7. THE MASSACHUSETTS ROBOTICS CLUSTER

Greater Boston is home to 55 colleges and universities. Massachusetts spends more on research and development than any other region in the world, and Boston attracts a diverse, technologically fluent workforce.

—Jeff Immelt, CEO, GE

The robotics cluster in Massachusetts is substantial and growing. As with other technology clusters, the Massachusetts robotics sector includes a localized concentration of core companies, of various sizes and levels of maturity, providing robotics technologies and products, as well as a range of services. These companies are themselves sustained by an array of supplier and services firms.

The Massachusetts robotics cluster benefits greatly from the many world-class educational and research institutions residing in the State. They are a leading source for an educated, skilled workforce, as well as the development of new capabilities and technologies resulting from fundamental and applied research undertaken in local laboratories. Universities and research institutions also support the cluster through technology transfer activities, facilities sharing, and networking events.

Other groups supporting the Commonwealth's robotics cluster include Massachusetts economic development groups, the investment community, industry associations, end-user companies, business and technology media, and much more. The resulting dynamic creates a self-reinforcing, beneficial web of innovation, reciprocality, and promotion, whose total impact greatly exceeds the sum of its individual parts.

7.1. NUMBER AND TYPES OF COMPANIES

It can be difficult to ascertain what defines a Massachusetts robotics cluster participant. For some entities, such as commercial firms iRobot and Boston Engineering, which are headquartered in the State and derive the majority of their revenue by providing robotics-related technologies, products, or services, the definition is clear, but for many other robotics firms, it is not. Although a wide variety of entities can contribute to the cluster's value chain, to eliminate ambiguity, reduce subjectivity, and increase the accuracy of both the current and future cluster assessments, it was necessary to define cluster members as formally as possible. For this study, cluster membership was limited by the following requirements:

- **Headquarters:** Commercial cluster members should be headquartered in the Commonwealth, or have an office in the State that is a major subsidiary or regional division office.

- **Primary Robotics Cluster:** The focus of this report is the primary robotics cluster which consists of over 95% of all robotics companies in the State (see Appendix H). Formally defined, the primary robotics cluster consists of the concentration of geographically bounded, localized, mutually supportive businesses found within 50-mile radius of Boston and Cape Cod. The robotics companies outside this area lack the critical mass and concentration to form another regional robotics cluster.

- **Revenue or Support:** Commercial cluster companies must derive approximately 35% or more of their revenue from robotics products, enabling technologies, or services, or a "robotics" division or subsidiary within a larger firm must do the same. Exceptions are made for startups without revenue, as well as larger firms evaluating robotics opportunities or supporting the cluster in other ways.

- **Universities and Labs:** Massachusetts-based private and public university research laboratories; national laboratories and testing centers; or private, non-profit laboratories with currently active robotics research programs or initiatives are cluster members.

Using the criteria above, the Massachusetts robotics cluster includes a total of 122 commercial companies (see Appendix H). A significant number of businesses do not qualify using this formal definition. Some are not geographically proximal to the Boston robotics hub, including companies in Western Massachusetts, New Hampshire, and Rhode Island. Others do not develop robotics products or technologies per se, but support the cluster indirectly with a variety of business services. Examples include design firms, public relations companies, marketing and engineering services providers, and more.

Most Massachusetts robotics cluster members are located within 50 miles of the Boston city center.

7.1.1. Funding Sources

When the companies in the greater Massachusetts robotics cluster were classified based on the primary payment/funding sources for their products, technologies, or services, it was found that most rely on commercial and industrial sources (see Figure 19). A sizable number of companies also depend on public sources for funding for research and defense work (the DoD, Defense Advanced Research Projects Agency (DARPA), National Science Foundation (NSF), etc.). A relatively fewer number of firms look to monies targeted for public services and education, as well as consumer dollars. Many companies had multiple sources for revenue.

The Massachusetts robotics cluster is well balanced with regard to primary payment/funding sources. No source is completely dominant.

The Massachusetts robotics cluster is well balanced with regard to primary payment/funding sources. No source is completely dominant, and as a whole, the cluster should be resistant to all but the most severe levels of business contraction, as well as large oscillations in state and national public funding levels.

7.1.2. Key Industries and Application Areas

The Massachusetts robotics cluster as a whole is not reliant on a single, large industry, and therefore is at a reduced risk from the effects of a sector downturn.

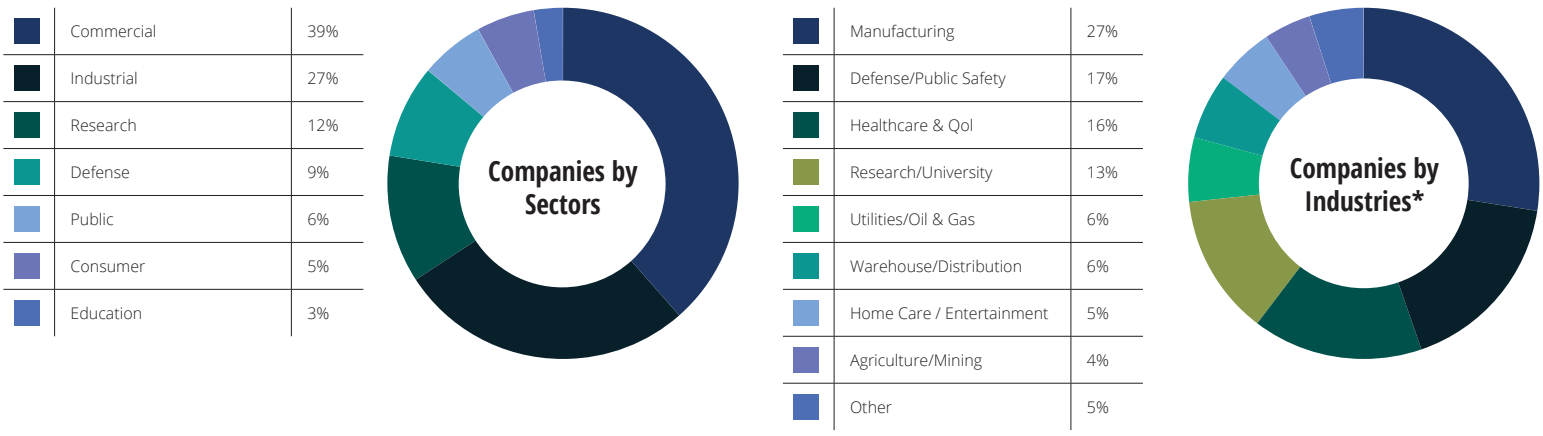
The Massachusetts robotics cluster draws revenue from a wide range of disparate industries and other sources, a reflection of the variety of the companies located in the State. This diversity reduces the risks associated with overdependence on a single, large industry segment, and the negative consequences of downturns impacting them. San Diego (defense and communications) and Detroit (automotive) serve as cautionary notes in this regard.

Manufacturing was the largest single target industry for Massachusetts robotics cluster members' products and services, with discrete manufacturing accounting for 19% of the companies, and process manufacturing equaling 4% (Figure 19). For a large percentage of cluster companies, the healthcare industry is a chief source of revenue, as is defense. A number of other industries/markets classified as "Other" also ranked fairly well. This group included utilities (4%) and warehouse/distribution (4%), along with research and exploration (6% and 4%, respectively).

Additional Insight: *Sizable industries that are not as yet primary markets for Massachusetts robotics cluster products and services include construction/demolition, agriculture, mining, and oil and gas. If companies developing new classes of outdoor mobile service robots, unmanned underwater vehicles, and particularly, commercial drone technologies and services can flourish, Massachusetts robotics cluster companies will expand into these markets as well. In many cases, entirely new companies will be formed.*

Figure 19: Massachusetts Cluster Member Companies by Primary Sectors and Industries

(Source: ABI Research)



** Other includes transportation, K-12 education, retail, and resource management.*

7.2. KEY TECHNOLOGIES, PRODUCTS, AND SERVICES

Massachusetts robotics cluster companies provide a wide variety of robotics products, technologies, and services, with no one class dominating over the others (Figure 20). This is a reflection both of the breadth

The number and range of companies in the Massachusetts robotics cluster eliminates the risk of regional over-specialization, along with the effects of a single-sector collapse.

and diversity of companies making up the sector, and the requirements for developing or operating robotics systems. It is also a measure of the extensive range of form factors that robots can assume. sUAVs, surgical robots, robotic pool cleaners, unmanned surface vehicles, and smart toys just begin to illustrate the form factors. Companies producing solutions for the industrial, consumer, public services, and commercial services markets are all represented.

7.2.1. Technologies and Services for Developing Robotics Systems

As a class, articulated robots, which include most collaborative designs, along with unmanned underwater systems (UUS), play an outsized role within the Massachusetts robotics cluster.

For 11% of the companies in the greater Massachusetts robotics cluster, software is a primary offering, usually for the design and development of robotics systems (as opposed to application software). Software was joined by controllers, vision/imaging technology, and other parts and supplies in this regard. Cluster companies also provide engineering and integration services for developing and deploying robotics systems.

It is notable that the number of companies producing "whole cloth" robotics systems—articulated robots and UUVs —approximates that of businesses selling enabling technologies or offering services that have wide applicability. This indicates that these system types play an outsized role within the cluster..

More Insight: *During the cluster evaluation process, each Massachusetts robotics company was categorized based on the assignment to each firm of up to three classes of products, technologies, or services out of a total of 74 options. This is a large number of choices for a comparatively small number of companies, and is another contributing factor to the single-digit results given in Figure 20.*

Figure 20: Massachusetts Cluster Member Companies by Primary Classes of Technology, Products, and Services

(Source: ABI Research)

Engineering Services/ Systems Integration	14%
Sensors/Vision/Misc. Hardware	14%
Software/Libraries/SDKs	10%
Industrial Robots	7%
Consumer Robotics	6%
Controllers/Haptics	6%
Marine Systems	6%
End Effectors/Arms/ Manipulators	5%
Prosthetics/Orthotics/ Rehabilitation/Exoskeleton	5%
Laboratory/Cleanroom	3%
Operator, Data & Design Services	3%
Surgical/Interventional Systems	3%
Mobile Platforms / AGVs	1%
Other	7%

7.3. REVENUE, EMPLOYMENT, AND NEW BUSINESS FORMATION

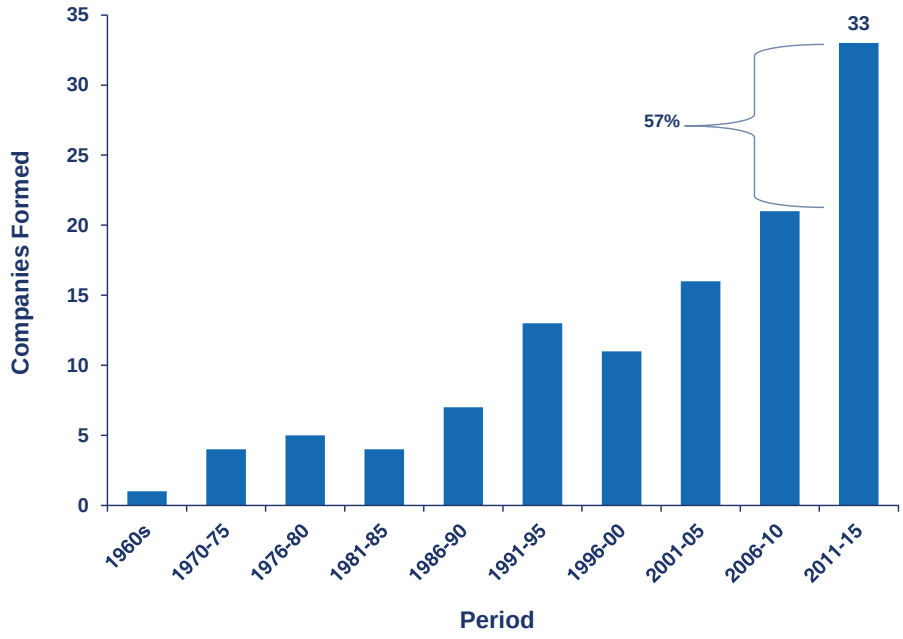
The 122 commercial companies in the Massachusetts robotics cluster generated US$1.6 billion in revenue for their products, technologies, and services in 2015. They also employed approximately 4,716 individuals with the majority consisting of engineers.

In Massachusetts, the rate of robotics business formation over the last decade has been exceptional, with 33 new companies formed since 2011 alone.

One measure of the dynamism and overall health of a technology cluster is the rate of new business formation. In this regard, the Commonwealth's robotics cluster is in good stead. New robotics businesses are being created at a steady rate, especially over the last decade (Figure 21). Between 2011 and 2015, 33 new robotics businesses were created, up 57% from 5 years earlier. Approximately 60% of robotics cluster member companies were formed since 2000.

Figure 21: Massachusetts Robotics Cluster Business Formation

(Sources: ABI Research, Massachusetts Technology Leadership Council)



The rapid growth in the numbers of Massachusetts robotics companies in the last 5 years will be offset somewhat in the future with the failure on the part of some firms. This is a common occurrence among young startups, and robotics companies are particularly susceptible. Compared to other technology startups, software companies particularly, robotics firms require more time to develop working prototypes, stressing fledging businesses lacking deep pockets. Designing for manufacturability, particularly for consumer systems, also delays time-to-market.

Robotics startups take a longer amount of time to bring products to market compared to software and other types of technology startups.

Even with this understanding, it is clear that over the last 5 years the rate of robotics business formation in Massachusetts has been exceptional. Example companies include RightHand Robotics (industrial grasping and manipulation), Jibo (consumer social robots), Locus Robotics (mobile service robots), Aquabotix (unmanned underwater systems), and more.

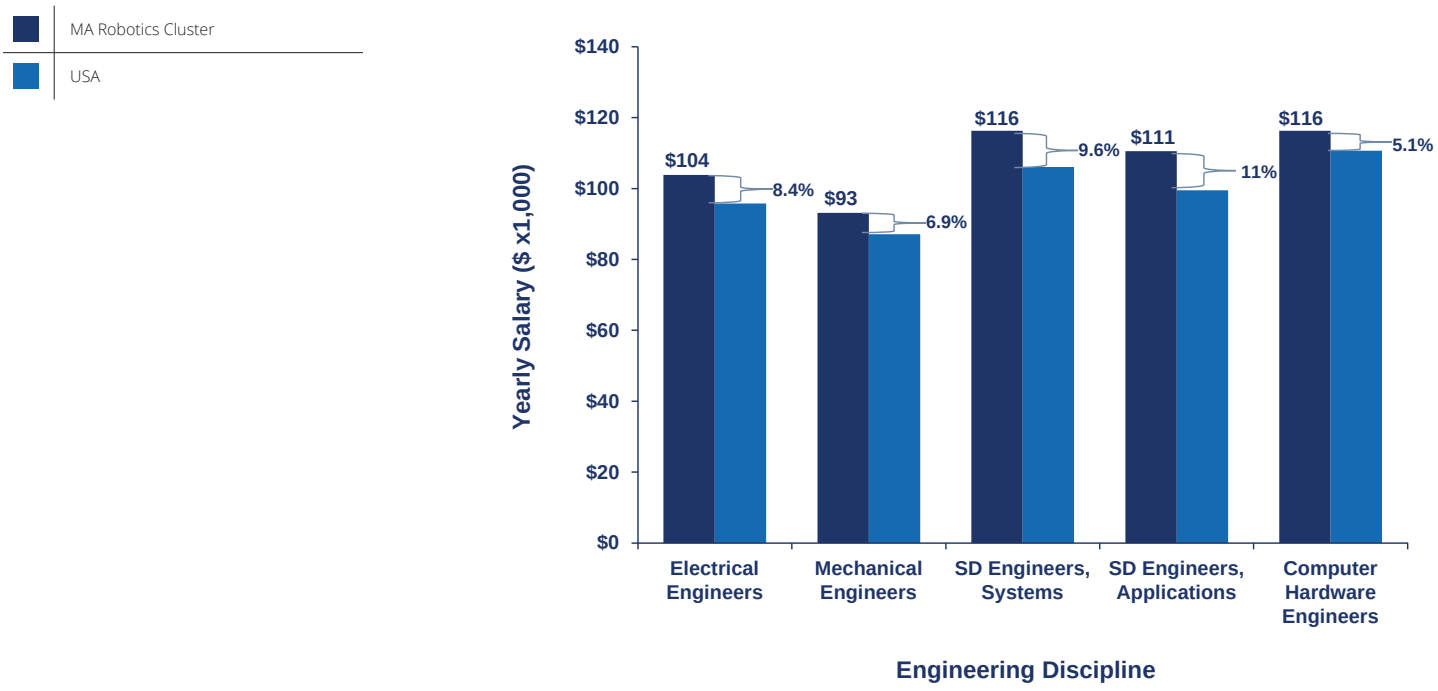
7.4. SALARIES FOR ROBOTICS ENGINEERS

The term "robotics engineer" is rarely used in job descriptions because it is not a formal descriptor in common use. The development of robotics technology requires the combined skills of software, electrical, and mechanical engineers, as well as a good deal of systems engineering support. Determining the average salaries of robotics engineers, therefore, requires that the wages for each of these classes of engineers be considered separate and compared to industry norms.

As described in Figure 22, the average yearly salary for the various classes of engineers commonly employed for robotics development in the Massachusetts robotics cluster region is substantial, and higher than for the United States as a whole. The Massachusetts robotics cluster area salaries are not the highest in the nation. For the most part, that distinction expectedly goes to Silicon Valley and greater San Francisco, and occasionally elsewhere (see Appendix C). Massachusetts engineers, however, consistently earn more than their counterparts in other states (see Appendix C).

Figure 22: Robotics Engineers Average Yearly Salaries, Massachusetts versus United States

(Source: US Department of Labor, Bureau of Labor Statistics)



More Insight: *The year 2015 was a banner one for private equity investment for robotics companies. Historically, however, robotics investments have been very limited compared to other sectors, such as social networking, biotech, green tech, and communications. One of the reasons given for the hesitancy on part of the investment community for funding robotics startups is the length of time required to bring products to market. Incubator programs and hardware accelerators can act to reduce the time to develop prototypes, as well as ensure that they are correctly engineered for manufacturability.*

7.5. OFFICE LOCATION/RELOCATION OF NON-STATE-BASED ROBOTICS FIRMS

Eastern Massachusetts is a magnet for foreign robotics companies establishing North American regional and subsidiary headquarters.

A significant number of international robotics firms and technology suppliers have made Eastern Massachusetts their regional or subsidiary headquarters. The companies range from personal robotics suppliers Aldebaran and Blue Frog Robotics (France), to precision drive producer Maxon Motor (Switzerland) and exoskeleton maker ReWalk Robotics (Israel). Others, such as Japan's Harmonic Drive, have their U.S. manufacturing headquarters in the area.

A metro Boston address has brand value for companies wishing to be perceived as forward thinking and innovative.

The specific reasons given by robotics firms for a greater Boston regional or subsidiary headquarters vary from company to company, but access to a sizable, qualified labor pool, close proximity to an international airport, and the multiplier effect resulting from agglomerated robotics expertise, are typically cited. Recognition of metropolitan Boston as an international hub for robotics research and innovation is of special note. In addition to the practical benefits, a metro Boston headquarters communicates to customers, stockholders, and the world at large that the company is a robotics leader, and the corporate culture forward thinking and highly innovative, which has a strong brand value.

Robotics companies also locate in Eastern Massachusetts because the region is dominant in their sector of activity, such as the healthcare, defense, research, and education markets. Robotic therapeutic technology provider Hocoma (Switzerland), for which the Boston area's reputation as a world-class healthcare cluster was key, is representative.

Additional Insight: *Dedicated, ongoing, and often aggressive branding campaigns for specific products or companies are very common, as are branding programs for travel and tourism. Massachusetts has done well branding the Commonwealth as a technology and innovation leader in a variety of industry segments. While common regional branding techniques of the past, such as international junkets and trade shows, do provide value, they can no longer be considered a competitive differentiator, but more "table stakes." More aggressive, non-traditional approaches are now required.*

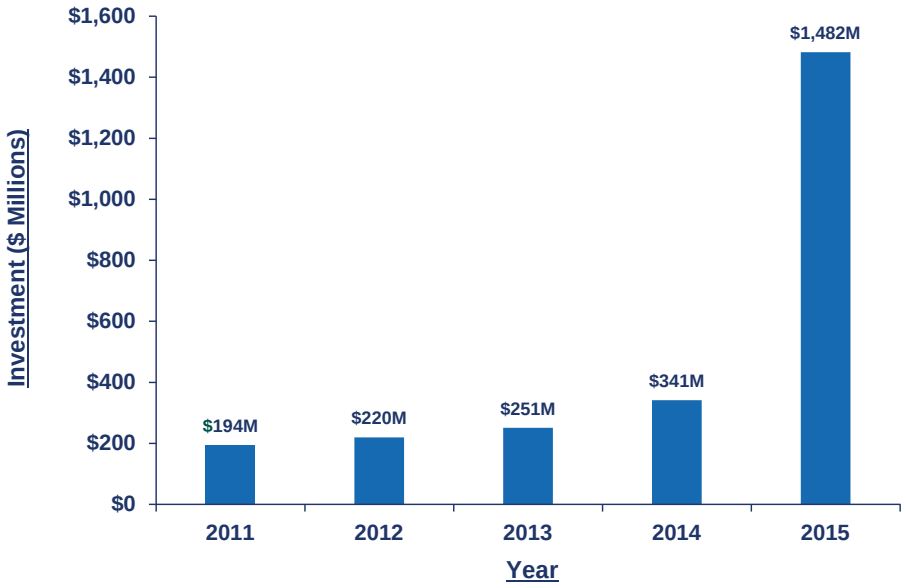
7.6. INVESTMENT IN ROBOTICS

Private sector investment in robotics companies increased dramatically in 2015. Approximately US$1.5 billion was invested, a dramatic increase over the previous year.

VC and other private sector investment in robotics companies increased dramatically in 2015, following years of upward, but unexceptional growth (Figure 23). Robotics investments in 2015 represent an increase of more than 330% over the previous year. It should be noted, however, that investing in the years 2011 to 2014 was significant. Funding rounds for robotics investments prior to 2011 were very small, and in some years, non-existent. In some respects, 2014 also represents a turning point, with year-over-year investment increasing more than 35%.

Figure 23: Worldwide VC and Private Sector Robotics Investment

(Sources: Hizook, Robot Report, ABI Research)



* Other includes transportation, K-12 education, retail, and resource management.

U.S.-based companies received 57% of the worldwide VC and private sector robotics investment in 2015, for a total of US$845 million.

Companies headquartered in the United States received the majority of VC and private sector investment dollars in 2015: 57% or approximately US$845 million (Figure 24). According to the National Venture Capital Association (NVCA), this figure represents only 1.4% of the total 2015 U.S. investment figure. Still, this is a sizable amount compared to previous years, and demonstrates an undeniable upward trend.

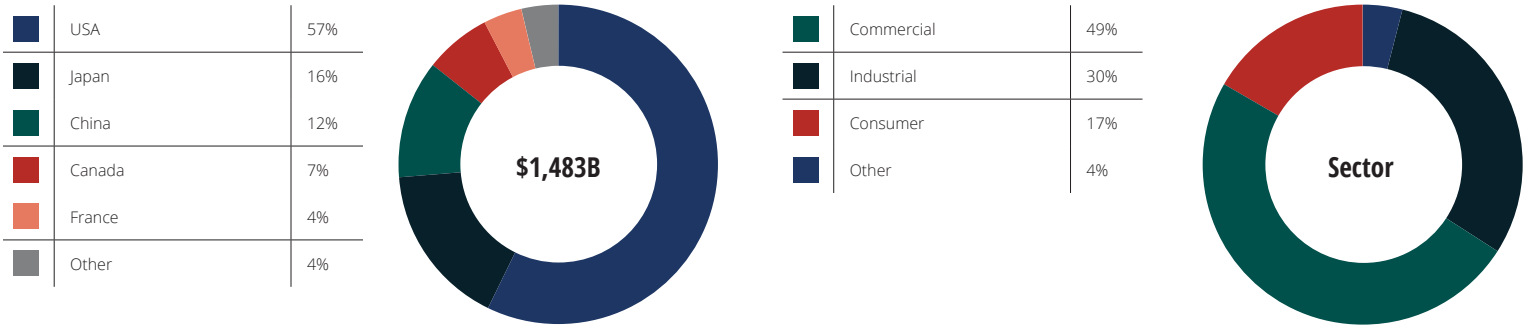
Additional Insight: Even if 2015 comes to be viewed as a robotics investment outlier, robotics investment for 2016 and beyond will continue to be robust. This is contingent on a number of factors, often unrelated, including:

- *Absence of market failures*
- *Continued availability of hardware-centric business accelerators*
- *Increased numbers of robotics exits, initial public offerings (IPOs), and acquisitions*
- *Stability of international financial markets*

As described in Figure 24, when 2015 robotics investments are examined on a per sector basis, it can be seen that the commercial segment dominates, with strong representation by companies developing solutions for the industrial and consumer markets. Venture investment for companies targeting the defense, research, and education sectors are in the low single digits. This is a reflection of investor emphasis on short-term returns, but also of the uncertainties and limited ceiling of public sector investments and public sector growth overall.

Figure 24: 2015 VC and Private Sector Robotics Investment by Country and Sector

(Source: ABI Research, Robot Report)



When 2015 VC and private sector robotics investments are broken down into specific target industries, as well as the technologies/products and services that the funded companies offer, it appears that no discernible trends emerge (Figure 25). This is not entirely correct. While the target industries of recipient companies do vary greatly, there are themes and commonalities in the types of products, technologies, and services developed for them (Table 13). For example, all companies producing mobile ground robots are targeting a combination of the manufacturing, warehouse/distribution, and healthcare industries. These markets share a working environment that is semi-structured, indoors, and heavily peopled.

Similarly, the agriculture, mining, and utilities sectors are the key markets for drone manufacturers and drone operator/data services providers. The majority of the recipient companies producing software/libraries/software development kits (SDKs) were also doing so in support of the UAV sector, and thereby pursuing the agriculture, mining, and utilities sectors indirectly. Sensor/vision system producers offer solutions for multiple classes of robotics providers and, therefore, support a wide range of industries.

Table 13: Target Industries for Robotics Technologies/Products/Services Investments

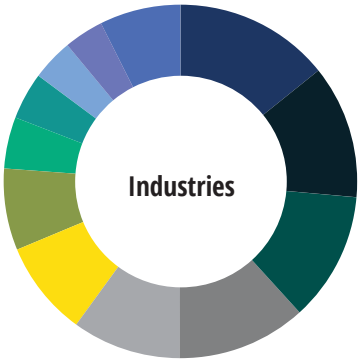
Technologies/Products/Services	Industries
Mobile Platforms/AGVs	Manufacturing, Warehouse/Distribution, Healthcare
UAVs	Utilities, Agriculture, Mining, etc.
Operator Services/Data Services	Utilities, Agriculture, Mining, etc.
Software/Libraries/SDKs	Utilities, Agriculture, Mining, etc.
Sensors/Vision Systems/Hardware	All Systems

(Source: ABI Research)

Figure 25: 2015 Global Robotics Investments by Target Industries and Technologies/Products/Services

(Source: ABI Research, Robot Report)

Manufacturing	14%
Healthcare & QoL	12%
Toy/Hobby/Social	12%
Warehouse/Distribution	12%
Agriculture	10%
Utilizes	9%
Mining and Quarrying	7%
Transportation	7%
Defense/Security/ Public Safety	4%
Home Care	4%
Retail/Wholesale	4%
Other	7%



Mobile Platforms/AGVs	15%
Software/Libraries/SDKs	15%
Unmanned Aerial Vehicles	15%
Sensors/Vision Systems/ Enabling Hardware	11%
Operator Services/Data Services	10%
Consumer Robotics	7%
End Effectors/Arms/ Manipulators	5%
Controllers	4%
Engineering Services/ Systems Integration	4%
Industrial Robots	4%
Surgical/Interventional Systems	4%
Other	9%

** Other includes prosthetics / orthotics / rehabilitation / exoskeletons, lifestyle enhancement, marine systems, laboratory / cleanroom, and networking / connectivity.*

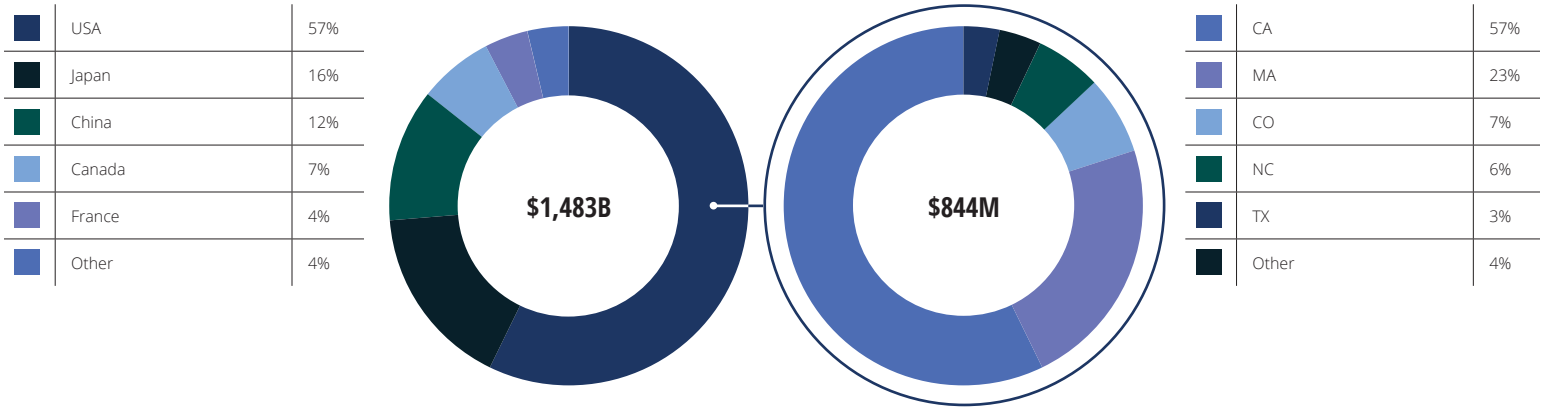
7.7. PRIVATE INVESTMENT IN MASSACHUSETTS-BASED ROBOTICS FIRMS

Massachusetts-based companies, all of which are located in the greater Boston metro area, received US$190 million in private investment in 2015.

As noted above, worldwide investments in companies producing robots and robotics technologies, as well as services and enabling technologies that directly support them, increased dramatically in 2015, reaching in excess of US$1.4 billion (see Figure 26). U.S. firms were on the receiving end of the bulk of this funding (57%), taking in approximately US$845 million. Massachusetts-based firms attracted approximately 23% of the investments to companies in the United States, which reached a total of more than US$190 million. Of these, all were located in the greater Boston area.

Figure 26: 2015 VC and Private Sector Robotics Investment, Global and United States

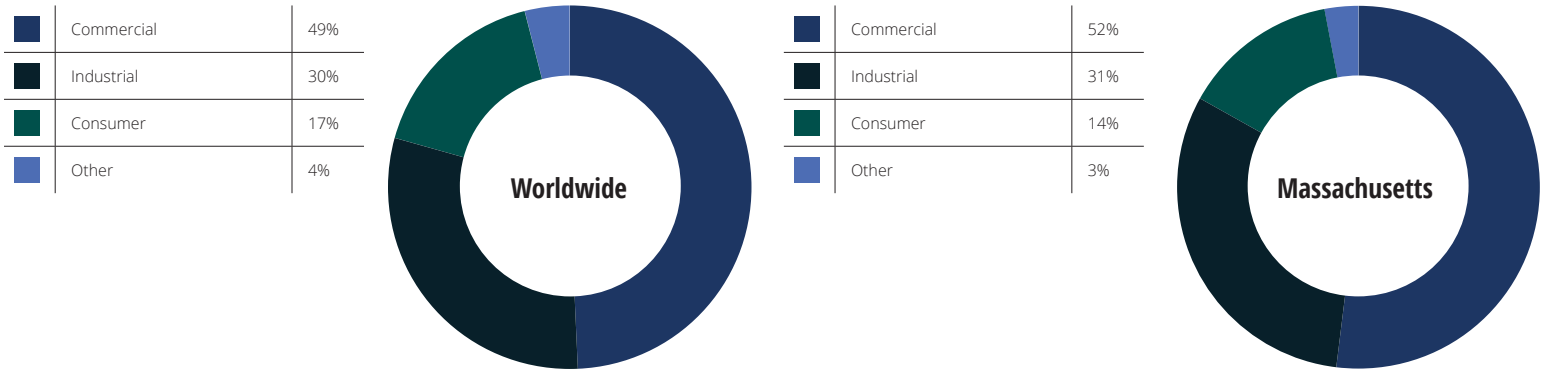
(Source: ABI Research, Robot Report)



When 2015 Massachusetts robotics investments are compared with the world at large, it can be seen that sector investment proportions are roughly comparable (Figure 27). The commercial segment dominates, with strong representation by those companies developing solutions for the industrial and consumer markets. Venture investment for companies targeting the defense, research, and education sectors is in the low single digits. This is a reflection of investor emphasis on returns in the short term, but also their unease with the uncertainties and limited ceiling of companies reliant on public funding sources.

Figure 27: 2015 VC and Private Equity Investment by Sector, Global and Massachusetts

(Source: ABI Research, Robot Report)



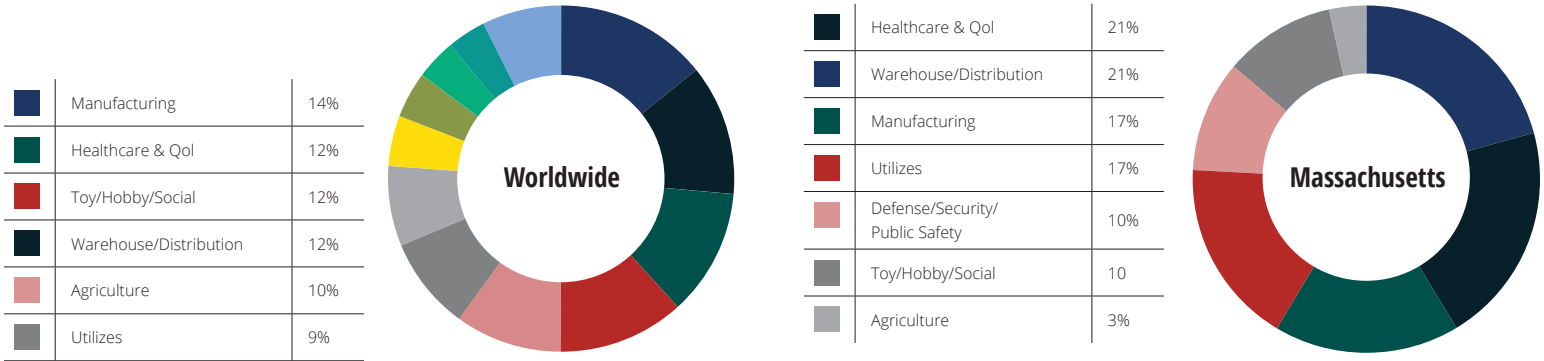
Global private investment trends for robotics were reflected, to a large degree, in the funding of Massachusetts-based firms. In both cases, sizable amounts of investment went to companies developing solutions for the manufacturing, utilities, and warehouse/distribution sectors (Figure 28). Investments for companies developing solutions for the utilities industry were almost exclusively commercial drones, and the technologies and services that support their use. The applications, for the most part, are for infrastructure inspection.

Massachusetts-based healthcare robotics firms that recently received investment funding include Medrobotics, Myomo, and BionX Medical Technologies.

Massachusetts received a greater proportion of investment for those businesses producing robotics products for the healthcare/quality of life (QoL) sector, a consequence of the State's leadership role in this market. Investments in healthcare robotics companies were split among those developing interventional systems, and others offering robotics technologies for rehabilitation or for use in prosthetic devices. Massachusetts firms in this category include Medrobotics, Myomo, and BionX Medical Technologies.

Figure 28: 2015 VC and Private Equity Investment by Target Industry, Global and Massachusetts

(Source: ABI Research, Robot Report)



7.8. MASSACHUSETTS INCUBATORS, ACCELERATORS, AND WORKSPACES

Massachusetts is home to incubators and accelerators of all types, offering an assortment of different programs. Some are general purpose, while others focus on industry segments including healthcare, cleantech, and education. No dedicated robotics incubator/accelerator exists, although robotics firms have been accepted into technology-oriented incubator/accelerator programs.

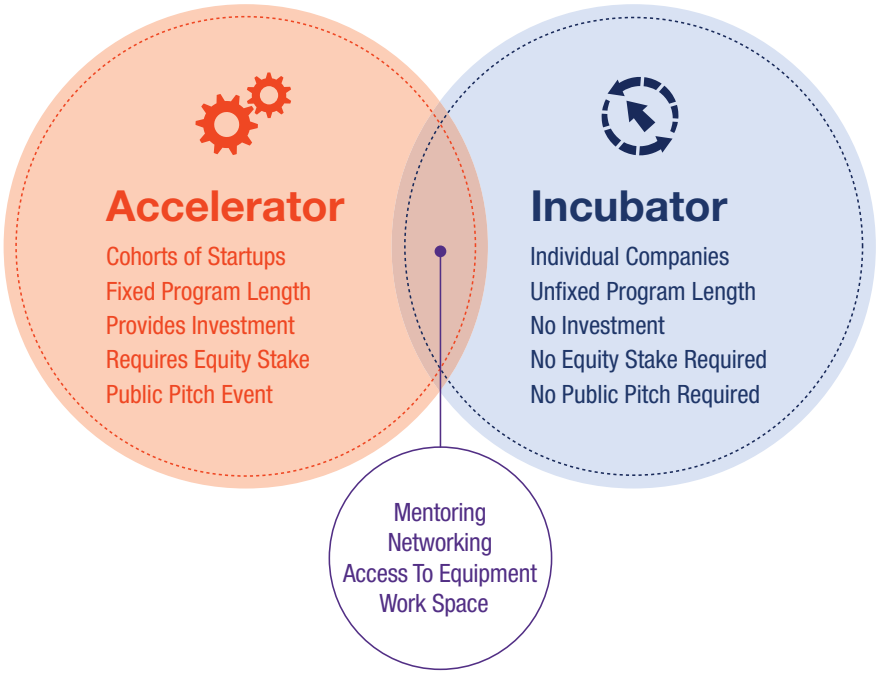
Both startup incubators and accelerators assist young companies to make them both entrepreneurial and successful (Figure 29). They differ in approach and the demands placed on the startups involved. For the most part, accelerators are more suited to more mature companies that are amenable to a structured, rigorous, short-term approach. Incubators are more flexible in their methods, and usually deal with very young firms. For some companies, incubators are used in preparation for entering accelerator programs.

In essence, accelerators are investment companies, and their numbers are increasing. They join VC firms and the investment arm of private companies as an additional source of funding for young companies.

Some incubators and accelerators have proven successful at fostering the development of successful companies. This success, in turn, has bred success. It is estimated that more than 300 accelerators and incubators are now found in the United States. Critics of incubators and accelerators, however, are quick to point out that measures of success, such as number of company launches and the acquisition of follow-on funding, are very uneven, and that the data sources are limited or lacking.

Figure 29: General Characteristics of Accelerators and Incubators

(Sources: Dempwolf, Auer, and D'Ippolito, 2014; ABI Research)



7.8.1. Accelerators

Accelerators, typically for-profit organizations, assist early-stage startups by providing a combination of stipends, workspaces, business mentorships, and connections to potential investors. The participating companies provide an amount of non-controlling equity (usually 5% to 10%). In this sense, accelerators are for-profit investment companies. The selection process for accelerator programs is competitive, which increases the appeal of accepted companies to potential investors.

Hardware accelerators typically provide 3D printers, CNC machines, injection molders, and other equipment used for hardware design, prototyping, and manufacturing.

As their name implies, hardware accelerators are designed to speed the development of hardware technologies, as well as reduce the risk of innovative designs failing to reach the market due to the business and volume manufacturing inexperience of hardware entrepreneurs. Hardware accelerators are distinguished from their more generic counterparts by the on-site availability of 3D printers, computer numeric control (CNC) machines, injection molders, and other equipment used for hardware design, prototyping, and manufacturing. Also, the length of accelerator programs often extends beyond the typical run of 6 to 12 months.

Notable hardware accelerators that have had success producing robotics technologies include Y Combinator (California), TechFounders (Germany), Lemnos Labs (California), Seedcamp (United Kingdom), and HAX (California). Hardware-centered accelerators in the greater Massachusetts cluster region include Bolt (Boston), MIT Global Founders' Skills Accelerator (Cambridge), and Harvard Innovation Lab (Cambridge). Massachusetts-based accelerators that have robotics alumni include:

- **MassChallenge (Boston):** MassChallenge, which claims to be the world's largest startup accelerator, is open to startup companies in any field. Under the program, which is competitive, companies are awarded grants equaling US$50,000 or US$100,000 after a 4-month program period. Robotics alumni include Hydroswarm and Juice Robotics (underwater vehicles), XactSense (drones and sensors), Bounce Imaging (mobile sensor), and Iron Goat (outdoor mobile robots).

Massachusetts-based accelerators Techstars Boston and MassChallenge have seven robotics alumni between them.

- **Techstars Boston:** Techstars is a highly competitive accelerator program with a very solid reputation. The Techstars terms include a 6% equity stake for US$18,000 seed capital and the option for a convertible note of US$51,000 to US$100,000. Rise Robotics (actuators and exoskeletons) and Neurala (software) are Techstars Boston alumni.

7.8.2. Corporate Accelerators

A number of large corporations have also established accelerators, with the objective of improving their capacity for innovation and gaining access to promising new technologies. These corporate accelerators often work in partnership with smaller firms with startup experience, and many also have their own venture investment divisions. Cisco, BMW, Flextronics, Deutsche Telekom, Google, Intel, and Microsoft serve as examples.

Large corporations also act as accelerators.

7.8.3. Incubators

Unlike accelerators, incubators do not provide capital for startups and do not take an equity stake. Many, but not all, are supported by outside grants from universities or national and state governments. Businesses are also contributors, as are private investors. Incubators are selective, but they do not provide upfront payments. Most incubators are focused on a specific industry or narrow vertical markets.

Incubators provide mentorship and networking, as well as office and workspace, with some providing tools and other equipment. Typically, program lengths are not fixed. Example incubators include the Advanced Technology Development Center (Georgia), MGE Innovation Center (Wisconsin), and Massachusetts-based Greentown Labs. Greentown, an incubator for cleantech startups, provides co-working space, prototyping facilities, and business services. Robotics firms Autonomous Marine Systems (robotic surface vehicles), Rise Robotics, RailPod (robotic rail inspection systems), and RightHand Robotics (manipulators) are alumni of Greentown.

Four Massachusetts robotics companies are alumni of the Greentown Labs incubator.

7.8.4. Co-working Spaces and Makerspaces

The greater Boston area is also home to both co-working spaces and makerspaces, which can provide temporary workspace and, in the case of makerspaces, access to equipment. Examples include WeWork (Boston), Artisan's Asylum (Somerville), and Cambridge Hackspace. Social robot maker Jibo was once housed in the WeWork Boston office.

Additional Insight: *Over the last 5 years, a number of startup incubators and accelerators have been launched, and programs continue to proliferate. It is important to note, however, that startup accelerators have also been discontinued, "pivoted" to another business model, or relocated. Many of these accelerators are startups themselves, and therefore, this behavior is in keeping with other young companies. In other instances, business simply dropped support. For example, Qualcomm, as part of a cost-cutting initiative, ended its partnership with Techstars for the Qualcomm Robotics Accelerator. The announcement came only weeks after the accelerator graduated its first class of 10 robotics startups. Incubators, which are often supported with funding from universities and government sources, are less likely to fall away in this manner.*

7.9. EDUCATION AND RESEARCH

Massachusetts has a well-earned international reputation as an education leader. K-12 education in the Commonwealth consistently ranks among the highest in the United States, as well as globally. Massachusetts is also recognized throughout the world for the quality of its colleges and universities, as well as the groundbreaking research that occurs within the State.

7.9.1. Degree Programs

More than 16 educational institutions in the Boston area have undergraduate engineering programs for disciplines critical to robotics development.

Massachusetts is densely populated with institutes of higher learning. Metropolitan Boston alone is home to more than 50 private and public colleges and universities, and within the entire State and other geographic areas that define the Massachusetts robotics cluster, many more can be found. More than 16 institutions in the Boston area have undergraduate engineering programs for some combination of the three disciplines critical to robotics development: electrical engineering, mechanical engineering, and computer science. Undergraduate robotics engineering programs are rare, although robotics minors are available.

Advanced degree programs for electrical engineering, mechanical engineering, and computer science are also offered at a number of universities in the greater Boston metropolitan area. Worcester Polytechnic Institute (WPI) is notable in that it has a dedicated graduate robotics engineering program. WPI also offers BS and MS degrees in robotics engineering, and was the first institution in the nation to offer all three degrees in robotics.

7.9.2. University Research Laboratories

The Massachusetts robotics cluster is also home to world-class robotics research laboratories and innovation centers. Across 10 Massachusetts academic institutions, in more than 40 separate laboratories and study groups, researchers are performing groundbreaking primary and applied robotics research, as well as

carrying out investigations into other associated areas of study. The academic institutions where this critical work is ongoing are given in Table 14. Appendix B provides greater detail.

Table 14: Representative Massachusetts Research Universities	
Boston University	Tufts University
Brandeis University	University of Massachusetts, Amherst
Harvard University	University of Massachusetts, Dartmouth
Massachusetts Institute of Technology	University of Massachusetts, Lowell
Northeastern University	Worcester Polytechnic Institute

(Source: ABI Research)

The neighboring states of Massachusetts also have universities that are performing important research and contributing indirectly to the greater Massachusetts robotics cluster. Examples include University of Rhode Island, Brown University, Dartmouth College, University of New Hampshire, University of Maine, University of Vermont, University of Connecticut, Yale University, and more.

Massachusetts Spotlight: NASA Awards Two R5 Humanoids to Northeastern and MIT

In November 2015, NASA selected MIT and Northeastern University/UMass Lowell to receive a Valkyrie humanoid robot, so that research focused on adapting the systems for use in space and possibly on Mars can be conducted. The awarding of the Valkyrie robots followed an extended, competitive selection process, with potential recipients drawn from the international collection of teams that competed in the 2015 DARPA Robotics Challenge. The DARPA Robotics Challenge was designed to foster the development of autonomous robotics capable of performing various emergency response tasks.

The MIT group will work out of the Computer Science and Artificial Intelligence Laboratory (CSAIL) under principal investigator Russ Tedrake. The Northeastern University/UMass Lowell team is led by Taskin Padir, and includes Rob Platt at Northeastern and Holly Yanco at UMass Lowell. The Northeastern/UMass Lowell Valkyrie robot is housed at the NERVE Center. Both groups will receive US$250,000 in funding per year for a 2-year period to develop new algorithms that will extend the capabilities, increase the autonomy, and improve the dexterity of the bipedal, 6-foot-tall, 290-pound humanoids. NASA is also providing each research group with on-site and virtual technical support.

7.9.3. Private, Non-profit Research Facilities

Massachusetts is recognized worldwide as a leading center for advanced R&D. This includes private, nonprofit R&D facilities. Two of the more notable examples include Falmouth, Massachusetts-based Woods Hole Oceanographic Institution (WHOI) and the Charles Stark Draper Laboratory (Draper) located in Cambridge, Massachusetts.

WHOI, the largest independent oceanographic research institution in the United States, is responsible for the development of some of the most iconic marine systems in the world.

The WHOI is the largest independent oceanographic research institution in the United States and a leading developer of marine robotics technologies including the only deep-diving research submersible in the United States, the iconic Alvin Human Occupied Vehicle (HOV). Like Alvin, the Jason series of ROVs, which were famously used to survey the wreck of RMS Titanic, was also developed by WHOI's National Deep Submergence Facility. The marine robotics company Hydroid was spun off from Woods Hole to commercialize another Woods Hole submersible, the REMUS AUV.

In addition to performing research and engineering advanced marine technologies, Woods Hole also boasts of undergraduate, graduate, and postdoctoral programs for educating the next generation of marine scientists, engineers, and entrepreneurs, often in partnership with other institutes of higher learning. For example, in 2016, WHOI reached a milestone: it conferred the 1,000th graduate degree as part of a joint education program between MIT and Woods Hole.

In 2014, Massachusetts awarded WHOI a US$5 million grant for developing marine robotics technologies.

Funding for Woods Hole research has many sources, both public and private. Commercial companies partner with WHOI for the development of new technologies, as do governmental agencies, such as the NSF, the NOAA, the Environmental Protection Agency, and more. Academic institutions such as Cornell University, MIT, the U.S. Naval Postgraduate School, University of Tokyo, and more have partnered with WHOI, as have a number of private foundations. The State of Massachusetts, too, supports the work of Woods Hole. In 2014, the Commonwealth of Massachusetts awarded WHOI a US$5 million grant for developing and testing marine robotics technologies.

Draper has a long history of innovation in multiple fields, many of which intersect with robotics: autonomous navigation, medical devices, AI, and more. This work is often accomplished in partnership with research universities. For example, Draper was recently awarded a US$3.4 million contract by DARPA to develop UAVs that autonomously sense and navigate through unknown environments without external communications or global positioning system support.

7.9.4. Robotics Research at Medical Centers

Massachusetts research hospitals, medical institutions, and rehabilitation centers also perform robotics research and commercialization efforts.

The institutions described above are joined by others performing investigatory robotics work in the many research hospitals, medical institutions, and rehabilitation centers for which Massachusetts is celebrated. Renowned institutions, such as the Lahey Hospital & Medical Center, Tufts Medical Center, Massachusetts Eye and Ear Infirmary, Brigham and Women's Hospital, and others, have their own dedicated robotics research efforts underway, often working in partnership with others from academia and industry. For example, researchers working in the Pediatric Cardiac Bioengineering Lab at Boston Children's Hospital are developing new medical techniques using robotics technologies to improve healthcare results. So, too, are the Pediatric Cardiac Bioengineering Laboratory and Developmental Endoscopy Research Lab at Massachusetts General Hospital.

7.10. NATIONAL LABORATORIES

Massachusetts is home to two federally funded R&D centers that address critical national security issues using advanced technology, including robotics. The first, Lexington-based Lincoln Laboratory, is sponsored by the U.S. DoD and is administered by MIT. Research programs at Lincoln Laboratory deal specifically with robotics, particularly work related to autonomous ground and air systems, and human-robot collaboration.

The National Security Engineering Center (NSEC) in Bedford is also sponsored by the DoD. Administered by the MITRE Corporation, NSEC is actively developing solutions in the areas of unmanned aerial and ground systems, micro robotics, mobile telepresence robots, advanced manipulation, and more.

Lincoln Laboratory and NSEC are Massachusetts-based, federally funded R&D centers that contribute to the overall Massachusetts robotics ecosystem both directly and indirectly.

Lincoln Laboratory and NSEC contribute to the overall Massachusetts robotics ecosystem both directly and indirectly. Ongoing R&D work is often a collaborative effort with outside support from academia and industry, typically from Massachusetts. Broader outreach efforts, ranging from on-site technical workshops to community-based STEM education initiatives, are also common.

7.11. MASSACHUSETTS MILITARY INSTALLATIONS

Massachusetts is home to six military installations, two National Guard bases, and a number of smaller Army Reserve and National Guard units. According to the UMass Donahue Institute, these installations contributed approximately US$1.3 billion to the Massachusetts economy in 2013, the latest year for which figures are available (UMass Donahue Institute, 2015). Among the activities undertaken at these facilities is research, often in partnership with local Massachusetts companies.

7.11.1. U.S. Army Natick Soldier Systems Center

Natick Labs is a DoD research and engineering facility responsible for developing innovative soldier support items, including clothing, food, portable shelters, and warfighter survivability equipment. By extension, the technology developed at the lab can also be used for disaster relief or for other humanitarian purposes. Research, development, and testing activities at Natick Labs have involved robotics technologies such as exoskeletons, advanced sensors and controllers, miniature robots, and more.

Natick Labs performs research for the DoD, including work involving robotics technologies.

Natick Labs is populated with its own research scientists and engineers, but also partners with academia and private industry on some projects. Engineering and testing services are also available on a fee-for-service basis.

Natick Labs offers research, engineering, and testing services to third parties on a fee-for-service basis.

7.11.2. Joint Base Cape Cod

The Federal Aviation Administration (FAA), in accordance with the FAA Modernization and Reform Act of 2012, selected six public entities, located in six different locations throughout the United States, to develop UAS test sites around the United States. The six sites are conducting research into the requirements necessary to safely integrate civil and commercial UAS into the U.S. national airspace (NAS).

One of the six public entities selected to develop the test sites and perform research was the Northeast UAS

The NUAIR Alliance, one of six groups selected by the FAA to develop UAS test sites and carry out research, includes many Massachusetts-based universities and research labs.

Airspace Integration Research (NUAIR) Alliance. The non-profit NUAIR Alliance consists of a research network of more than 20 universities and research laboratories, such as MIT, UMass Lowell, WPI, Draper, Cape Cod Community College, and Boston University. Each institution focuses on specific standards, technologies, capabilities, protocols, risks, and procedures.

NUAIR is also made up of New York and Massachusetts private businesses, as well as facilities supporting testing of UAS. Raytheon, ARCON Corporation, and Charles River Analytics are Massachusetts-based NUAIS partner companies. The NUAIR test sites include Griffiss International Airport in New York State and Joint Base Cape Cod (JBCC) in Massachusetts, plus other locations on a case-by-case basis. Testing flights at JBCC sites are coordinated through the Massachusetts Unmanned Aircraft Systems Test Center (MA UASTC). MassDevelopment, the Commonwealth's economic development and finance agency, has contracted with the private firm Avwatch to manage UASTC operations.

Massachusetts private businesses, as well as JBCC, are also part of the NUAIR Alliance.

7.11.3. Fort Devens

For almost 80 years, Fort Devens was an active-duty military base. The 4,888 acre site closed in 1996, and at that time, MassDevelopment, the Commonwealth's finance and economic development agency, purchased the base. Since then, nearly 100 companies have located to Fort Devens (the Massachusetts Army National Guard also maintains a presence). Among them are:

- **Quiet Logistics:** Quiet Logistics is a third-party fulfillment services provider for e-commerce companies. The company has recently spun off Locus Robotics, a maker of indoor mobile service robots for goods-to-man picking.
- **DCS Corp:** DCS Corp is an engineering services firm serving the defense sector. The company has developed solutions for the DoD, often working with outside R&D laboratories, in the areas of UAS and autonomous ground vehicle systems.
- **MagneMotion:** MagneMotion provides electro-magnetic conveyance systems for transportation and material handling, which are often used in conjunction with robotics in a manufacturing automation role. Rockwell Automation, the world's largest supplier of industrial automation solutions, including systems employing robotics technologies, recently announced that it was acquiring MagneMotion. MagneMotion will be incorporated into Rockwell's motion solutions group, which also includes robotics.

7.11.3.1. Devens Interoperability Playground

In 2014, MassDevelopment, the New England chapter of the Association for Unmanned Vehicle Systems International (AUVSI), an international unmanned systems trade group, along with the Mass Technology Leadership Council (MassTLC), a technology business development association, signed a memorandum of understanding (MOU) to work cooperatively toward developing a center of interoperability for unmanned systems at Fort Devens. In 2015 and 2016, AUVSI New England hosted a robotics industry trade event at Fort Devens, Robotica. The event will also take place in 2017.