become more widespread, the industry will likely attract—again, to repeat, we are not saying whether this is for better or for worse—the attention of governmental agencies and lead to more intervention in the economy.

Which Issues Might Attract Government Attention And Potential Intervention?

We believe that the issues discussed below represent some of the more likely candidates that would encourage government intervention—either at the federal level or the state level. This list is not meant to be exhaustive (we don't want to lose your attention!), but rather is indicative of a broader range of potential hot-button issues. Before we dive in, it is important to note that government intervention may come in different forms, many of which are not mutually exclusive, including laws, regulations, oversight, taxation, or the proliferation of standards. Note also that government intervention is a two-sided coin: intervention might slow or inhibit the pace of robotics adoption in some instances, and it might accelerate or stimulate adoption of robots throughout the economy in other cases.

1. Safety, Security And Privacy Issues

On the safety and security front, it is important to remember that, by and large, robots have actually increased safety in aggregate by substituting robotic labor for human labor in jobs characterized by the "3 D's": dirty, dull and dangerous. One only needs to think about how robots have been used in outer space, nuclear power plants, and in defense and military applications to be assured of this. In fact, we believe that it is not unreasonable to say that increased safety is one of the greatest benefits to humans provided by robots.

But safety is a two-way street, and many new exciting robot use cases may give rise to safety issues. As more situations arise where humans and robots interact and come into contact with one another, mishaps are bound to occur. The fatal 2019 accident involving one of Tesla's self-driving cars provides an example. In that instance, two people were killed when a Tesla car crashed and exploded into flames. Apparently, neither person was driving the car or even behind the steering wheel at the time the crash occurred. It is still unclear whether the battery or the autopilot feature (or something else entirely) were at issue, and it does not really matter to make the point that safety and loss of human life are hot-button issues.

Similarly, privacy is another important and topical issue that could—some observers would say "definitely will"—attract government attention to the robotics industry, just as it has attracted a great deal of governmental focus on the social media industry as companies like Facebook, Instagram and Twitter can well attest. One way in which this issue may arise in the future is if, for instance, a robot containing private data about an individual or group of individuals is hacked, and its confidential data stolen. Would this lead to government regulation? How would liability be determined, and damages assessed? These questions are unanswerable at this stage, but to ask them is to highlight that privacy concerns will be important going forward.

2. Rising Income Inequality

We mentioned earlier that all revolutions occur within a broader context and that context is important as we think about what developments might lead to greater government intervention in the robotics industry. By way of context, it is true to say that American society today—again, we are making no political judgments or commentary—is characterized by (relatively) high and increasing income inequality and wealth inequality. (Income inequality gets most of the attention, so we will use it for our discussion, but we would note that increasing income inequality is highly likely to lead to increasing wealth inequality.) We wrote earlier about the potential labor market consequences of widespread robotics adoption and noted this adoption has the potential to increase the returns to owners of capital and to those who possess high-value skills. If highly-skilled workers experience increases in income and low-skilled and moderately-skilled workers—who represent the majority of the workforce—lose their jobs or keep their jobs but face stagnating wages, then that development would exacerbate the already (relatively) high income inequality in the United States. The relative movement would be the killer for the low-skilled and mid-skilled workers: if the already high incomes of the highly-skilled increase and the already-lower incomes of the low-skilled and moderate-skilled workers decrease, then inequality rises due to both wage movements. The income inequality issue has already attracted significant government attention—both at the federal level and the state level—and it will attract more attention if a significant proportion of the workforce is negatively affected by adoption of robots.

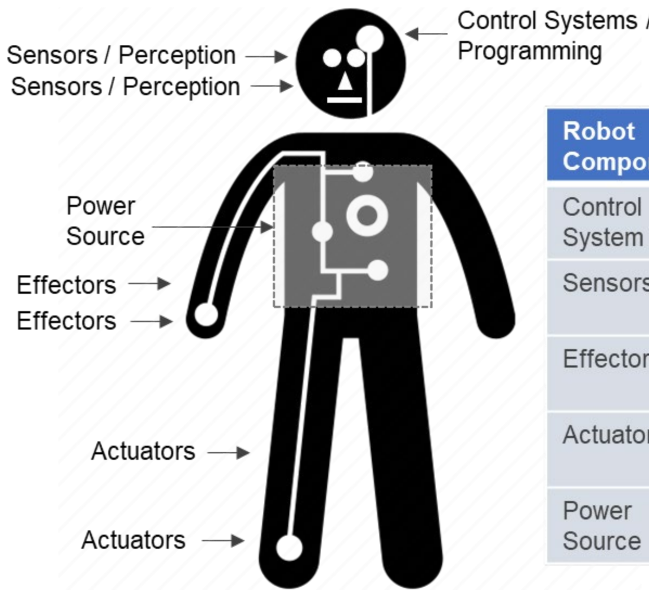
3. <u>Last, But Not Least: Jobs, Jobs, Jobs</u>

We have already discussed jobs and the labor market in *Prediction #7* above. The only point we want to add is that a number of commentators have mentioned that jobs have an importance beyond just providing income to workers. Beyond the psychic and psychological benefits that jobs provide, observers have noted that in the United States important benefits such as health insurance and pensions are very closely tied to being employed. So, if large numbers of individuals become unemployed, under-employed, or suffer wage stagnation, then the government will likely be one of the primary institutions people look to for a remedy. Retraining programs for displaced workers—sponsored and supported by government and private employers—is a viable measure to mitigate some of the potential consequences of the Robotics Revolution. Importantly, job retraining is one potential remedy that is endorsed by most commentators regardless of their political affiliation.

Concluding Thoughts

When we look back at the Robotics Revolution years from now, we will likely marvel at the extent to which robots have penetrated so many areas of society. From their valuable yet relatively humble beginnings as industrial productivity tools decades ago, robots will have found use cases and applications across a remarkable range of environments that many barely could have imagined. Billions have been invested in the many existing technologies that will continue to fuel this revolution. Billions more will be invested in technologies yet to be discovered in the decades ahead to continue the momentum. Advances in these technologies will transform the world we live in and hopefully increase human happiness. Stay tuned. It promises to be an interesting ride.

Exhibit 1: Introduction To Robot Anatomy



Robot Component	Human Analog
Control System	Brain
Sensors	Eyes, Ears, Nose, etc.
Effectors	Fingers and Hands
Actuators	Legs and Feet
Power Source	Stomach

Exhibit 2: Robots Today Are Able To Operate In Incredibly Diverse Environments

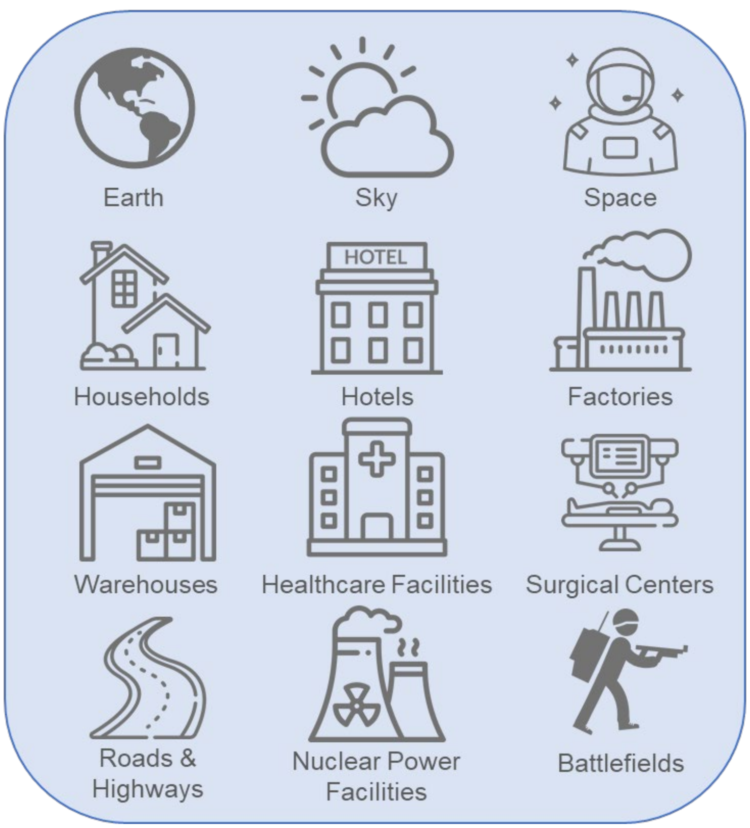


Exhibit 3: Selected Robotic Applications And Use Cases

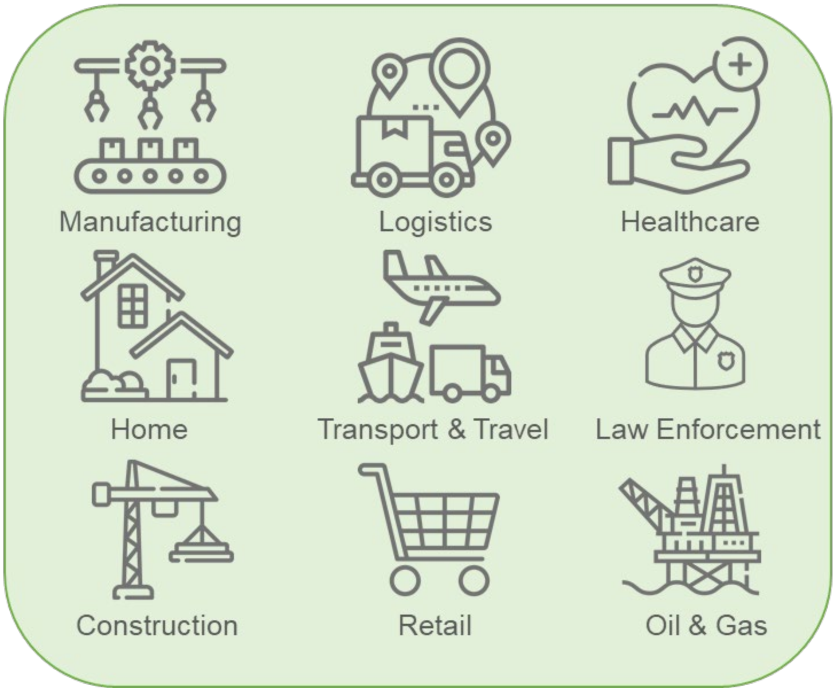


Exhibit 4: Selected Robotics Industry Growth Drivers

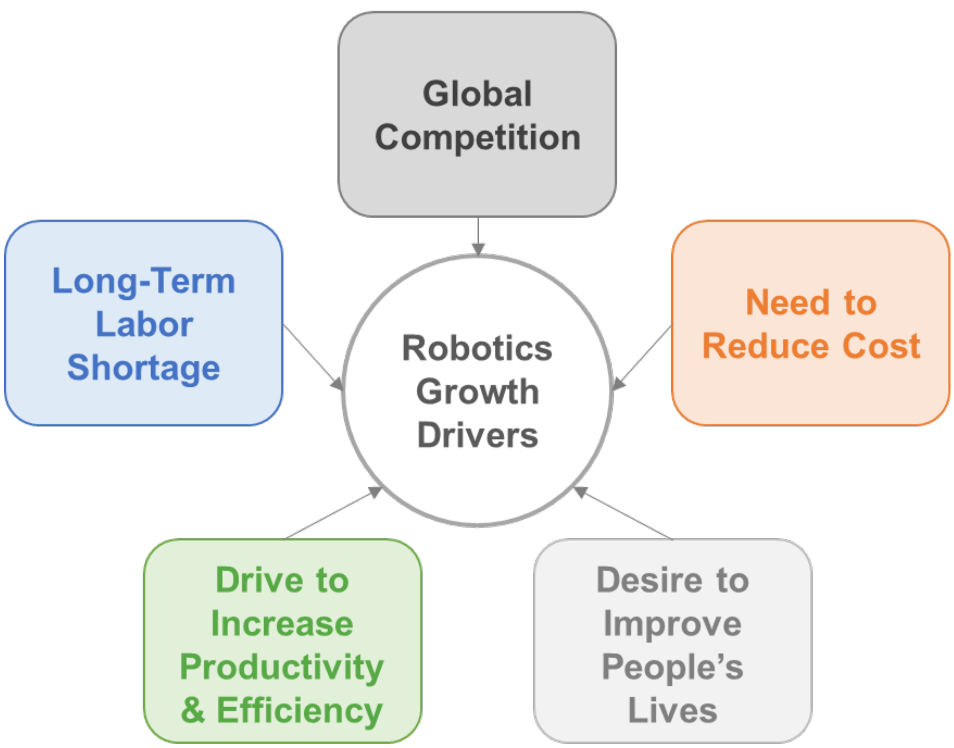


Exhibit 5: Why RaaS Will Become The Dominant Business Model In The Robotics Industry

Lower Upfront Costs
Reduced Initial Cash Outlays
Capital Expense Converted To Operating Expense
Greater Flexibility And Scalability
Enhanced Ability To Add Capacity As Needed
Greater Control Over Growth
Ongoing Access To The Latest Technology
Reduced Risk Of Technological Obsolescence

Exhibit 6: Three Competing Theories On The Impact Of Robots On The Labor Market

View	Basic Equation	Comments
"The Pessimistic View"	Jobs Lost > Jobs Created	Robots will create massive displacement of human labor as millions of jobs are lost due to robotic deployment
"The Optimistic View"	Jobs Created > Jobs Lost	Robots will certainly eliminate some jobs, but they will also create many new jobs and even new industries over time
"The Neutral Transformation of Work View"	Jobs Created = Jobs Lost	The major impact of robotics will be to transform the type of work that humans do rather than eliminate human labor

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