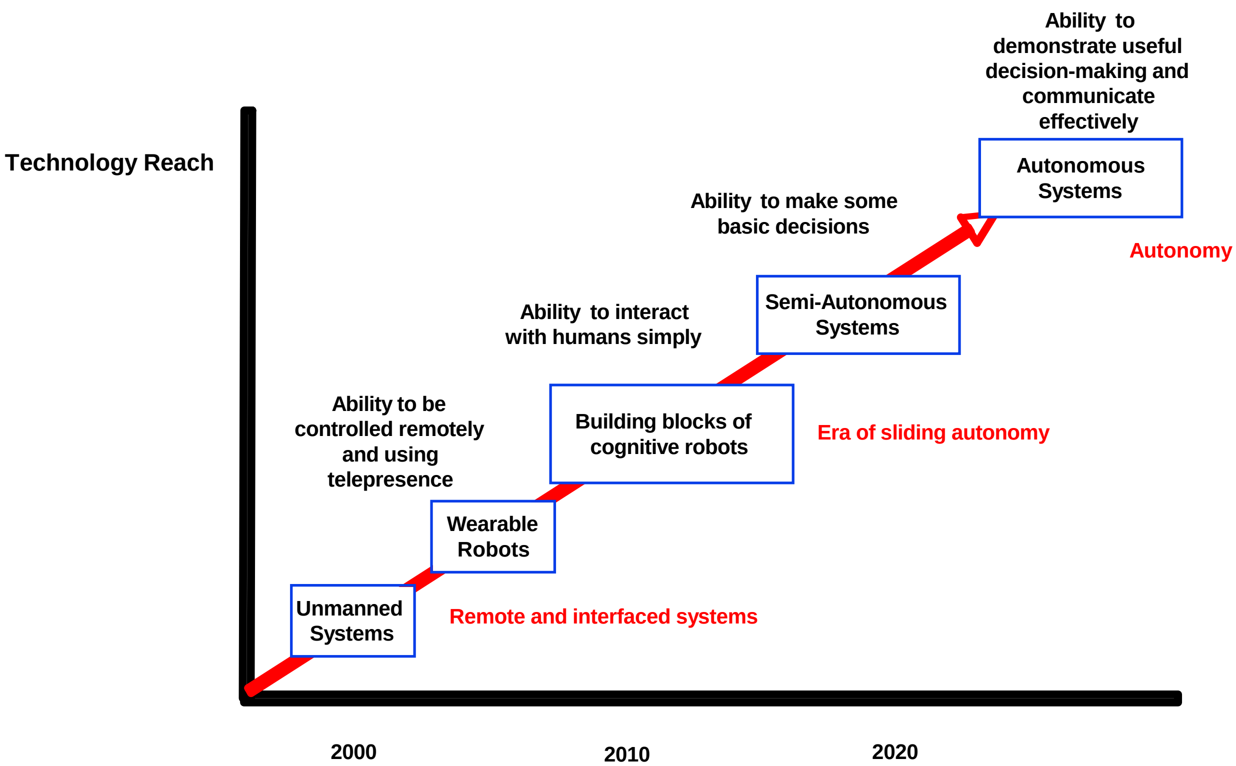
APPENDIX E: SERVICE ROBOTICS (BACKGROUND)

The Technology

Figure 11[1]
TECHNOLOGY ROADMAP: SERVICE ROBOTICS



Source: SRI Consulting Business Intelligence

Service Robotics

A robot is a mechanical device that can perform preprogrammed physical tasks. A robot may act under the direct control of a human (for example, a UAV) or autonomously under the control of a pre-programmed computer. According to the IFR (International Federation of Robotics), a service robot is a robot which operates semi or fully autonomously to perform services useful to the well being of humans and equipment, excluding manufacturing operations.

Robotics is a wide technology area that also encompasses a subset of valuable enabling technologies. Robotics is an area of increasing interest, investment, and hype. Within this backdrop,

[1] The Technology Roadmap highlights the timing, features, and applications of significant technology milestones that would be necessary for developers of this technology to achieve if successful (equivalent to commercial) application—and possible disruption—is to occur by 2025.

domestic, military, and healthcare are applications that could be instrumental in driving service robotics commercialization.

The Enabling Building Blocks

Mobile robots and unmanned systems comprise several subsystems. All these separate systems and their components must work together to enable the robot to function properly. The technologies involved in these systems will all require advances if robots are to see extensive use in personal home and security applications.

- *Hardware Technologies*. Affordable robots will continue to be built using fairly conventional hardware—off-the-shelf electronic components, batteries, motors, sensors, and actuators. The availability of cost-effective hardware is extremely important.
- *Practical Robot Software Platforms*. Robot software platforms are already available (e.g. Evolution Robotics). These systems can provide a cost-effective way of producing and operating home-security robots, and will continue to increase in functionality.
- *Robot Cognition and Artificial Intelligence*. The development of robots with cognitive abilities. Advances in artificial intelligence and associated technologies are vital for the development of intelligent, autonomous robots for domestic applications.

Implications of Advancement in Various Technological Capabilities

Of all the enabling technologies, the development of effective artificial-intelligence systems for robots is the most uncertain and potentially the most important. However, a paradigm shift in computing and AI technologies is necessary for it have a major impact on the future of robotics and their power to be disruptive. If robots obtain the ability to perform multiple jobs around the home and interact effectively with people socially, the subtleties of the behavior of such personal robots will become highly important. Monitoring developments in the way humans relate to existing robots will certainly help researchers improve the products of the future. Fundamental psychological and neurological research may play a key role in determining how humans and robots can communicate effectively. The development of AI systems that enable such developments is unlikely (even given favorable conditions) before 2020.

If a step change occurs in robotics/AI technologies, and players develop robots that are able to think and act autonomously—or at least act with a large degree of autonomy—then the implications of the technology will be great. Robots will be able to carry out tasks without any human intervention, including military, security roles, industrial roles, and even domestic tasks. Such robots would not only remove the need for humans to perform dull or strenuous work and improve the safety of some jobs, but could also completely remove any danger from some work. For example, robots will minimize war casualties—destruction of a robot soldier would not cause any harm to a human soldier, and such systems could be used to counteract guerilla and terrorist tactics. The use of an intelligent robotic workforce could improve the competitiveness of U.S. industries.

However, the complete automation of military and civil tasks could also have more negative implications. As an extreme example, if all domestic tasks are performed by robots, then obesity could become even more of a problem than it is today. In addition, families and domestic workers (cleaners, cooks, gardeners) could also be affected by the increasing use of robots. The use of robots for traditionally “skilled” tasks could result in higher levels of unemployment in some areas, although industry has already adapted well to the use of industrial robots.

Synergistic Technologies

The field of robotics is multidisciplinary and advances in any number of scientific and engineering field could improve robot capabilities. Because robots are computer-controlled machines, advances in computer hardware and software are obviously synergistic. Advances in microprocessor speeds and abilities are directly applicable to improving the speeds and capabilities of robots. Some specific examples of key synergistic technologies follow:

- *Wireless communications technologies*. Wireless technologies already enable robots to communicate with the outside world. Wireless technologies and infrastructure will continue to advance and thus enable an increase in robot functionality.
- *Sensor technologies (vision, chemical, infrared, sonic)*. Robots require a multitude of sensors to gather data in order to perform home security functions. These sensors must work well together (sensor fusion) and must be cost-effective.
- *Advanced materials and electronics technologies*. Advances in processors (and other microelectronics), and also in advanced actuators (e.g. artificial muscles) will be necessary to improve the functionality and performance of robots, and especially to limit the overall size and complexity of advanced robots.
- *Low-cost high-performance energy and power systems*. Robots currently have a severely limited range. For a home-security robot to operate effectively, it needs to be able to work for long periods without charging or re-fuelling. In addition, the charging or re-fuelling process must be a quick and convenient process. Totally new power systems will likely be required before robots can operate effectively for long periods of time.

Applications

Key Uses and Instantiations of Service Robotics

Robots are in use—and are under development—to automate difficult, tedious, or dangerous jobs across a broad range of applications (see below). In addition, robots can also be used for pure entertainment, and also for educational purposes.

Current Affected Products or Services

Industrial robots have already revolutionized many manufacturing environments. The industry in general is now fairly mature, with considerable progress having occurred in the past 20 years.

Service robots are also in use in military applications and in our homes and in society (such as toy robots and domestic robots, but their impact so far has been limited). In Japan, professional service robots are emerging for applications such as security, patrolling shopping malls and for reception-type applications, especially as robots for hire. In addition, surgery, telecommunications, and robotics have combined to enable remote surgical systems (such as those developed by Intuitive Surgical).

New Capabilities Created by Advanced Service Robotics Technologies

- *Defense robots*. By employing advanced sensor technologies, robots can potentially detect threats more readily than humans can—with clear advantages in combat and surveillance applications. Micro robots and robot swarms could prove extremely useful in surveillance and search-and-rescue roles. Autonomous robots could significantly improve the effectiveness of both ground and air forces. In addition, robots could reduce the number of military personnel injured or killed in combat situations. Relatively simple military robots are already in active service, providing important support to soldiers in many situations, but not engaging in direct combat. However, future robot systems may actively participate in combat. Foster-Miller (Boston, Massachusetts) has already developed a version of its Talon UGV platform to carry weapons (including machine guns and grenade launchers) for use in urban warfare situations, and similar robots are likely to emerge for combat applications. Players will leverage robotics- and bionic-related technologies to produce many systems that have clear defense applications, from wearable devices such as exoskeletons to thought-controlled vehicles.

- *Healthcare robots.* Aging populations are creating many opportunities for robotics players. Demand for existing technologies (for example, robot wheelchairs) could increase significantly. Nursing care is another promising market for robots. Trials in Japan have shown that, much like pets, robots can encourage elderly people to speak and interact (with both the robot and each other) and the development of therapeutic robots could well accelerate. The possibility also exists for developers to produce home robots that not only provide pet-type therapy, but also monitor users' health and report any problems via wireless networks. In addition, advanced prosthetics and human augmentation systems are likely to emerge for rehabilitation applications.

- *Domestic robots*. Simple robots that perform some useful functions within the home, such as cleaning the floor or mowing the lawn, are now commercially available and are set to become extremely popular in the next few years. However, beyond these simple applications, little is really certain in terms of how domestic robots will develop. Other tasks that people can perform relatively simply, such as tidying up around the house, stacking crockery, or dusting surfaces actually require fairly high levels of dexterity and intelligence. Despite many researchers' claims of developing advanced interactive robots, current systems invariably have severe limitations, both in dexterity and in intelligence. The creation of robots that perform many domestic tasks thus requires significant advances in technology. Nevertheless, rapid developments in some synergistic technologies will likely enable even simple robot platforms to undertake several tasks. Significant advances in consumer electronics and home networks (including wireless systems) mean that more devices will be able to communicate with each other in the future. A robot will be the mobile part of a network of domestic tools. Even a simple, low-cost, cleaning robot could be used as a platform. The addition of a camera and a wireless interface will enable a user to monitor developments in their home from a remote location.

- *Diffusion of robotics technologies*. Future solutions to our everyday problems may not necessarily involve robots as we currently imagine them: Developments in enabling software technologies specifically designed for robots could find many alternative uses. Devices could emerge that combine some of the important functionality of robots but less of the pitfalls—key examples include autonomous vehicles and human augmentation technologies.

Timeline

Figure 12 indicates the likely implementation of robotics technologies in the above applications:

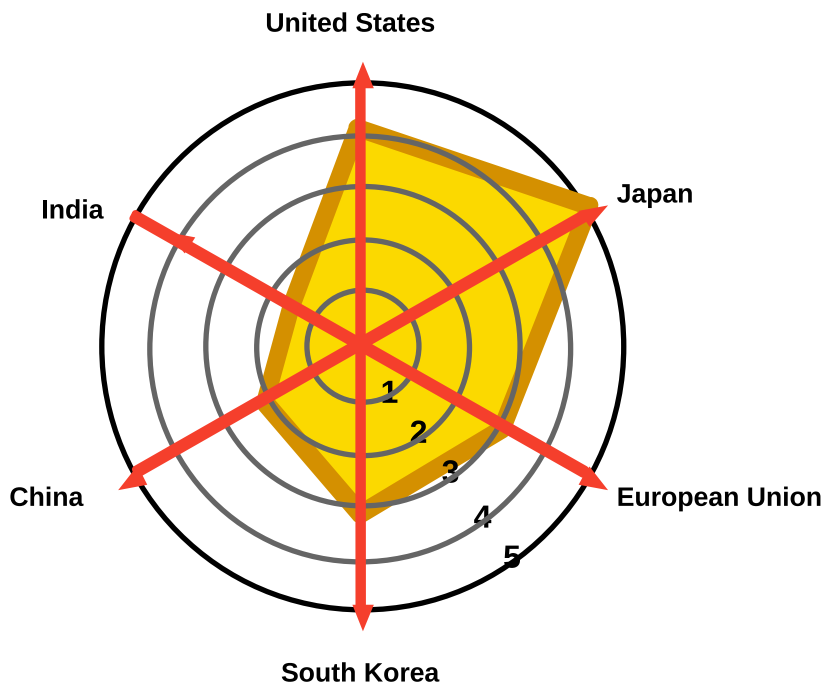
Figure 12
ROBOTICS TIMELINE

Application Category	Current Business	Emerging Opportunities	
		By 2015	Beyond 2020
Defense	UAVs, UGVs, Medical Robots	Military Human Augmentation Non-autonomous Combat Robots	Robot Swarms Micro Robots Autonomous Robots
Professional Service	Non-autonomous Robots	Workplace Assistance	Skilled Worker Robots
Domestic	Single-use Semiautonomous Robots	Toy Robots become Tool Robots	General Home Assistance
Healthcare	Robotic Surgery and Telemedicine Pharmacy Automation	Human Augmentation Therapeutic	Elder-Care Robots
Technology Diffusion	Assisted vehicles	Consumer Electronics`	Autonomous Vehicles

Source: SRI Consulting Business Intelligence

Issues Determining the Development of Service Robotics Technologies

Figure 13
INTERNATIONAL STATUS OF ROBOTICS INDUSTRY



Note: Numbers indicate progress in robotics R&D and commercialization:
1 = mostly manufacturing
2 = nascent robotics industry; R&D at some universities
3 = some robotics players established; key R&D efforts underway
4 = leading players and centers of excellence established
5 = global leader in robotics R&D and commercialization.
Source: SRIC-BI

Service robotics (or, nonindustrial robotics), is still an emerging technology, but several key stakeholders exist. Many robots are already in use in our homes and in society. Key service robotics players and their products have already emerged, for example:

- Robosapien is a hit robot toy that has sold millions. Although it is a toy, it's functionality has increased significantly with each generation
- iRobot's robot floor cleaner, Roomba, has sold over 1.5 million units worldwide
- In Japan, key players such as Honda and Toyota are developing advanced humanoid robots, and spinning off technologies into other products.

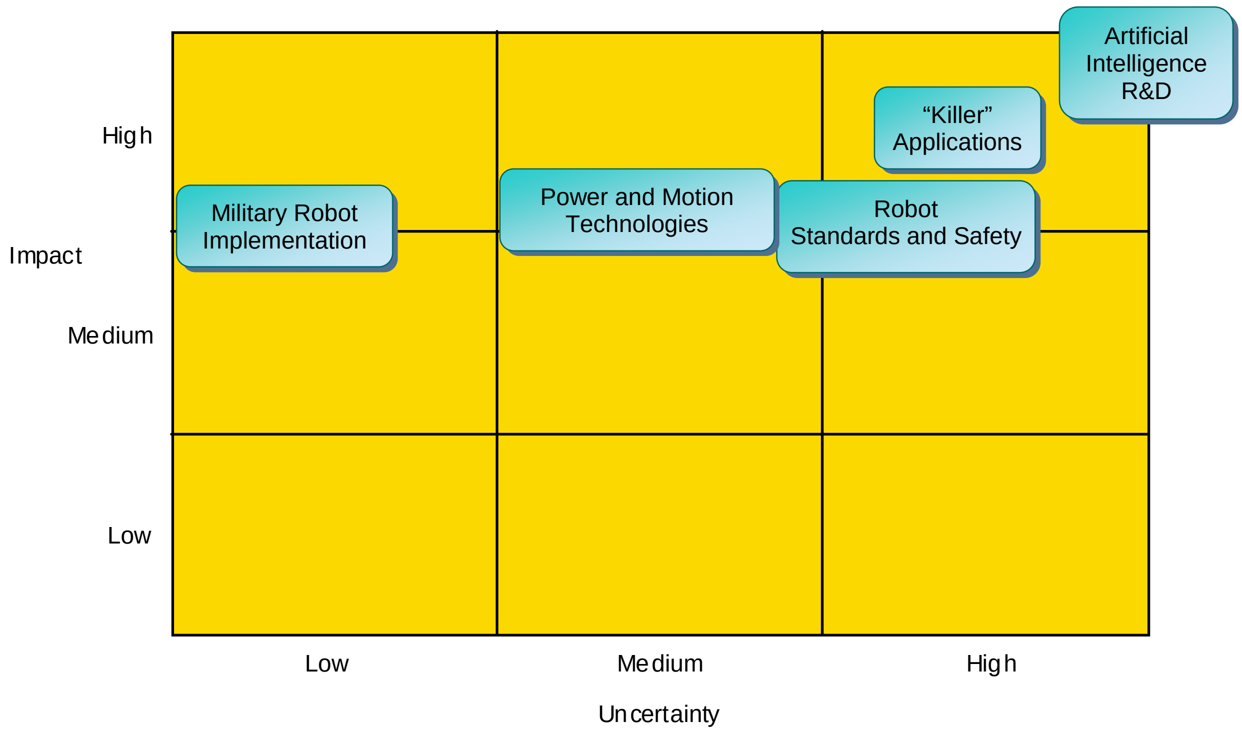
Across the globe, R&D leaders continue to make important advances in robotics technologies. Hundreds of universities worldwide have research programs in robotics. Japanese commercial and academic researchers have led the world in advanced and humanoid robot development. However, Such R&D has not yet resulted in many advanced commercial robots.

Defense organizations (DARPA, for example) generate substantial funding for R&D, and defense applications often act as a proving ground for innovative technologies (including robotics) and thus the impact of developments in this sector is extremely high.

The global nature of robotics and the countries involved is also important. From an applications standpoint, a cursory glance at global activity would unveil two countries at the forefront of robotics development: Japan and the United States. For a considerable time, Japan has been at the forefront of robot development. Japanese researchers—commercial and academic—have been responsible for many of the major developments in entertainment, domestic, and humanoid robotics. Robotics researchers in the United States have also been extremely influential, with key developments in autonomous vehicles, robots for security, defense robots, and domestic robots. In addition, U.S. and Japanese researchers continue to make important developments in health care robots, autonomous vehicles (unmanned aerial vehicles and unmanned ground vehicles), and human-augmentation technologies (for example, exoskeletons). An interesting contrast also exists between some of the two countries' most prolific robot projects—for example, the sophisticated prototype humanoid robots of Honda and Toyota (both in Japan) versus the simple functionality of iRobot's (United States) commercially successful products. The media continue to focus on the research efforts of large universities in these countries—especially high-profile institutions such as Carnegie Mellon University and Waseda University. Of course, much important work is ongoing outside Japan and the United States—for example, in Europe and China. South Korea also seems particularly determined to make an impact on the nascent nonindustrial robotics industry.

Items to Watch

Figure 14[2]
SERVICE ROBOTICS: ISSUES AND UNCERTAINTIES



Source: SRI Consulting Business Intelligence

From Figure 14, the key areas of uncertainty to monitor and better understand are:

- *Military-robot implementation*. Military applications account for a growing number of robot installations, especially in the United States. Trends and developments in this area are certain, but nevertheless important to monitor. However, the U.S. military has set clear goals on the capabilities of future unmanned systems, and whether or when these goals will be achieved is still under debate. In addition, it is uncertain how applications for many military-derived robots will spread beyond military applications and into civil applications. For example, UAVs for police and coastguard use are natural successors to military UAVs.
- *Power and motion technologies*. From research laboratory prototypes to production-ready models, mobile robots already move around in many different ways. Researchers continue to integrate existing technologies into robots, and develop totally novel mobile-robot designs. Many simple mobile robots feature wheels, while other robots rely on

[2] Figure 14 illustrates major issues and events that will have an impact on the rate or direction of a technology's development and thereby application. The impact of these issues and events is plotted against a measure of uncertainty, where uncertainty implies insufficient knowledge of how (and usually just when) the issue or event will be resolved or be sufficient to drive or hold back development of the technologies. An organization that is able to accurately predict or (better) influence or dictate the outcome (thereby moving the issue/event to the left of the figure), will have a distinct advantage over organizations that are still in the dark or just passively following developments.

sophisticated motion systems—for example, the legs of bipedal and quadraped robots. Developments in motion systems could simplify future robot systems significantly. Most mobile robots currently rely on existing power technologies—namely motors and batteries—but existing systems can place limits on a robot's operation time and range. Developments in battery technologies could significantly improve the performance of mobile robots. In addition, developments in other power technologies are important to monitor. Many companies are now developing fuel-cell technology for a wider range of products—for example, cellular phones and laptop computers. The use of fuel cells in mobile robots is currently at an early stage of development, but growth in demand for service-sector robots could drive their development.

- *Robot standards and safety*. In some applications, robot users, vendors, robot developers, and enabling technology providers will need to develop standards for robot capabilities and interoperability of components. Players are starting to collaborate to develop standards for professional service-sector robots. However, in general, standards surrounding personal robots are still nascent and developments in this area are far from certain. Monitoring activity in this area is important, including progress in the development of standards in general—such as those that the Object Management Group is promoting. The safety of any new technology is also a key issue—especially in a litigious society such as the United States. If robots are to fulfil useful roles outside industry and in society, ensuring their safety is of prime importance.
- *Killer applications*. The emergence of a killer application for service robots likely requires a step-change in the intelligence or capabilities of robots. Although manufacturers have taken many important steps toward the commercialization of service-sector and consumer robots, the future for the industry in general is far from certain. Despite extensive R&D and initial successes in some applications, a lurking concern among many players is that too few people will buy robots to sustain a viable consumer-robot industry. Many questions remain unanswered, relating to technology, applications and markets. Monitoring for "killer applications" is difficult, but rapid, sustainable growth is the only true indicator. In terms of domestic robots, cleaning is perhaps the closest thing to a killer application at present (with over two million units sold worldwide). Several uses for professional service robots could become killer applications; in particular look for developments in robots for agricultural applications. And in both literal and metaphorical terms, military robots could also become a killer application area for robots.
- *Artificial intelligence and artificial life*. The development of effective artificial intelligence systems for robots is extremely uncertain. However, a paradigm shift in AI technologies would have a major impact on the future of robotics, and so monitoring developments in this area is essential. (Also, developments in AI-related technologies and components—such as fuzzy logic and neural networks—need monitoring.) The ultimate manifestation of AI, artificial life, would have even greater—some commentators would say Machiavellian—implications. Bottom-up AI approaches derive from an understanding of how biological systems accomplish complex sensory, cognitive, and motor tasks. Other, (top down) approaches seek to create robots with intelligence by equipping them with advanced sensors and high-power processors. The (more) conventional, top-down approach, which has been the pursuit of roboticists and

AI researchers since the 1960s, has achieved a fair degree of success in addressing the application of robots in highly structured and controllable environments—that is, in industrial automation, and simple non-industrial applications. Bottom-up approaches have yet to prove their potential, although researchers have succeeded in creating biomimetic robots that approximate the behavior of some animals.

Directional Signposts

Identifying the major issues that will determine how service robotics will develop and understanding the uncertainty of items important to watch help us to understand better the potential dynamics of development and application that we might see in the future. That heightened sense of awareness is necessary because the United States will want to formulate a policy and act before unambiguous evidence on the drivers and barriers to, and direction of advancement of service robotics technology is available. Preparation for a watch-and-respond system is essential to identify signposts that would indicate whether the advancement of this technology is proceeding rapidly or not. The following developments are likely to occur near the suggested years, and their outcomes will strongly influence the status of service robotics. Their occurrence would indicate that the above issues and uncertainties were being resolved in the direction of positive development and application of service robotics.

- 2007—DARPA Urban Challenge successfully completed by at least one team
- 2009—Future Combat Systems (FCS) Test Unit implemented
- 2010—Chinese army implements military robots
- 2011—WowWee releases Robosapein V10, a toy robot that can recognize and fetch many items belonging to the user from around the home
- 2012—Brain machine interface developed that enables noninvasive control of devices
- 2014—Robots used alongside soldiers in combat situations (unmanned combat vehicles—robot soldiers that can fire on an enemy)
- 2015—Global market for nonindustrial robotics reaches $15 billion
- 2019—Semiautonomous robot home-helpers launched by Japanese and South Korean players
- 2020—Thought-controlled unmanned vehicles with “sliding autonomy” used in military operations
- 2025—Autonomous robots find first applications.

Within the timeline that these developments are likely to occur, various signposts will be important to watch for and to monitor on a global level in order to understand the direction and pace with which the field is advancing and to better assess the potential threats to and opportunities for U.S. interests. Key signposts, which, if positive, would indicate that service robotics technologies are progressing, include:

- The size and nature of robotics investments in the United States
- Players involved in robotics R&D—watch for either another key player to follow Sony’s lead and abandons robotics altogether, or for a new player to follow Microsoft and invest heavily in robotics.

- Global levels of funding for robotics research—in particular, whether investment continues to rise or is cut.
- Toy becomes tool: The point when a toy robot has the ability to perform a useful task within the home (for example, retrieving an object for the user).
- The establishment of centers of excellence in robotics research outside the United States and models for research and commercialization.
- The completion of initial (international) research programs for the development of cognitive robots
- The development of noninvasive brain-machine interfaces
- The launch of Chinese designed and built robots for domestic, service-sector, and defense applications
- Development of unmanned vehicles with sliding autonomy for both civil and defense applications
- The development and implementation of national and international standards for service, domestic, and military robots.

Abbreviations

The following abbreviations are used in this Service Robotics disruptive technology profile:

AI	artificial intelligence
DARPA	Defense Advanced Research Projects Agency
FCS	Future Combat Systems
IFR	International Federation of Robotics
MIT	Massachusetts Institute of Technology
R&D	research and development
UAV	unmanned aerial vehicle
UGV	unmanned ground vehicle