Feasibility Analysis and Action Plan for a Regional Robotics Innovation Hub

Report prepared by the Center for Economic and Community Engagement
Virginia Tech and DAUGERS LLC

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Executive Summary

The goal of this project was to assess conditions and offer guidance for development of a Robotics-focused Innovation Hub in the Hampton Roads region. This report includes four primary components:

1) Global, National, and State Robotics Industry Situational Assessment
2) Regional Robotics Industry and Innovation Ecosystem Situational Assessment
3) Proposed Focus Areas and Concept Summary for a Robotics Innovation Hub
4) Roadmap and Implementation Plan

Robots are programmable machines able to carry out a series of actions autonomously, or semi-autonomously. Our **global, national, and state robotics industry situational assessment** was comprehensive. The total 2025 robotics industry market is projected to be in the range of $147 billion to $181 billion (or $164 ±17 billion). Appendix A includes a detailed market analysis and Appendix B includes an accompanying industry analysis. The robotics industry is rapidly evolving, spurred by the introduction of cognitive computing into the robotics industry – generally called Industry 4.0 Collaboration. Industry 4.0 Collaboration included adding artificial intelligence, machine learning and automated reasoning capabilities as well as advanced sensory and perception capabilities to robots. The industry continues to be moving to the next generation of robots that can sense and think and, in response, act; i.e., they can and do act autonomously. For **the global, national, and state robotics industry situational assessment,** we also spoke with or received data from 12 robotics companies (2 in Virginia and 10 national); 8 higher-education institutions with robotics-related programming; and 6 innovation hub or accelerator programs.

Our **state and regional robotics industry and innovation ecosystem situational assessment** was similarly comprehensive. We engaged a local steering team, reviewed existing data and information, and interviewed 9 Hampton Roads region companies (including two robotics-focused companies and seven companies that significantly use robotics); and 6 regional organizations that are key figures in the Hampton Roads innovation ecosystem. Robotics, machine learning, virtual reality, artificial intelligence, and inter-connected cyber-physical systems are becoming increasingly important and prevalent, globally, nationally, and in Hampton Roads.

The region has a number of related supportive assets in areas such as autonomous systems research and development, space and military research, technology-intensive manufacturing, digital shipbuilding and repair, distribution and logistics, and other industries. Industry leaders in the region such as Huntington Ingalls, Canon, the Port of Virginia, and others are increasingly focusing on robotics and cyber-physical system improvements and innovations, often conducting extensive internal research and development. One major company in the region describes their manufacturing operation as having more robots than any company on the East Coast, and another recently spun

out a new robotics-focused company through its research division. The Hampton Roads regional innovation ecosystem continues to grow and expand, with 757 Collab being a prominent example.

The information from these two assessments informed our **proposed focus Areas and concept summary for a Robotics Innovation Hub in Hampton Roads.** We find that there appears to be a market opportunity and a fit in the regional innovation ecosystem for a robotics innovation hub to be developed with the following considerations in mind:

- A focus on "*intelligent robotics*", by which we mean the design, construction, and programming of physical robots (and their associated and connected cyber-physical systems) that employ advanced sensory, perception, or process capabilities or employ some level of machine learning or artificial intelligence. Intelligent robotics tend to exhibit radical innovation (the development of new products based on new technologies) as opposed to incremental innovations (developing new products based on existing technologies). Intelligent robotics includes those companies and products at the intersection of AI and robotics, as well as much of the activity around collaborative robots.
- A hub should directly address the most significant challenge in growing a stronger robotics sector in Hampton Roads: the *very low number of existing or emerging in-region robotics-related start-ups and younger ventures*. SVT Robotics is a notable exception.
- A hub should also directly address the *second most significant challenge: technology talent attraction and retention*. The region has self-identified a need to increase the its ability to attract and retain technology talent. Along with capital, talent is the primary need for the small robotics companies in Virginia and nationally with which we spoke. Almost all of our interview respondents within Hampton Roads, cited a workforce and talent gap in the region, particularly for robotics related jobs such as engineers, computer scientists, and technologists.
- A *hub space alone is insufficient* and unlikely to significantly add value to the regional ecosystem or address the two challenges listed above. The companies we spoke with varied in size and stage but seemed to agree that a physical space by itself was less valuable to start-ups than a more concerted and comprehensive range of assistance to help founders with the social and economic aspects including legal, talent, technical, collaborative, and leadership aspects.
- To be clear, *a robotics innovation hub must be intentionally designed and not simply about space or the physical infrastructure*. We understand and emphasize here that any new hub space must be accompanied by an intentionally developed, highly customized, tightly focused, and well-implemented series of programmatic and assistance activities and resources.
- In addition, *a new innovation hub in Hampton Roads should be non-duplicative and non-competitive* with the work of other regional ecosystem players. A hub that is broader than robotics or that provides general incubation or acceleration for a wide range of ventures and start-ups would likely be duplicative of existing spaces and services. The innovation ecosystem in Hampton Roads is in an active state of expansion (757 Collab, Norfolk Innovation Corridor, Tech Center, etc.) with many existing and emerging resources such as space and expertise. The

hub should be structured to complement and connect with other regional programs and should not function as competition in the ecosystem.

- A new innovation hub in Hampton Roads should be focused on *a clear niche related to intelligent robotics*. To re-emphasize what we mean by this focus, intelligent robotics products and ventures sit at the intersection of the physical (devices or hardware); the cyber (automated, networked, or virtual); and the intelligent (employing advanced sensory, perception, or process capabilities or employing some level of machine learning or artificial intelligence). Moreover, an intelligent robotics product or venture would more often represent radical innovation as opposed to more incremental innovation.
- A hub could play a valuable role in *connecting with and advancing networking opportunities between robotics-related research and development companies, engineers, and technologists* in the region, many of whom work with larger corporations in a complicated environment with proprietary, security, and competitive barriers to collaboration. Larger regional entities that are robotics users (such as Huntington Ingalls, Stihl, and the Port of Virginia) are interested in opportunities to connect with each other, to learn about new technologies, and to solve shared problems related to automation, but do express concerns with inconvenience due to distance/geography; proprietary technologies/confidentiality; and appear to have a low to moderate interest in a formal or ongoing off-site physical research presence in a hub-type facility.
- *Minimize extensive up-front investment in shared-use robotics equipment and hardware, but devote space and capital to future build-out and gradual purchases over time.* Initial investments by the hub in expensive equipment for a robotics lab or a "playground" with equipment and hardware for demonstration or shared research purposes should be minimal, although lab spaces with room to grow may be called for. Larger companies (robotics and automation users) in Hampton Roads often have their own specialized needs for robotics hardware performance and use and may find it most valuable to see the hardware demonstrated in dynamic environments (ships, docks, warehouses, etc.). Start-ups or new product innovations in a hub may have their own specialized needs and it may be best to only minimally equip a lab and "playground" space until precise needs are better identified.

These and other selected findings from our situational assessments, in addition to our extensive engagement with a local project steering team, informed our recommendations for exploring the development of an Intelligent Robotics Innovation Hub, with a more precise and branded name and identity to be determined. Regardless of the final name, we propose a hub with a sector-focus on intelligent robotics, along with a tripartite mission centered on:

- **Attracting robotics-focused newer ventures** through an innovation challenge that is national in scope, comprehensive in design, and residency-based.
- **Retaining and attracting technology talent** through a multi-faceted internship program, connected to the in-residence challenge-winning ventures at the Hub. The program would include a summer internship component that attracts college student interns from across Virginia and beyond for summer robotics internships in

Hampton Roads. There would also be an academic year internship program primarily drawing from the region's pool of undergraduates at area higher education institutions, including community colleges.

- **Engaging with and connecting with larger Hampton Roads companies and entities that are robotics users in advanced manufacturing, logistics, and related** sectors. One aspect of this engagement would entail working with individual companies or small groups of companies in identifying and addressing industry or company-specific problems. The Hub might provide technical assistance to companies and help encourage new innovations by shaping a specific innovation challenge around seeking product and venture ideas for intelligent robotics-related solutions. Individual companies might sponsor a specific challenge, help select one or more challenge "winners" and partner in the innovation development.

This report also contains **a roadmap and implementation plan** that includes a tentative program design model, a staffing plan, a description of the space needs of a hub facility, an operating and start-up budget and a series of recommended implementation steps.

Section 1: Global, National, and State Robotics Industry Market and Situational Assessment

Size of Robotics Industry

Robotics products are typically divided into two main sectors: Industrial and Service. Appendices A and B provide a detailed breakdown of market segments and a description of the evolution of the robotics sector over time.

The Industrial Robotics Sector has been growing since the 1960's when automotive OEMs introduced robots into their weld shops. A second growth spurt started in about 2000 when dramatic developments in technology were introduced to industrial applications in response to rising labor costs and increasing labor turnover and shortages. In general, costs to adopt automation have decreased and the competitive environment and increasingly interconnected systems has made automation more of an imperative. Based on an extensive review of market studies, a best estimate on the size of the global Industrial Robotics Market is that it will reach $75 - $80 billion by 2024, with a Compound Annual Growth Rate (CAGR) of 9-10% over the period to 2024.

Service Robots, for professional or personal use, are mobile robots designed to assist or service humans in a wide variety of tasks. The Professional Service Robotics Sector comprises four major market segments: Logistics, Healthcare/Medical, Military & Defense, and Field or Agriculture & Forestry Robots. The 2025 global professional service robotics sector size will be taken as the sum of segment projections shown in Appendix A, or $71.8 billion:

Professional Service Robotics Segments	Projected 2025 Market Size, $ Billion
Logistics	$12.4
Healthcare/Medical	23.8
Military & Defense	23.2
Field: Agriculture & Forestry	12.4
Total	***$71.8***

Market studies for the global Personal & Domestic Service Robotics segment were used to estimate the 2025 market size as $26 billion:

Personal & Domestic Service Robotics Segments	Projected 2025 Market Size, $ Billion
Cleaning Robots	$6.3
Rehabilitative & Assistive Robots	13.7
Entertainment Robots	5.95
Total	***$25.95***

In the 21st century, the introduction of cognitive computing into the robotics industry – generally called Industry 4.0 Collaboration – has included adding artificial intelligence, machine learning and automated reasoning capabilities as well as advanced sensory and perception capabilities to robots. The industry is also currently moving to next generation robots that can sense and think and, in response, act; i.e., they can and do act autonomously. The trend continues towards collaborative robots or cobots as well as toward more flexible or soft robots. The North American market for collaborative robots alone is projected to reach $2.09 billion by 2026 while the global 2026 market is projected to reach $7.97 billion.

In general, we employ the term intelligent robotics to encompass cobots as well as the increasing portion of the total robotics market that employs four design principles integral to Industry 4.0:

1. Interconnection: the ability of machines, devices, sensors, and people to connect and communicate with each other
2. Information transparency: provide operators with comprehensive information to make decisions
3. Technical assistance: the technology facility of systems assisting humans in decision making and problem solving; and the ability to help humans with difficult and unsafe tasks
4. Decentralized decisions: the ability of cyber physical systems to make decisions on their own and to perform their tasks as autonomously as possible

The Role of Hubs in Robotics Sector: Past and Present

The first robotics hub was Willow Garage. Founded in 2006 by an early Google employee, the Garage was a robotics research lab located in Menlo Park. By the time it closed in 2014, it had launched a revolution (one that cost an estimated $80M). Garage employees and fellows designed and built their own personal robot and gave 11 models away to research institutions around the world. They also launched the "Robotics Operating System" (ROS), a massive open-source project with modules for the most common robotics use cases, allowing developers to spend less time on the basics of motion, sensing, and communication and more on the problem they wanted to solve. And, perhaps most importantly, they trained over 200 interns—the best and brightest in engineering departments around the world—to use ROS in their own labs and commercial projects.

Roboticists seem to have a reverence for Willow Garage, but also note that the industry has changed substantially since then. One engineer we spoke with likened the current period to the transition between mainframes and PCs, when computers went from being huge machines that only experts could program to small ones that anyone could. The factors enabling this transition include the rise of open-source robotics projects like ROS, the falling cost of hardware, and the ability to realistically simulate robots in virtual space. This latter achievement, an offshoot of ROS called Gazebo, enables roboticists today to design and develop software remotely for hardware they never see in person.

Thus, one interviewee could write "mechanical engineering nowadays means software development for machine builders" and another "locality doesn't matter in robotics right now. All the challenges are in software." These software problems touch entirely new domains like computer vision and robot collaboration with both humans and other robots.

Today's cutting-edge innovation hubs, labs, and accelerators focus most centrally on products incorporating Industry 4.0 technologies; such products are radical innovations versus the incremental developments typically undertaken by existing companies. The focus on radical innovation focuses a hub on the expanding technology market segments. The following table compares incremental innovations to radical innovations:

Characteristic	Incremental Innovation: Developing New Products Based on Existing Products & Technologies	Radical Innovation: Developing Completely New Products Based on New Technologies
Strategic Intent	Cost, Profit	Innovation, Growth
Critical Tasks	Operations, Efficiency	Adaptability, New Products
Competencies	Operational	Entrepreneurial
Structure	Formal, Mechanistic	Adaptive, Loose
Control – Rewards	Margins, Productivity	Milestones, Growth
Culture	Efficiency, Low Risk, Quality	Risk Taking, Flexibility, Experimentation
Leadership Role	Authoritative, Top Down	Visionary, Involved

A hub that includes support for radical innovation in intelligent robotics would focus on sensing – thinking – acting intelligent robots that:

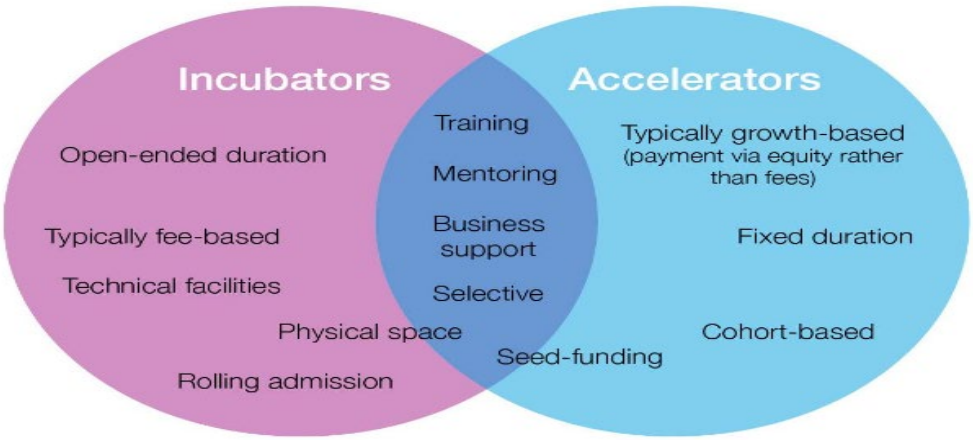
- Employ some level of artificial intelligence and control algorithms
- Include advanced sensory and perception capabilities
- Include process capability/machine learning
- Can interact with other robots

In addition to a focus on radical innovation, hubs usually focus on promoting open versus closed innovation between venture companies. This is at the heart of the definition of an innovation hub:

Open vs. Closed Innovation

OPEN INNOVATION	CLOSED INNOVATION
▪ Not all of the smart people work for "us"; we must find & tap into knowledge & expertise of others	▪ The smart people in our field work for us
▪ External R&D can create significant value for "us"	▪ To profit from R&D we must discover, develop and employ it ourselves
▪ We don't have to originate the research to profit from it	▪ If we discover it ourselves, we will get it to the market first
▪ Building a better business model is better than getting to market first	▪ If we are the first to commercialize an innovation, we will win
▪ We will win if we make the best use of internal & external ideas	▪ If we create the most & best ideas in the industry, we will win
▪ We should profit from others' using our IP AND us using others' IP	▪ We should control our IP so that our competitors don't profit for our ideas

In this report, we focus on the prospects for a hub that is focused more on radical than incremental innovation, more on open than closed innovation, and more on acceleration activities than incubation activities. Thus, an Innovation Hub is not synonymous with an incubator or an accelerator, but may share some areas of overlap as seen in the diagram below.



Company Interviews and Surveys (National and State - non-local)

To better understand how a robotics-focused innovation hub could support and assist the formation and growth of small to mid-sized robotics companies, the research team contacted 36 such robotics companies directly and posted requests for interviews on ROS Discourse (an online robotics software community) and a survey on Reddit. We had most success with direct contact and ROS outreach. Ultimately, we interviewed 6 executives at robotics startups and SMBs across the country and received another 6 complete written replies for a total of 12 responses.

Two of these were from companies headquartered in Virginia. Most participating companies have less than 50 employees. They produce robotics hardware and software with commercial and industrial applications, though there are more software responses than hardware. A full list of participants, including names, titles, companies, and locations, is appended. All participants were asked a series of common questions, also appended. Interviewees were asked additional questions appropriate to their background.

Key Takeaways

- The vast majority of robotics startups we spoke with expressed their greatest growth challenges and needs as: access to capital, access to talent and expertise, access to customers, and (a distant 4th) access to information and networking.

- The single greatest reported need or challenge was access to capital.
    - "The biggest problem for start-ups NOT in Silicon Valley or New York City or Boston is access to capital. Hands down. Your best bet is to give them a free apartment to crash at in Silicon Valley, a few plane tickets, and a bunch of introductions. Uniformly the investors outside of the big cities are slow to move and have horrible terms."
- A close second in terms of challenge or need is talent.
    - "The second biggest problem is access to people. This means qualified contractors, engineers, and back office staff, and the working capital to pay them. To that end having a shared, vetted accountant / electrical engineer / contract manufacturer are probably 10x more useful than a 3D printer."
    - "The people are what you need" said another interviewee. "Money and talent are everything."
- Access to clients and customers and network relationships was another key need.
    - "The third biggest problem is access to PAYING CUSTOMERS. Most VCs won't give you a term sheet unless you have a paid pilot or a LOI for a paid pilot. VCs don't care how cool / technologically innovative your product is; they care if it makes money."
    - "Putting together a portfolio of Fortune 500 companies with a list of their biggest problems that they would pay for, along with a point of contact, would be very helpful."

- In priority order, startup executives report choosing their primary locations for access to the following: capital, talent, clients, quality of life, and suppliers.
- Respondents were nearly unanimous in discounting the importance of space or of a central physical location to their business, voicing high satisfaction with distributed teams and work-from-home cultures.
    - "Office space is fungible" one said, and another expressed skepticism that "the benefits of putting people in a room together consistently overcomes costs of getting/keeping them there." The new problems are not about physical access to buildings and machines, but social access to people and funds.
    - One of the respondents was a veteran of 5 startups (3 in robotics), "I think there is a tiny bit of merit to having an incubator, but less than you would think. To be really upfront, you and every other university / economic development corporation has had this idea and they are uniformly horrible at it. Generally, you'll get more leverage out of solving the *social*/"economic" problems of starting a company than solving the *physical* problems. If I had a dollar for the number of times I have heard "we'll put a 3D printer, a laser cutter, and some power tools in the room and the startups will just emerge magically," I could buy a really nice dinner."
- When asked "What, if anything, might a hub provide to your business?", the interviewees provided a long list of ideas/requests, organized loosely here as physical amenities, member services, and public services:

Amenities	Member Services	Public Services
- A private hardware lab - Fast internet - Parking for big trailers - Tracks/space to test robots, indoors and outdoors - CAD and 3D printing for parts prototyping (and knowledgeable staff to run them) - Soldering stations - Parts storage, warehousing - Big monitors and lots of terminals	- Shared specialists: accountant, lawyer, electrical engineer, contract manufacturer, industrial designer, product manager, HB-1 visa assistance - A portfolio of Fortune 500 companies with a list of their biggest problems that they would pay for, along with a point of contact - Trips to and contacts in the major hubs (Silicon Valley, Boston, Austin)	- Collaboration/networking opportunities - Talent pipeline, graduate student interns - Updates from academics on the latest research findings

University and Accelerator Interviews and Program Review

To learn more about the existing innovation hubs and about the ways that university-focused robotics programs have supported innovation and entrepreneurship activity, we conducted interviews and background research. We contacted a number of academic institutions and robotics programs in the United States, including those at four-year institutions and community colleges. We also interviewed and conducted background research on a selected number of incubators and accelerators. There is a complete list of our respondents and our interview questions in the appendices.

Academic Institutions

Faculty reported that students who engaged in a robotics related program or lab during their studies often went on to work in the robotics field or to a graduate program. However, only a small portion of these students that studied in robotics created their own start-up. Still, that smaller percentage may be meaningful and could be higher for graduate degree completers. For instance, one department head estimated that, of their master's graduates with American citizenship, approximately 50% work for either the government or private sector, 40% continue their education or work in academia, and 10% create their own start-ups.

The extent to which institutions supported students in creating new ventures was largely dependent on the institution. Most of the institutions with well-known and established robotics programs had many services to aid and guide students with creating new ventures whether it be connecting them with appropriate contacts and funding opportunities or helping them navigate the barriers that often prevent students from creating start-ups. Additionally, these larger, well-established institutions in the robotics field appear to take a more market or industry centered approach where they have multiple labs and programs that offer students the opportunity to work on robotics related to a certain industry.

Multiple interviewees attributed the low number of student start-ups to barriers that included awareness, perception, time, and funding. One interviewee described "time and money" as the biggest barriers to students creating their own start-up and many other interviewees echoed this sentiment. Students have concerns over the amount of money it takes to create a new venture and finishing their degree if they start a new venture. One interviewee also added that students may be concerned about the stability of a start-up in an industry with many larger players. Many interviewees indicated that students and graduates often look for a safe, steady employment at an established and often well-known company, organization, and or institution. The popular locations that interviewees said students gravitate towards for work after graduation are cities with well-established robotics industries or needs that were either close to the academic institution or extremely well-known for robotics. This included places like Boston, Pittsburgh, and San Francisco.

Industry relationships are very important to universities and to student learning. Faculty engage with external companies to help students with internships, research, and funding opportunities. When asked about the most useful and needed function for a robotics-focused innovation hub, professors cited:

- the provision of internship opportunities and programs for students,
- funding and research opportunities for teachers and students, and
- maker spaces that are well equipped with machinery that students and faculty can use for learning, testing, and constructing robots.

Faculty also responded that an innovation hub would need to have a unique and/or cutting-edge draw or "hook" to entice students, entrepreneurs, or companies to participate. Respondents also emphasized:

- designing the space for collaboration and exploration,
- having an interdisciplinary setting,
- having strong public and private sector partnerships,
- providing access to capital, and
- the need for a point person with many contacts and connections in the area and in the industry.

One respondent suggested the need for critical mass in the local area meaning a strong local student pipeline that would easily contribute to building the robotics industry. A different interviewee suggested that having an anchor university would be a critical component to the success of a robotics center. One interviewee predicted that Covid-19 will increase demand for robotics, specifically the manufacturing and automations sectors.

Incubators and Accelerators

We spoke with incubators and accelerators outside the region including Lighthouse Labs and program participants and the NexPCB Accelerator. We then conducted background research on accelerators and innovation hubs in general and some specific hubs such as Mass Robotics. We connected with regional players including 757 Accelerate and the ODU Innovation Center but included this information in the "Regional Situational Analysis" section of the report. We also looked at a few internal company innovation hubs such as Honeywell Robotics.

Many incubators and accelerators we spoke with had around 10 new ventures in their programs. Programs and services vary depending on the incubator or accelerator and its purpose. Some incubators and accelerators are focused on product and idea development while other incubators and accelerators focus on manufacturing and prototyping. All accelerators and incubators seem to have an online application process. Some interviewees recommended having an interview process for top applicants before admission into a program. Some suggest taking applicant referrals from mentors and program alumni.

One interviewee discussed the timing aspect of going into the right accelerator at the right time for a new venture. Additionally, one of the accelerators that was researched advertised themselves as "stage agnostic," which means that they are accommodating to multiple stages in a new venture development. This indicates that an innovation hub may need to consider whether it will be conducive to multiple stages of new venture and company development, or if it needs to target a particular stage of new venture development.

Many incubators and accelerators that focus on product and idea development offer services such as "mentorship, programming, in-kind services, and access to a workspace during program." Overall, it seems that most of the product and idea development incubators and accelerators focus on helping new ventures receive funding, network in the industry, and test their concepts to ensure they work and are market viable. Some accelerators require equity but many of the accelerators do not. One respondent emphasized that a hub or accelerator should strike a balance between higher education involvement and private industry linkages.

Most of the accelerators and incubators that were researched do not appear to be restricted to selecting projects from a single industry. However, these seemed mostly to be well-established accelerators and incubators. It was indicated in an interview, that accommodating a specific market or industry may be most practical and beneficial for a new innovation center. This focus on a specific industry or market would allow for an innovation hub to be specialized and appropriately equipped to attract new ventures in a specific industry. Additionally, this specialized approach would support the creation of a hook for an innovation hub.

Some of the robotics-focused programs we explored were very useful, though not directly comparable or easily replicable models. Most prominent of these is Mass Robotics. This hub is structured as a standalone nonprofit, with a focus on serving as an innovation hub for robotics and smart connected devices in the Boston region. Mass Robotics was established in 2015 and opened its initial space in February of 2017. Later, they constructed a 25,000 sq. ft addition. The organization represents a true public-private partnership. A $2.5 million state grant assisted in funding more than half the design and construction investment in the facility addition. The balance of the funding was raised from more than 35 corporate partners with the largest contributions from Analog Devices, Amazon Robotics, iRobot, Harmonic Drive, Mitsubishi Electric, MITRE, General Motors and Cowens.

The innovation hub supports "more than 70 companies and more than 200 employees". The facility includes office space, lab space, prototyping equipment., and shared workspaces, kitchen facilities, meeting rooms and a large event space. The organization employs an "escalator" model helping startups to get established and to grow. The organization is multi-faceted, delivering STEM learning and supporting STEM learning and advocacy for robotics and tech sector companies. Mass Robotics is somewhat unique in its placement within a very robust existing robotics ecosystem in Massachusetts. The state has more than 350 companies producing and utilizing robotics

applications serving 11 different markets as well as a critical mass of proximately located world-class universities with more than 35 robotics R&D programs across 18 institutions.

Honeywell Robotics, in Pittsburgh, is another interesting model. This is a private sector venture, though Honeywell researchers are also collaborating with AI researchers at Carnegie Mellon University's National Robotics Engineering Center to develop new and advanced robotics technologies for distribution centers. Honeywell has also created a ventures investment fund to strategically support robotics companies. This example is different in kind than a pure accelerator or incubator, but similar in some respects. It is an open question as to whether industry-supported innovation hubs are actually effective. Some recent research has pointed out that most hubs do not appear to increase company innovation.[i]

In Virginia, Lighthouse Labs, based in Richmond, has become a premier accelerator program for high-growth potential ventures regardless of industry or product-type. Their model includes a direct non-equity investment (@ $20,000) in participant startups. They provide their companies with a focused 3-month experience designed to help founders develop their market and gain the help of mentors, industry experts, investors, support services, lean startup education, and office space.

[i] See, for instance, https://www.capgemini.com/news/despite-mass-investment-innovation-centers-are-not-making-organizations-more-innovative/

Section 2: Regional Robotics Industry and Innovation Ecosystem Situational Assessment

GO Virginia Region 5 is comprised of Hampton Roads and surrounding localities. They include the cities of Chesapeake, Franklin, Hampton, Newport News, Norfolk, Poquoson, Portsmouth, Suffolk, Virginia Beach, and Williamsburg; and the counties of Accomack, Isle of Wight, James City, Northampton, Southampton, and York. This region has a population of approximately 1.7 million, 786 thousand of whom are employed. Priority industry clusters for this region include:

- Advanced Manufacturing
- Cybersecurity/Data Analytics/Model-Sim
- Logistics/Port Operations/Warehousing
- Shipbuilding and Repair
- Water Technologies
- Unmanned Systems and Aerospace

All of these industries have a growing dependence on robotics technology as illustrated in the market analysis found in the appendices. Thus, while there are only two "robotics" companies in the region, many of the larger companies operating in the region in these industries and others (e.g. healthcare) rely on robotics technology and the competitive advantage they ensure. For a list of companies that heavily rely on robotics in and around this region, see Appendix C. For a list of support resources for these companies in Virginia, see Appendix D.

The research team interviewed nine regional companies and six regional ecosystem resource providers to assess the strengths and challenges present in the region when considering opportunities for a robotics innovation hub. A list of entities that participated in the regional interviews is provided below for reference. The following section is a summary of those interviews.

Regional Interviews	
Robotics Using Companies	
Canon Virginia	Port of Virginia
Eastern Virginia Medical School	Swiss Log
Huntington Ingalls (Newport News Shipbuilding & Hydroid)	VRC Metal
NASA	Xperience Robotics
Innovation Ecosystem Stakeholders	
757 Collab (757 Angels & 757 Accelerate)	Hampton Roads Innovation Collaborative
Old Dominion University - Institute for Innovation & Entrepreneurship	Norfolk Innovation Corridor/Greater Norfolk Corporation
Old Dominion University – Engineering Department	Tech Center Research Park

Regional Description

Opinions of GO Virginia Region 5 and its suitability for a regional robotics hub vary. One perspective is the region is primed for growth and business/talent attraction. Interviewees described the region's good quality of life for residents and businesses**.** The region is affordable, has access to recreational amenities such as the beach, and is proximate to several good universities. Moreover, with its diversifying economy, the region has many options with regard to how it grows. Multiple respondents noted how far the region had come related to supporting startups and pointed out the national attention these efforts had garnered.

Others question the region's competitiveness and its support of businesses. According to one respondent, "We're dominated by the military. Healthcare is expensive because of retirees and military… Air service is horrible. Our customers are elsewhere because of horrible air service." While the economy is diversifying, a few interviewees noted that there are no obvious emerging clusters in the region. They argued that the current regional pipeline for workers and industry growth is too small, and a robotics hub would need a good "hook" or regional differentiator to draw entrepreneurs and businesses to the region.

Regional Strengths

Entrepreneurial and business assets are growing in the region. Most regional interviewees observed the deliberate focus on ecosystem development and the good strides that the region has made in the last several years to develop the regional innovation ecosystem. Today, there are more mentors, better access to funding, plenty of space for start-ups and more support resources overall compared to just a few years ago. Interviewees cited key resource organizations such as 757 Collab (757 Angels & 757 Accelerate), Old Dominion University and Tech Center to name just a few. The 757 Accelerator program and 757 Angels group have been particularly successful as ecosystem leaders. The accelerator program has had specific experience working with regional robotics startups and 757 Angels has been a success with over 150 members for both deal-making and education. Several interviewees suggested the combined efforts of this group (757 Collab) would make for a strong prospective partner. 757 Collab and other similar regional organizations could provide expertise, existing services, infrastructure, and combined funding to establish a strong foundation for a prospective robotics hub. A 2021 assessment report conducted by TechStars to evaluate entrepreneurship in the Hampton Roads region noted four advantages the region has as it relates to why technology entrepreneurs are showing increased evidence of success: 1. Quality of life, 2. Positive momentum (startup support), 3. Quality of talent, and 4. Low cost of doing business. While our qualitative data doesn't support quality of talent as a strength, the other three advantages tracked alongside with data collected from interviewees for the robotics innovation hub study.

Businesses in the region have a growing demand for robotics. GO Virginia Region 5 has an assortment of corporate, military and other government entities that benefit from robotics technology and will continue to do so as a means of gaining and maintaining a competitive advantage in the global market. Respondents offered example of supportive robotics businesses and

industries such as the port, augmented reality and virtual reality, logistics, unmanned systems, and healthcare. Canon, for example, claims to have more robots that any other company on the East Coast. Other businesses and organizations cited by interviewees were Huntington Ingalls, NASA and the Port of Virginia. Many of these companies have shared research and robotics interests. Old Dominion University was also noted as playing a connecting role between industry, research and talent from respondents. There was a strong interest from multiple individuals affiliated with Old Dominion University for the university to set into a leadership role in supporting the development of a robotics hub as there is regional and state-wide demand. A list of Virginia companies affiliated with robotics technology is shown in Appendix C.

Many of these larger companies set aside funding for internal research and development work. For instance, NASA funded the Langley autonomous incubator in the region for three years, focusing on full stack integration and cross disciplinary research. Huntington Ingalls' R&D has resulted in spin-offs like Dogfish Labs. Canon is in the process of building out their own "robotics innovation hub" of sorts to be on their campus for testing, R&D and to support general innovation and learning.

There is a trend toward open innovation nationally, which may affect business collaboration within the region. According to some interviewees, corporations are focusing on development investments more than basic research today. They are leveraging open, collaborative innovation to improve the efficiency and productivity of their companies. Several interviewees agreed that drawing groups of likeminded people and groups together in the same space could generate a significant value added for the participants and the region. Most of the robotics using companies interviewed mentioned the non-existent network among other similar companies in the Hampton Roads region. These respondents genuinely seemed eager and hungry to want to establish connections and networks with other companies.

Regional Challenges

The companies that work with robotics need talent. Almost all interview respondents cited a workforce and talent gap in the region, particularly for robotics related jobs such as engineers, computer scientists, and technologists. Although some interviewees noted that the pool of talent in the region possess advanced skills, most of that talent leaves the region. Regional companies described a need for a robotics space that could be used to upskill workers, i.e. a place where engineers and technologists alike could get extra training, crash-courses, or certificates on new robotics software and tools.

The region's geography hinders regional collaboration. The region is large and spread out, making the location of any one physical hub difficult. For instance, a hub in Norfolk would not be used as often or wouldn't be as accessible to companies in Hampton or Newport News. Due in part to the disjointed geography of the region, many of the regional resource providers are not collaborative. In fact, many support organizations are actually competitive, which prevents a more cohesive and supportive ecosystem for businesses. The 2021 TechStars report also listed the lack of

regional collaboration as one of the systemic problems within Hampton Roads. "The lack of collaboration among entities based in different cities and counties. This issue is also a challenge within the regional entrepreneurship community, as there is no umbrella organization working to coordinate local entrepreneurship initiatives. As a result, there are very few multi-organization initiatives or even shared goals among entrepreneurship organizations in the region, and few funders require that local support programs build on the work of other organizations. The need for collaboration was among the most commonly mentioned challenges among economic development officials and other local leaders." This provides an opportunity for the robotics innovation hub to address the collaboration challenges and leverage other regional support organizations to ensure success.

While the regional innovation ecosystem has shown significant growth in the past few years, more funding and a greater cluster of robotics-related businesses are needed. Robotics is a hardware-intensive domain that can require a lot of capital. Pre-seed, SBIR and bootstrap funding is lacking in the region, as is venture capital and other funding for later stages of business growth. One challenge to funding is also the limited concentration of robotics related businesses in the region. According to one interviewee, of the 620 companies across the state in the 757 Angel database, only 9 are in robotics/automation and only one of those 9 is in Hampton Roads. Moreover, few viable businesses are currently spinning out of Virginia universities. Several interviewees questioned the name and scope of a "robotics" hub, wondering what businesses and industries that would include and draw to the hub considering the dearth of actual "robotics" businesses.

Companies in the Hampton Roads region may not take advantage of the robotics hub resources due to little time and willingness to collaborate. Many companies in the region have had to streamline to become more cost competitive, and now employees have very little time to do anything else but the tasks related to their job. They may have little motivation to visit the hub unless it shows some particular value to regional companies or their employees. Depending on the company culture, it may be more difficult for some company employees to participate. Proprietary technologies may limit collaboration potential. Some interviewees described their past experiences collaborating with other regional companies, saying their partners often hesitated to share information and struggled to "play together well." In other cases, some companies had mixed success working with area universities on projects and proposals, which soured any appetite to collaborate again.

Regional Opportunities

The most cited opportunities for a robotics hub were 1) building and attracting talent for businesses in the area, 2) building a larger pipeline and cluster of businesses in the region, and 3) encouraging more collaboration and learning among businesses and service providers that would ultimate strengthen the larger regional economy. Overall, those interviewed seemed less interested in a physical hub than in the services and programming that a hub could provide such as talent development and attraction, business development, and networking opportunities.

Most interviews emphasized an "applied" focus for the hub. Rather than a sanitized lab, research focused initiatives or office space, interviewees expressed the desire for a dynamic environment that could generate solutions for company or industry-specific problems. One interviewee described a living lab, or a place to show how to apply robotics and automated process solutions. As part of this lab, companies could see new technologies. Other interviewees agreed that offering space for vendors to show their latest technology and engineers to experience that technology would be helpful. Still another interviewee described the opportunity to develop a giant makerspace for robotics such as The Foundry (UnderArmor) concept in Baltimore. Those interviewed tended to warn against hubs that mimicked CCAM or Booz-Allen Innovation in DC, both of which became more about meetings and "big ideas" rather than development and application of new technology.

To be successful, interviewees agreed that the hub would need multiple businesses supporting the hub as anchors as well as at least one key organization driving the hub programming. One interview respondent asked, "Who is the credible seed that brings this all together?" Similarly, most interviewees suggested a mix of strong collaborating entities. First, interviewees suggested that at least one service provider, possibly in collaboration with a university, would be essential to the programming of a hub. Second, they observed that it would be critical to have some of the larger companies regularly collaborating and supporting the hub operations. If the hub were to have a physical space, many agreed that two or more established regional companies located in a facility, for research and development purposes off their main regional campus, would help in supporting the hub's success.

Finding companies that can act as "competimates", or friendly competitors willing to learn with each other, is essential. Some companies expressed possible concern with losing talent/talent poaching if they were to participate in a collaborative hub. Before initiating the robotics hub project, most interviewees highlighted the need for companies to promise support on multiple levels including financial and collaborative support. Many noted that one of the robotics companies based in Hampton Roads, SVT Robotics, would not be able to provide sufficient company support for a regional robotics hub.

Section 3: Proposed Focus Areas and Concept Summary for a Robotics Innovation Hub

Throughout this study, we employed the lens of customer discovery. The process involves getting to know (verify/not verify) whether a proposed solution can help solve a potential customer's problem; i.e., there is a product-market fit between the customer's problem and a proposed solution. The proposed solution was a robotics-focused innovation hub. Our market study, and discovery-focused conversations with companies, universities, and others helped us better understand the problems faced by smaller robotics companies and start-ups and to better gauge and assess possible foci for a robotics innovation hub in Hampton Roads.

At regular intervals, we reviewed and discussed our findings with our Virginia Tech project team as well as with the regional advisory group. Those discussions were robust and helped identify knowledge gaps and additional questions. We often sought new respondents or followed up as needed to explore these gaps. In this section, we offer our proposed focus area and general concept plan for a robotics hub to be located in the Hampton Roads region. The next section provides more details for a proposed roadmap and implementation. Our proposal is derived from our key findings and their related implications, assumptions, drawing from:

- The market study
- Interviews and questionnaires with small robotics companies around the United States
- Interviews and questionnaires with universities with robotics-related programs on the East Coast
- Interviews, questionnaires, and document review on incubators/accelerators, including those with a robotics focus
- Interviews with regional innovation ecosystem partners in Hampton Roads
- Interviews with regional companies that have a robotics relationship or are robotics users

Based on the findings and implications from our research, and in consultation with the local study team, we developed a plan for a proposed hub, that in our view would be both viable and additive to the region's innovation ecosystem, while also engaging and supporting existing industry and contributing to talent attraction and retention. We find that there appears to be a market opportunity and a fit in the regional innovation ecosystem for a robotics innovation hub developed with the following considerations in mind:

- A focus on "*intelligent robotics*", by which we mean the design, construction, and programming of physical robots (and their associated and connected cyber-physical systems) that employ advanced sensory, perception, or process capabilities or employ some level of machine learning or artificial intelligence. Intelligent robotics tend to exhibit radical

innovation (the development of new products based on new technologies) as opposed to incremental innovations (developing new products based on existing technologies). Intelligent robotics includes those companies and products at the intersection of AI and robotics, as well as much of the activity around collaborative robots.

- A hub should directly address the most significant challenge in growing a stronger robotics sector in Hampton Roads: the *very low number of existing or emerging in-region robotics-related start-ups and younger ventures*. SVT Robotics is a notable exception.
- A hub should also directly address the *second most significant challenge: technology talent attraction and retention*. The region has self-identified a need to increase its ability to attract and retain technology talent. Along with capital, talent is the primary need for the small robotics companies in Virginia and nationally with which we spoke. Almost all of our interview respondents within Hampton Roads, cited a workforce and talent gap in the region, particularly for robotics related jobs such as engineers, computer scientists, and technologists.
- A *hub space alone is insufficient* and unlikely to significantly add value to the regional ecosystem or address the two challenges listed above. The companies we spoke with varied in size and stage but seemed to agree that a physical space by itself was less valuable to start-ups than a more concerted and comprehensive range of assistance to help founders with the social and economic aspects including legal, talent, technical, collaborative, and leadership aspects.
- To be clear, *a robotics innovation hub must be intentionally designed and not simply about space or the physical infrastructure*. We understand and emphasize here that any new hub space must be accompanied by an intentionally developed, highly customized, tightly focused, and well-implemented series of programmatic and assistance activities and resources.
- In addition, *a new innovation hub in Hampton Roads should be non-duplicative and non-competitive* with the work of other regional ecosystem players. A hub that is broader than robotics or that provides general incubation or acceleration for a wide range of ventures and start-ups would likely be duplicative of existing spaces and services. The innovation ecosystem in Hampton Roads is in an active state of expansion (757 Collab, Norfolk Innovation Corridor, Tech Center, etc.) with many existing and emerging resources such as space and expertise. The hub should be structured to complement and connect with other regional programs and should not function as competition in the ecosystem.
- A new innovation hub in Hampton Roads should be focused on *a clear niche related to intelligent robotics*. To re-emphasize what we mean by this focus, intelligent robotics products and ventures sit at the intersection of the physical (devices or hardware); the cyber (automated, networked, or virtual); and the intelligent (employing advanced sensory, perception, or process capabilities or employing some level of machine learning or artificial intelligence). Moreover, an intelligent robotics product or venture would more often represent radical innovation as opposed to more incremental innovation.
- A hub could play a valuable role in *connecting with and advancing networking opportunities between robotics-related research and development companies, engineers, and technologists* in the region, many of

whom work with larger corporations in a complicated environment with proprietary, security, and competitive barriers to collaboration. Larger regional entities that are robotics users (such as Huntington Ingalls, Stihl, and the Port of Virginia) are interested in opportunities to connect with each other, to learn about new technologies, and to solve shared problems related to automation, but do express concerns with inconvenience due to distance/geography; proprietary technologies/confidentiality; and appear to have a low to moderate interest in a formal or ongoing off-site physical research presence in a hub-type facility.

- *Minimize extensive up-front investment in shared-use robotics equipment and hardware, but devote space and capital to future build-out and gradual purchases over time.* Initial investments by the hub in expensive equipment for a robotics lab or a "playground" with equipment and hardware for demonstration or shared research purposes should be minimal, although lab spaces with room to grow may be called for. Larger companies (robotics and automation users) in Hampton Roads often have their own specialized needs for robotics hardware performance and use and may find it most valuable to see the hardware demonstrated in dynamic environments (ships, docks, warehouses, etc.). Start-ups or new product innovations in a hub may have their own specialized needs and it may be best to only minimally equip a lab and "playground" space until precise needs are better identified.

These and other selected findings from our situational assessments, in addition to our extensive engagement with a local project steering team, informed our recommendations for exploring the development of an Intelligent Robotics Innovation Hub, with a more precise and branded name and identity to be determined. Regardless of the final name, we propose a hub with a sector-focus on intelligent robotics, along with a tripartite mission centered on:

- **Attracting robotics-focused newer ventures** through an innovation challenge that is national in scope, comprehensive in design, and residency-based.
- **Retaining and attracting technology talent** through a multi-faceted internship program, connected to the in-residence challenge-winning ventures at the Hub. The program would include a summer internship component that attracts college student interns from across Virginia and beyond for summer robotics internships in Hampton Roads. There would also be an academic year internship program primarily drawing from the region's pool of undergraduates at area higher education institutions, including community colleges.
- **Engaging with and connecting with larger Hampton Roads companies and entities that are robotics users in advanced manufacturing, logistics, and related sectors**. One aspect of this engagement would entail working with individual companies or small groups of companies in identifying and addressing industry or company-specific problems. The Hub might provide technical assistance to companies and help encourage new innovations by shaping a specific innovation challenge around seeking product and venture ideas for intelligent robotics-related solutions. Individual companies might sponsor a specific challenge,

help select one or more challenge "winners" and partner in the innovation development.

The most prominent activity focus for the Intelligent Robotics Innovation Hub would be to draw new ventures focused on developing intelligent robotics products to Hampton Roads through a competition program. The Hub would house venture creators, connect them to local talent and industry, and help them develop their competition winning concept into a new innovation.

The program has been designed to address most of the challenges that new robotics ventures experience in the initial stages of their development that were identified through the project's Customer Discovery activity:

1. Access to capital is their #1 issue
2. Access to a trained workforce (& expertise) is essential and is almost as critical as their capital needs
3. Getting the attention of potential customers is among their top 3 issues
4. Focus of today's robotics ventures is software and the associated technologies of artificial intelligence, machine learning, and cognitive computing, not hardware
5. Because of the extensive technologies involved in developing intelligent robotics systems, a collaborative environment is needed for fast innovation
6. Teams can work remotely on developing concepts but need demonstration space to create commercially acceptable products

To put the concept simply, an innovation challenge competition provides the "hook" and a clear and compelling focus for a hub. The substance of the hub extends beyond and between the competitions to encompass a comprehensive and integrated robotics-focused technology talent attraction, retention and innovation development initiative. This initiative includes:

- an acceleration type program bringing competition winners to the Hub from across the state and nation for a focused residency period of concentrated support and assistance;
- internship programs bringing college interns from across the state and nation to Hampton Roads for a robotics and innovation focused summer internship, and also connecting area college students to the Hub and its ventures through an academic year program;
- industry engagement through networking activities, problem-focused challenge competitions, sponsorships, and talent connectivity.

Each competition might focus on a specific industry-defined problem or challenge shared by an industry segment or sub-segment. Marketing Maps for Robotics market segments would serve as a starting point for identifying companies that could propose and support radical innovation concepts needed within their industry. Companies in each segment or sub-segment of the Robotics market would be expected to propose 2 to 3 concepts needing development to ensure continued advancement of their market.

Competitions might also be organized around specific thematics such as resiliency or microrobotics. Once such a program is established, our proposed concept anticipates 3 competitions each year at the innovation hub, with funding coming from private sponsors and companies that identified the market need. Funding requirements are reviewed below. Note that concepts being funded must not be direct competitors since one of the foundations of the innovation hub is open collaboration among the ventures at the hub.

The proposed prize for each competition winner would be to support the winning team in the development of their winning concept into a commercially viable product and start development of a marketing activity. All teams submitting responses to the competitions must be able to work in the United States.

It is proposed that the prize be $125,000 to be distributed as follows:

- $85,000 in pre-seed funding to the venture
- $15,000 toward a one-year full service lease - sufficient for 500 sq. ft. of office and lab space at $30/sq. ft. - at the innovation hub where the team would work on developing a minimal viable product
- Up to $11,500 in support of a US patent application securing the venture's technology
- $13,500 to an intern to work with the venture at the innovation hub for ten weeks during the summer; includes intern pay of $25/hour and a housing allowance of $3,500

Other options will need to be considered/reviewed as the program progresses.

The winner would also have access to:

- the innovation hub's robot development lab and support personnel where the team would develop/demonstrate their commercial product(s)
- the innovation hub's management team which would assist the team in developing a business plan, an appropriate corporate structure, an IP strategy, a marketing plan, interactions with prospective customers, and introductions to angel and venture investors

Prize winners would reside at the innovation hub for 2 years, after which they would be encouraged to move to a facility in the area that supports high-tech companies developing their markets and their businesses.

Section 4: Proposed Road Map and Implementation Plan for an Intelligent Robotics Innovation Hub

Proposed Innovation Hub Organization, Size and Annual Expenditures

It is **expected that the organization managing the innovation Hub would be structured as a nonprofit,** focused on advancing the robotics industry and not focused on renting space/real estate transactions. Therefore, the Hub is expected to include management offices and common spaces, office/development space for 6 new ventures (competition prize winners), and a robotics development lab. Rent would be charged using full service leases (includes real estate taxes, property insurance, utilities, repairs & maintenance, janitorial, management fees, and general & administrative expenses). The space rental charge for 2022 would be $30/sq. ft., with an expected inflation rate of 3% per year. Note that in the calculations below, inflation is not included.

The proposed size of the innovation hub would be 7,200 sq. ft.:

- Reception and management office area of 1,200 sq. ft. that would include a conference room and a kitchen open to participating ventures
- Development lab at 3,000 sq. ft.
- Office/development space for ventures, at 500 sq. ft. per venture – a total of 3,000 sq. ft. for the 6 ventures

The total annual rental charge is, thus, projected to be $216,000. $126,000 of this amount would be a Hub expense and $90,000 would be paid by the 6 ventures (in total) once the one-year $15,000 full service lease payment expires.

The proposed Hub's management structure and associated annual salary expense are:

Position	Annual Salary	Benefits @ 25%	Total Charge
Director	$150,000	$37,500	$187,500
Assistant Director	120,000	30,000	150,000
Lab Manager	50,000	12,500	62,500
Administrative Assistant	40,000	10,000	50,000
Total	***$ 360,000***	***$90,000***	***$450,000***

The Hub director would be responsible for establishing the Hub, leading competition activities including funding acquisition, lead Hub administration, and be a business development mentor for the ventures. The assistant director would focus on providing/coordinating services to the ventures;

and, with venture teams, developing business and marketing plans. The development lab manager would manage the shared prototyping and testing lab while the administrative assistant would be responsible for day-to-day operations and aiding the staff.

This is a fully-staffed "ideal" scenario from Year 0. It is possible that costs may be reduced if some functions are combined or reduced in scope.

Other annual charges associated with the management team/operations of the Hub are estimated at:

- Office Supplies: $10,000
- Kitchen Supplies: $5,000
- Internet/Phone Service: $12,000
- Travel $15,000

$42,000

The total projected annual cost associated with Hub management/operation is, thus, $708,000 for the first year (due to the $90,000 provided to the ventures to cover full lease payment) and $618,000 for the following years.

In one scenario, if the Hub runs 3 competitions per year and each competition is funded by 7 companies, then the Hub might be self-funded if each competition sponsor provided approximately $18,000 toward the competition prize and $29,500 to cover Hub expenses. Thus, each sponsor would need to provide $47,500. Again, this scenario may not be likely or ideal as it places funding sources and reliance solely on private industry solicitation and sponsorship. Ongoing local government and partner contributions would reduce the "ask" for company participants. Another scenario might be that the sponsors fees cover competition costs and that the local government and partner ongoing contributions cover annual Hub "overhead" expenses, in whole or in part.

Either way, the Hub managing team will need to consider possible ways to reward those companies providing monetary support to the Hub via sponsorships. Establishing buy-in and financial support from local robotics or robotics using companies and companies sponsoring competitions is imperative to the success and sustainability of the Hub. One option could be to provide them with access to technologies developed at the Hub at reduced royalty fee rates for either a given time period or until they recovered the amount of funding provided. If the typical technology royalty fee were 6%, one option could be to provide the technology at half that rate until the savings amounted to $47,500. That would occur with about $1.5 million in sales of their products using the technology.

It should be noted that interactions with high schools/K-12 and their students via the Hub – which was a proposed activity - has been dropped from the Hub's list of core activities. There are already well-established high school robotics programs throughout the US and the globe. For the

innovation hub to try to establish any substantive program with the high schools at its early stages is, thus, considered counterproductive, duplicative, and detracting from the core mission. At a later stage, high school internships may be a likely avenue for consideration. It is suggested this expansion into K-12 be considered and discussed once the Hub has been established, has proven to be successful and is sustainable.

Costs Associated with Establishing and Operating the Innovation Hub

For this document, 2022 is a planning year (see the proposed roadmap later in this section), and 2023 is considered a full year 0. It is assumed that Year 0 of the innovation hub will be a year for the organizing team to develop the programs out of some other office space or existing building, the space being rented at $30/sq. ft. There will be no competition in that year. It is envisioned that appropriate venture space would be located and available in the following year to accommodate the winning team of the hub's first competition.

It is proposed that there would be one competition in Year 1; and 2 in Year 2. Starting in Year 3, there would be three competitions each year. We propose here an ideal-state scenario wherein by the end of year 3 the costs for many of the core operating expenses would be covered by the funding from private sector company sponsorships. There would necessarily be additional core funding that could be borne by public sector annual support.

In terms of specifics, sometime in Year 0 (2023), we assume desks, chairs, tables, etc. needed for the 7,200 sq. ft. facility will be acquired. A first approximation for these costs is:

- Office furniture, including the conference room and common kitchen area $23,800
- Desks, chairs etc. for 6 venture spaces $31,200

$55,000

Development Lab furnishings are expected to be provided by robotics companies at no expense to the hub.

Thus, the funding needed – beyond that provided by competition sponsors - in the initial years of the hub is $1.27 million:

	Initial Year: Year 0	Year 1	Year 2	Year 3 & Beyond
Number of Competitions	0	1	2	3
Furniture	$55,000	-	-	-
Management Team Salaries[1]	302,500	$402,500	$450,000	$450,000

Other Expenses	26,000	35,000	35,000	42,000
Rent	216,000	196,000	176,000	126,000
Subtotal	**$599,500**	**$633,500**	**$661,000**	**$618,000**
Sponsor Fees	-	(206,500)	(413,000)	(619,500)
Total Funding Required	***$599,500***	***$427,000***	***$248,000***	***$ -***

[1]Management team salaries in Years 0 to 3[+] are expected to be:

Position	Year 0	Year 1	Year 2	Year 3[+]
Hub Director	$187,500	$187,500	$187,500	$187,500
Assistant Director	50,000	102,500	150,000	150,000
Lab Manager	30,000	62,500	62,500	62,500
Administrative Assistant	35,000	50,000	50,000	50,000
Total	***$302,500***	***$402,500***	***$450,000***	***$450,000***

To help fund the Hub startup, co-sponsorship funding from regional universities and facilities renting space to new venture companies may be a possibility as the competition winning teams would be expected to become renters at their facilities. Funding from these possible sources has not been included in the above calculations. While local contributions are also not included in the above calculations, it is highly recommended that localities in the region also consider financially supporting the hub.

In our recommended framework, the Hub would be formally established as a nonprofit with a core board of directors that includes at least 4 of the 7 Hampton Roads localities (such as Portsmouth, Norfolk, Hampton, and Newport News); at least 2 of the region's higher education entities (Old Dominion University and a community college); at least 4 ecosystem organizations (such as 757 Collab and Hampton Roads Alliance) and at least 6 private employers that are significantly engaged in the robotics sector (such as Huntington Ingalls, Canon, Stihl, Sentra, SVT Robotics, or others). Board members would represent their organizations/institutions and would have some expectation of annual or one-time supporting investment from their institution.

A possible scenario of proposed funding sources for the years 2021-2023

Using the above framework, we propose some possible funding sources and accompanying purposes:

Year	Expenditures Total	Sources
2021 (Q3 and Q4)	Minimal (staff time of planning committee members for planning and outreach activities; including fund-raising. Minor consulting fees as needed for marketing or outreach. See roadmap of activities in next section.)	Hampton Roads Alliance already-secured funds and time contributions from planning committee
2022	$500,000 secured by end of 2022 Q4 (though much of this will be for 2023 expenses – see roadmap of activities in next section)	Local government contributions = **$150,000** (4 @ $37,500 each or 7 @ $21,000 each);
		Higher education partners = **$50,000** (2 @ $25,000 each or 5 @ $10,000 each);
		*GO Virginia Region 5 Implementation Funding (2 years **at $250,000**, or $125,000 per year)
		Private sector contributions: **$50,000**
2023	$500,000 additional by end of 2023 Q4	Same as 2022

*The GO Virginia funding is competitive and not guaranteed. We anticipate a viable proposal for regional competitive funding is likely. The proposed activities of the Intelligent Robotics Innovation Hub would advance entrepreneurship and would support industry growth, job creation, and technology talent attraction and retention across all six of the region's priority sectors: Advanced Manufacturing; Cybersecurity/Data; Analytics/Model-Sim; Logistics/Port Operations/Warehousing; Shipbuilding and Repair; Water Technologies; and Unmanned Systems and Aerospace.

GOVA funding might support some personnel and project costs beginning in Q1 2023 (Year 0) and

including Year 1 (2024). The five year impacts might include the attraction and creation of 6 ventures per year (nearly 30 ventures over a 5 year period) with an *average* of 2-3 employees in year 1, at an *average* job growth of 3-5 employees per year, all in the technology sector and all earning over the regional median. In addition the summer internship program might serve an annual cohort of 15 technology interns, connecting them with regional employers. The academic year internship program might also serve 15 interns per year, connecting them with regional employers. Over a five year period, that would be 150 interns. Assuming that half receive in-region job offers, and that just over half accept, that might lead to the attraction or retention of 38 additional higher wage technology jobs in the during that period.

A Roadmap of Suggested Activities to be Addressed by the Hub Director and Board in the Early Years (2021-2023)

We offer in the table below a possible roadmap for establishing the Hub beginning with the remainder of 2021 and moving into 2022 which we see as the pre-startup and foundational year. Year 0 in our budget would then begin in 2023. The roadmap is a provisional "best guess" list of tasks at a particular point in time. Some of this is likely to change, and ideally should vary based on the Director and Board's vision, prioritizations, and responses to changing conditions and opportunities.

When	What	Who
Q3 of 2021	Endorse and refine the Hub concept plan, using this report as a foundation.	Current planning team, led by Hampton Roads Alliance
Q3 of 2021	Develop key talking points and a "road show" presentation of the Hub concept plan. Develop name for Hub (provisional name here is Intelligent Robotics Innovation Hub). Possible names to consider include an acronym (eg. the HI-RISE, Hub for Intelligent Robotics Innovation, Systems, and Enterprise; or similar). A shorter, catchier name followed by an explanatory sub-title is also possible (eg. The Yolk: Nourishing Intelligent Robotics Innovation and Talent).	Current planning team, led by Hampton Roads Alliance
Q3 of 2021	Develop outreach plan. As part of "roadshow" and talking points presentation development, create a list or map of key stakeholders and potential investors, including a specific "ask", tailored to type of stakeholder (local government, private industry, higher education, other partner). An "ask" might include: membership in Board or committee, an initial or recurring investment in Hub; and interest in future investment as an innovation challenge sponsor (if private company); current or future matching contributions per assistance, space, or other resources. Outreach plan should include a list of stakeholders to meet with individually as well as settings and times for "roadshow" group presentations.	Current planning team, led by Hampton Roads Alliance.
Q4 of 2021; Q1 of 2022	Execute outreach plan. Deliver "road show" presentation to key stakeholder groups in Hampton Roads region. Also use talking points to meet and speak individually with key executives and leaders (such as local government chief administrators, university lead contacts, and others). Secure initial investments or pledges.	Current planning team, led by Hampton Roads Alliance.
Q1 and Q2 of 2022	Formalize the Intelligent Robotics Innovation Hub planning team into a Board by adding members and selecting up to two co-chairs to guide and champion the project (possibly one private sector and one public sector). We recommend three distinct sub-committees or working groups, each with a committee chair (who is not one of the two overall co-chairs): funding and capital; marketing and communications; and programming.	Current planning team led by Hampton Roads Alliance

When	**What**	**Who**
Q1 and Q2 of 2022	Formally establish Hub as a nonprofit organization and establish Board; develop Bylaws and Charter. An alternative to strongly consider is to organize the Hub as a program or initiative under an existing entity as fiscal agent	Current planning team led by Hampton Roads Alliance
Q1 and Q2 of 2022	Make local government and initial investor and partner follow-up asks as needed. Seek initial public and private sector investments for pre-Year 0 expenditures, including filing fees, founding director salary from July-December 2022, program development work, travel and marketing costs. Secure $250,000 in funding pledges by end of Q2 2022	Hub Board of Directors
Q1 and Q2 of 2022	Board prepares GO Virginia regional competitive proposal for submission, regional consideration, and possible state board decision by the end of 2022	Hub Board
Q2 2022	By end of Q2 2022, Hub develops and adopts fiscal year (2022-2023) organizational budget.	Finance sub-committee and Hub Board.
Q3 2022	Develop job posting and conduct search for Hub Director. One of the tasks assigned to each prospective Hub Director (during the Interview Process) should be to identify the initial tasks he/she would/should undertake and the order in which they should be addressed (and why). In essence, the Hub Director, with Board input, would craft a new roadmap and action plan so it would be critical to get a sense of their ability to think strategically and work independently. A history of leading and growing programs and organizations (or start-ups) and securing resources and working across both public and private sector is key.	Hub Board of Directors, Chair and designated search committee
Q3 and Q4 2022	Hub Director is hired and begins work.	Hub Board
Q3 and Q4 2022	Develop Year 0 (2023) plan of work and refine innovation challenge concept. The Hub director is expected to spend considerable effort in the first months and years of the innovation Hub to develop and integrate the Hub's program with existing regional robotics activities in order to learn from their experiences and to maximize its effect on growing the high-tech workforce and infrastructure in the Hampton Roads region. The director will also be expected to visit and interact with communities or facilities in the US that have established themselves as robotics hubs or robotics venture centers. Hub director will begin to	Hub Director with Board oversight

	identify potential locations/facilities for Hub.	
When	**What**	**Who**
Q3 and Q4 2022	Fundraising and investment plan is developed and activities are continued (including grants, private sector donations, public sector contributions, etc) An additional $250,000 secured by end of Q4 2022..	Hub Director with Finance sub-committee and Hub Board.
Q3 and Q4 2022	Develop branding and marketing materials, and website and social media buildout	Director works with marketing committee
Q1 and Q2 2023	Begin hiring additional management team., select location for Hub and sign lease agreement, purchase furniture and schedule installation, continue to develop marketing assets (photos, logo for Hub, video b-roll, etc.)	Hub Director
Q1 and Q2 2023	Confirm specifics of innovation challenge including but not limited to: challenge name, goals, internship opportunities, timeline, application, marketing materials, marketing strategy and venture recruitment plan. Determine contingency plan to address potential challenges faced including lack of venture applications, lack of venture sponsors, etc.	Hub Director
Q3 and Q4 2023	Identify, secure, and occupy Hub space.	Hub Director and Board
Q3 and Q4 2023	Develop internship program summer model for 2024 and begin marketing and recruiting.	Hub Director and Board
Q3 and Q4 2023	Execute plan for innovation challenge (sponsor and competitor recruitment, event planning etc)	Hub Director and staff
Q3 and Q4 2023	Develop academic year internship program model	Hub Director and staff

Appendix A: Global Robotics Industry Market Size & Projections

Robotics products are typically divided into two main sectors:

1) Industrial Robots, which are stationary robots used in manufacturing processes for purposes of automation. The main benefit of these robots is higher speed and more accuracy than can be obtained from human labor. Typical industries using such robots include automotive, light manufacturing, heavy manufacturing, and food processing. The following are some of the applications of industrial robots:
    - Assembly: robots are capable of automating assembly tasks in factories
    - Material removal: includes grinding, polishing, cutting, and sanding, which are processes well suited for robots due to the need for high precision
    - Material joining and welding, especially arc welding
    - Loading and unloading, palletizing, and dispensing material and components during a manufacturing process
    - Packaging: this is most popular in the food processing industry; it involves performing repetitious tasks that could create ergonomic risks for humans

    Current markets using industrial robots include automotive, electrical/electronics, metal/heavy machinery, chemical – rubber - plastics, and food.
2) Service Robots, which are mobile robots designed to assist or service humans in a wide variety of tasks. They operate through control systems that allow them to respond to their environments.

    Service robots have become established over the last few decades; and they are typically subdivided into professional and personal segments.
    - Professional Service Robots are designed for applications in industry, especially where dirty, dangerous, or unique environments exist. They are employed in logistics, healthcare/medical, military & defense, field or agriculture & forestry, construction, and inspection & maintenance operations.
    - Personal Service Robots are domestic robots performing tasks that service humans at home. They include cleaning and domestic tasks, lawn mowing, rehabilitative & assistive robots, education, and entertainment.

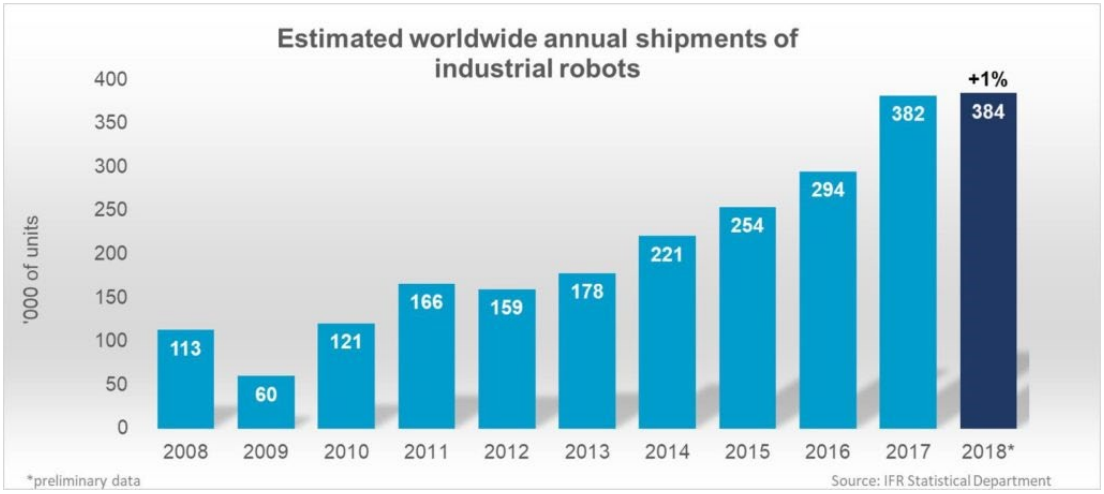
The global robotics market was investigated within each of these sectors in order to arrive at the total market. Existing market study information was reviewed on each of these sectors using over 35 existing market studies available on the Internet.

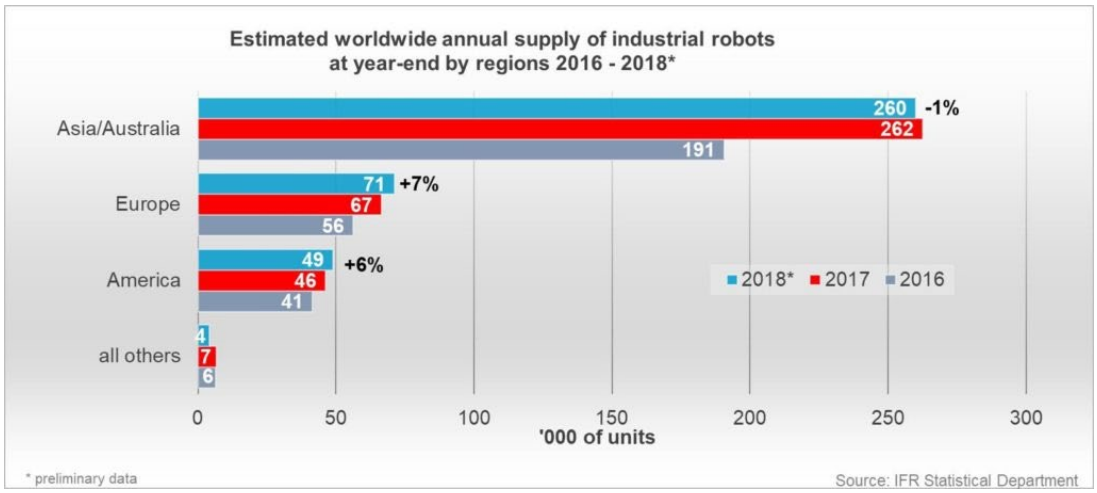
Industrial Robotics Market Sector

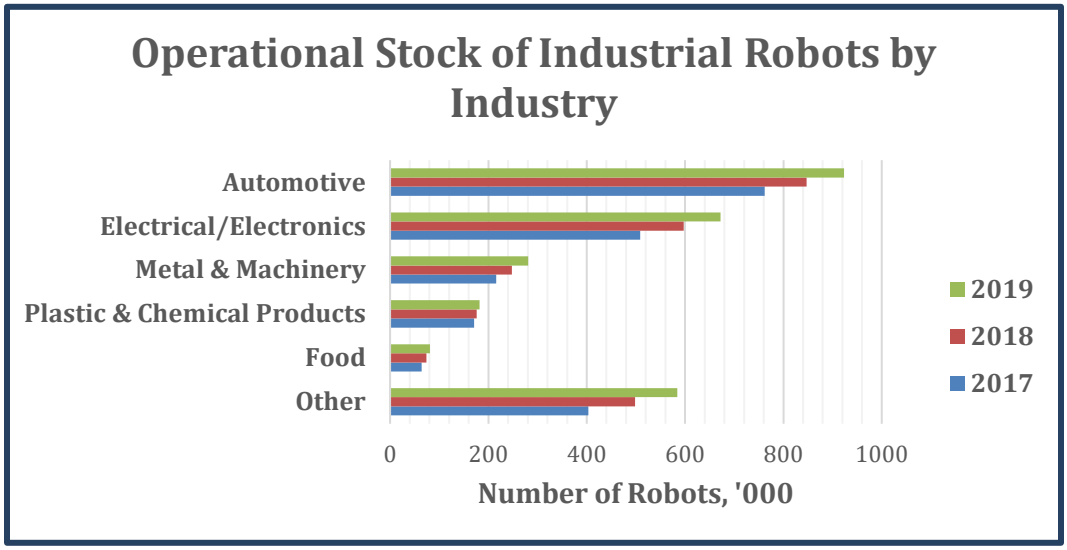
Sources reviewed include:

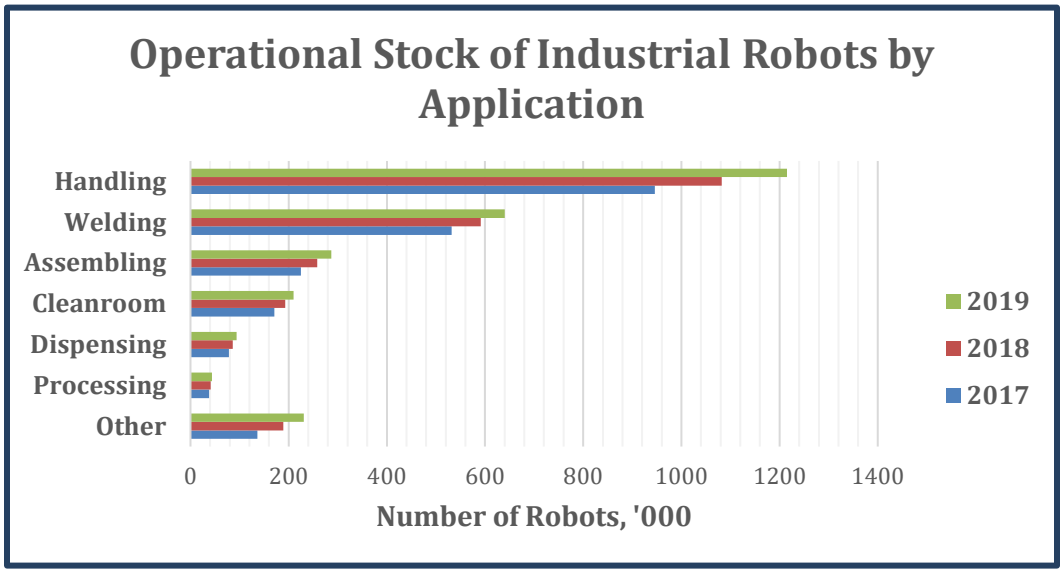
- **Industrial Robots**, McKinsey & Company, July 2019
- **Industrial Robot Cost Declines Should Trigger Tipping Points in Demand**, S Korus, ARK Invest, April 2019
- **Industrial Robotics Market Size, Price Trends, Competitive Landscape & Forecast, 2017-2024**, Global Market Insights, February 2018, Report GMI 1729
- **Industrial Robots Market Size & Regional Forecast, 2020-2027**, Fortune Business Insights, June 2020, Report FBI100368
- **Chart: Why Industrial Robot Sales are Sky High**, A Ahlstrom, May 2018
- **Industrial Robots – Enabler of Industrial Productivity**, Market Wrap, ICICI Securities, February 2018
- IFR Press Conference, September 2020

The following figures, which were published by the International Federation of Robotics, show the size of the Industrial Robotics Market in terms of units shipped: annual shipments worldwide, distribution of sales by region, and the operational stock and annual installation of robots by Industrial Robotics Market customer and application.




Estimated worldwide annual supply of industrial robots
at year-end by regions 2016 - 2018*
Asia/Australia
260
262
191
-1%
Europe
71
67
56
+7%
America
49
46
41
+6%
all others
4
7
6
2018*
2017
2016
0
50
100
150
200
250
300
'000 of units
* preliminary data
Source: IFR Statistical Department


Operational Stock of Industrial Robots by Industry
Automotive
Electrical/Electronics
Metal & Machinery
Plastic & Chemical Products
Food
Other
2019
2018
2017
0
200
400
600
800
1000
Number of Robots, '000


Operational Stock of Industrial Robots by Application
Handling
Welding
Assembling
Cleanroom
Dispensing
Processing
Other
2019
2018
2017
0
200
400
600
800
1000
1200
1400
Number of Robots, '000

Three market studies for the Industrial Robotics Industry have been published that covered the period to 2024 (at least). As seems typical for such market studies, the market size includes peripherals, software and system engineering. ***The robot itself typically accounts for 30% of the total cost when installing robots while accessories account for 25% and auxiliary hardware, software & programming, and installation account for 45%.***

- Global Market Insights: **Industrial Robotics Market Size & Forecast, 2017-2024**
  The global market was stated as exceeding $35 billion in 2016 and was projected to reach $80 billion by 2024, with a Compound Annual Growth Rate (CAGR) of 10% over 2017 – 2024
- MarketsandMarkets: **Industrial Robotics Market – Global Forecast to 2024**
  The global market for 2019 was stated as $48.7 billion and was projected to reach $75.6 billion by 2024, with a CAGR of 9.2% over 2020-2024
- Fortune Business Insights: **Industrial Robots Market Size, Share and Global Trend; and Geography Forecast till 2026**
  The global market for 2018 was stated as $18.78 billion and was projected to reach $59.99 billion by 2026, with a CAGR of 15.7% over 2020-2027. This implies that the Industrial Robotics Market would be $44.8 billion in 2024.

Based on these studies, a best estimate on the size of the global Industrial Robotics Market is that it will reach $75 - $80 billion by 2024, with CAGR of 9-10% over the period to 2024.
Finally, key market players in the Industrial Robotics Sector include: ABB (Switzerland), YASKAWA (Japan), FANUC (Japan), KUKA (Germany), Mitsubishi Electric (Japan), Kawasaki Heavy Industries (Japan), DENSO (Japan), NACHI-FUJIKOSHI (Japan), EPSON (Japan), Dürr (Germany), Universal Robots (Denmark), Omron Adept (USA), b+m Surface Systems (Germany/USA), Stäubli (Switzerland), Comau (Italy), Yamaha (Japan), IGM (Austria), ST Robotics (USA), Franka Emika (Germany), CMA Robotics (Italy), Delta Electronics (Taiwan), Rethink Robotics (Germany), Techman Robots (Taiwan), Precise Automation (USA), Siasun (China), Carbon Robotics (USA), Dahl Automation GmbH (Germany), Empire Robotics (USA), Gimatic Srl (Italy), Hanwha Precision Machinery (South Korea), HumaRobotics (France), iCobots (Israel), Industrial Vision Systems (UK), J Schmalz GmbH (Germany), Life Robotics (Japan), and micropsia industries GmbH (Germany).

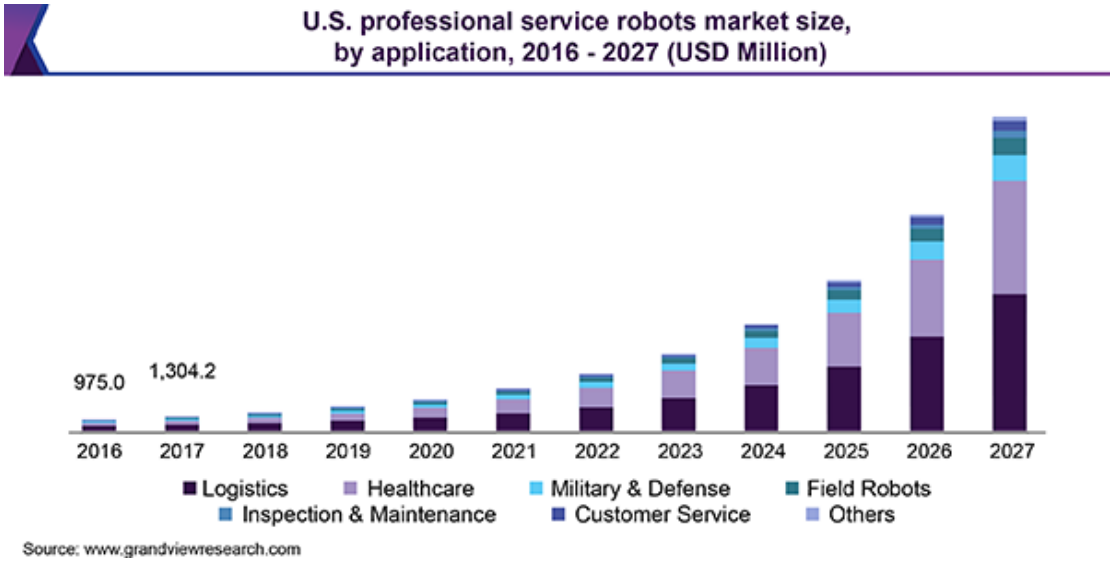
Professional Service Robotics Sector

Sources reviewed include:

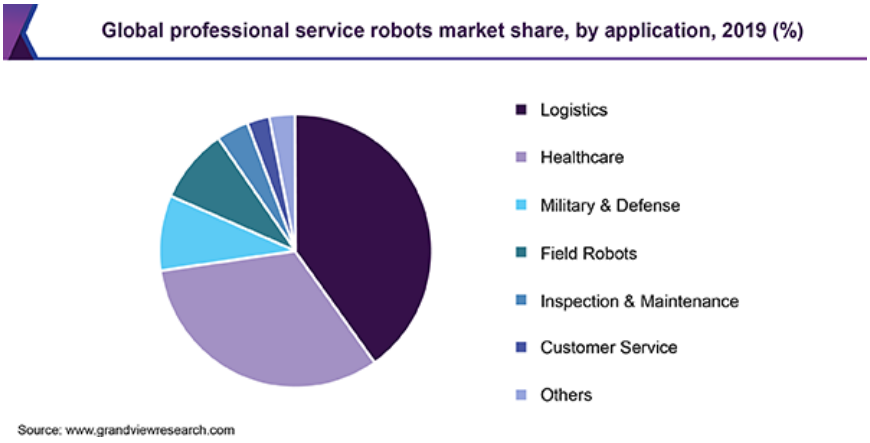
- **Professional Service Robots Market Size and Segment Forecasts,** Grand View Research, April 2020, Report GVR-4-68038-441-3

- **Service Robotics Market and Geography – Global Forecast to 2025,** MarketsandMarkets, March 2020, Report SE 2714
- **Logistics Robots Market Size and Regional Forecast 2020-2027,** Fortune Business Insights, June 2020, Report FBI102923
- **Medical Robotics Market Research Report – Global Forecast till 2027,** Market Research Future, February 2021, Report MRFR/MED/0803-HCR
- **Medical Robots Market and Forecast, 2018-2025,** Zion Market Research, February 2019
- **Surgical Robots Market Size – Forecast, 2019-2025,** Global Market Insights, March 2019, Report GMI 3122
- **Medical Robotic System Market and Forecast (2021-2026)**, Research and Markets, January 2021, Report 4591245
- **Surgical Robots Market Size and Segment Forecast, 2019-2025,** Grand View Research, December 2019, Report 978-1-68038-811-4
- **Military Robots Markets – Forecast and Analysis 2020-2025,** Technavio, January 2021, Report IRTNTR 46607
- **Professional Service Robots Market Size and Segment Forecasts, 2020-2027,** Grand View Research, April 2020, Report GVR-4-68038-441-3
- **Global Military Robots Market 2021-2025,** Technavio, February 2021
- **Unmanned Ground Vehicles (UGV) Market Size, Competitive Market Share & Forecasts, 2020-2026,** Global Market Insights, March 2020, Report GMI 4590
- **Unmanned Aerial Vehicle Market – Global Forecast to 2025,** ASD Reports, October 2019, Report AS2802
- **Underwater Robotics Market Size and Segment Forecast, 2018-2025,** Grand View Research, August 2918, Report GVR-2-68038-421-5
- **Autonomous Ships Market Size and Segment Forecasts, 2019-2025,** Grand View Research, December 2019, Report GVR-3-68038-944-9
- **Agricultural Robots Market Size & Trends Analysis, and Segment Forecasts, 2018-2025,** Grand View Research, April 2017, Report GVR-978-1-68038-665-3
- **Agricultural Robots Market with COVID-19 Impact Analysis – Global Forecast,** MarketsandMarkets, June 2020

The Professional Service Robotics Sector comprises four major market segments: Logistics, Healthcare/Medical, Military & Defense, and Field or Agriculture & Forestry Robots. As shown in the Grand View Research market study on the Professional Service Robots Market, the total sector had a global market of $12.3 billion in 2019 which was projected to reach $16.4 billion in 2020. The sector is expected to increase at a Compound Annual Growth Rate (CAGR) of 41% over the period 2020 -2027 to $96.65 billion by 2025.
The figure bellow shows the US market:



and the figure below shows the global market sector by segment:



When compared to the segment CAGRs shown below, 41% CAGR seems an excessive projection. Thus*, the 2025 professional service robotics sector size will be taken as the sum of segment projections shown below.*

Constraints on the market are, as stated elsewhere in this report, the high cost of initial setup and maintenance of the equipment.

Key players in the professional service robotics market include Daifuku (Japan), Northrup Grumman (USA), iRobot (USA), KUKA (Germany), Vecna Robotics (USA), Kongsberg Maritime (Norway), SZ DJI technology (China), Intuitive Surgical (USA), Parrot SA (France), GeckoSystems International (USA), Honda Motor Company (Japan), Adept Technology (USA), Bluefin Robotics (USA), ECA Group (Belgium), Aethon (USA), and Robert Bosch GmbH (Germany). But many startup companies are also working on robotic developments serving this market sector.

Logistics Segment

Two market studies were found that quantify the service robot logistics market:

- **Logistics Robots Market Size & Regional Forecast 2020 – 2027**, Fortune Business Insights, June, 2020
  The report states that the global logistics robots market was $4.70 billion in 2019 (with the North American market being $1.48 billion in 2019); and has projected it to reach $14.95 billion by 2027. The CAGR during the period is expected to be 15.7%. It states that 44.4% of the 2019 global market was automated guided vehicles.
- **Logistics Robots Market to 2027,** The Insight Partners, February 2020, Report TIPTE 100000924
  The report states that the global logistics market was $4.4 billion in 2018; and projects it to reach $20.3 billion by 2027, experiencing a CAGR of 19.1% from 2019 to 2027. Companies are increasing their use of robots to gain efficiency, speed and augmented profits that keep them competitive and help them in an expected labor shortage environment even though high capital cost is a major market constraint. Collaborative mobile robots are expected to capture the largest share of the market being deployed to perform packaging, machine tending, and material handling tasks.

The difference in the projected market size of the two studies is mainly due to the difference in the projected CAGR. ***The average for the 2027 market size is $17.6 billion; and this is taken as the basis for the projected 2025 Logistics Segment of $12.4 billion, having experienced a CAGR of 17.5% over the previous 5 years.***

Drivers of the logistics market segment are the increasing implementation of advanced technologies and the booming e-commerce industry, with many robots being used to perform tedious and/or uncomfortable tasks. They also help companies manage in the expected labor shortage. Logistics robots typically are used in pick & place, palletizing, packaging, and transportation activities within the plant. Constraints within the segment on using robots are the setup and maintenance costs, a factor that is keeping small and medium scale retailers from investing in robots.

Key players in this market segment are Toyota Industries (Japan), ABB (Switzerland), FANUC (Japan), Kawasaki Heavy Industries (Japan), Dematic (USA), Kuka AG (Germany), Yaskawa America (USA), Omron Corporation (Japan), Teradyne (USA), Toshiba Corporation (Japan), AGV International (Netherlands), Clearpath Robotics (Canada), Daifuku (Japan), Fetch Robotics (USA), Kion Group AG (Austria), and Kollmorgen (Germany).

Healthcare/Medical Segment

Four published market studies for the healthcare/medical segment of the Professional Services Robotics Sector were identified for review:

- **Medical Robotics Market Research Report - Global Forecast till 2027**, Market Research Future, February 2021, MRFR/MED/0803-HCR
  The global market is projected to reach $23.4 billion by 2025, having registered a CAGR of 23.21% over 2022-2027
- **Medical Robots Market and Forecast, 2018-2025**, Zion Market Research, February 2019
  The 2018 global market was found to be $6.62 billion; and the market is projected to reach $24.6 billion by 2025 at the CAGR of ~20.8%
- **Surgical Robots Market Size & Forecast, 2019-2025**, Global Market Insights, March 2019, Report GMI3122
  The 2018 global market was found to be $5.5 billion; and the market is projected to reach $24 billion by 2025 at the CAGR of ~24.4% over 2019-2025
- **Medical Robotic System Market and Forecast (2021-2026),** Research and Markets, January 2021, Report 4591245
  The 2020 global market was estimated at $8.307 billion; and the market is projected to reach $28.34 billion by 2026 at the CAGR of 22.18% over 2021-2026

These indicate that the healthcare/medical segment of the Professional Service Robotics Market will reach $23.8 billion by 2025, having experienced a CAGR of 22.6% over the previous 5 years. This is taken as the segment's contribution to the 2025 Robotics Industrial market.

Market drivers in this market segment include:

- The increasing trend to use minimally invasive surgeries that employ robotics systems. This trend was initiated in 2000 with FDA approval of the da Vinci surgical system.
- An increase in the number of medical areas using robotic systems; some of the robotic systems are:
    - Laparoscopic (diagnostic procedure to examine organs in the abdomen)
        - FreeHand endoscope holder system
        - Da Vinci robotic surgery system
        - Telelap ALF-X surgical system
    - Gynecological
    - Urological
    - Neurosurgery
        - Pathfinder surgical system
        - NeuroMate surgical system
        - Renaissance surgical system
    - Orthopedic surgery
        - iBlock surgical system
        - Robodoc surgical system
        - Navio PFS surgical system

        - MAKO RIO surgical system
        - Stanmore Sculptor surgical system
    - General surgery
    - Emergence response
        - LS-1 robotic system
        - Auto Pulse Plus robotic system
    - Noninvasive radiosurgery
        - TrueBeam STx radiosurgery system
        - CyberKnife robotic radiosurgery system
        - Gamma Knife Perfexion radiosurgery system
    - Hospital & Pharmacy
        - Telemedicine robots
        - IV robots
        - Pharmacy robots
        - Cart transportation robotics
- The growing incidence of chronic diseases worldwide
- The increased use of imaging guidance and 3-D imagining in medical procedures
- Growth in funding for medical robotic research

The major market constraints are the expense of robotic surgery systems and the lack of skilled operators needed in robot-assisted surgeries.

Key players in this market segment are: Smith & Nephew (UK), Styyker (USA), Aethon (USA), Intuitive Surgical (USA), Mazor Robotics (Israel), InTouch Technologies (USA), Renishaw (UK), Medtech SA (France), Ekso Bionics (USA), ReWalk Robotics (USA), Medrobotics Corporation (USA), McKesson Corporation (USA), Medtronic (Ireland), Zimmer Biomet (USA), Bionik (USA), Cyberdyne (Japan), Auris Surgical/Hansen Medical (USA), Accuray (USA), Hocoma AG (Switzerland), Omnicell (USA), Kirby Lester LLC (USA), THINK Surgical (USA), Health Robotics (Italy), Titan Medical (Canada), ARxIUM (Canada), BioTek (USA), MAKO Surgical (USA), Roche Holding AG (Switzerland), BD Rowa (Germany) and ZOLL Medical (USA).

Military & Defense Segment

Technavio published a market study report in January 2021 that estimates the global military robots market for 2020 at $1.13 billion and projects the segment to grow at a CAGR of ~7%, resulting in a market of $7.67 billion by 2026.

There are four market studies that individually cover unmanned ground vehicles (UGV), unmanned aerial vehicles (UAV), unmanned underwater vehicles (UUV), and autonomous ships:

- A CAGR of 13% for 2020 – 2026 for the UGV market, resulting in a projected 2026 market value of $7 billion

- A 2019 global market for UAV of $19.3 billion that is expected to have a CAGR of 15.5% for 2019 – 2025, resulting in a 2025 market projection of $45.8 billion. This projection includes military, commercial, government & law enforcement, and consumer sub-segments; thus, the market includes defense & security, agriculture & forestry, logistics & transportation, energy & power and other industries. The military & defense market segment is taken as 20% of the total ($9.16 billion).
- A 2017 global market for UUV of $2.52 billion that was projected to grow at a CAGR of 13.5% from 2018 to 2025 resulting in a 2025 market projection of $6.74 billion. Defense & security, commercial, scientific research and other industries were included in this projection. The military & defense market segment is taken as 30% of the total ($2.02 billion).
- For the autonomous ships market, a study was published in 2019 and valued the 2018 market at $6.03 billion; and projected the market would experience a CAGR of 13.5% over 2019 to 2025, resulting in a 2025 market projection of $14.6 billion. This study included both commercial & defense market segments; the defense market segment is taken as 40% of the total $5.84 billion.

The sum of the 2025 markets for these four sub-segments is $23.2 billion; and this is taken to be the segment's 2025 contribution to the Professional Services Robotics Sector. 44% of the market's growth is projected to originate in the Asia-Pacific region (China and India in particular).

The applications included in the projections are surveillance, intelligence, reconnaissance, deactivating potentially hazardous materials, sweeping mines, securing critical water passages, serving as naval targets, and performing multi-mission intrusion and attack tasks. The size of the robots can vary from something you hold in your hand to the size of cargo/fighter planes.

Key players in this segment include BAE Systems (UK), Boston Dynamics (USA), Elbit Systems (Israel), General Dynamics (USA), Israel Aerospace Industries (Israel), Armtrac Limited (UK), Clearpath Robotics (Canada), Cobham plc (UK), DOK-ING (Croatia), Endeavor Robotics (USA), General Dynamics Mission Systems (USA), Horiba Mira Ltd (UK), Icor Technology (Canada), Northrop Grumman (USA), Qineti Group plc (UK), RE2 Robotics (USA), Lockheed Martin (USA), Oshkosk Corporation (USA), BAE Systems (UK), iRobot (USA), FLIR Systems (USA), Milrem AS (Estonia), Textron Systems (USA), Howe & Howe Technologies (USA), L3Harris Technologies (USA), General Atomics (USA), Textron (USA), Boeing (USA), IAI (Israel), Aero Vironment (USA), GA-ASI (USA), Oceaneering International (USA), Bluefin Robotics (USA), International Submarine Engineering (Canada), Schilling Robotics (USA), Inuktun Services Ltd (Canada), Atlas Maridan AdS (Germany), ECA SA (France), Deep Engineering (USA), Eddyfi (Canada), TechnipFM plc (UK), Saab AB (Sweden), and Soil Machine Dynamics Ltd (UK).

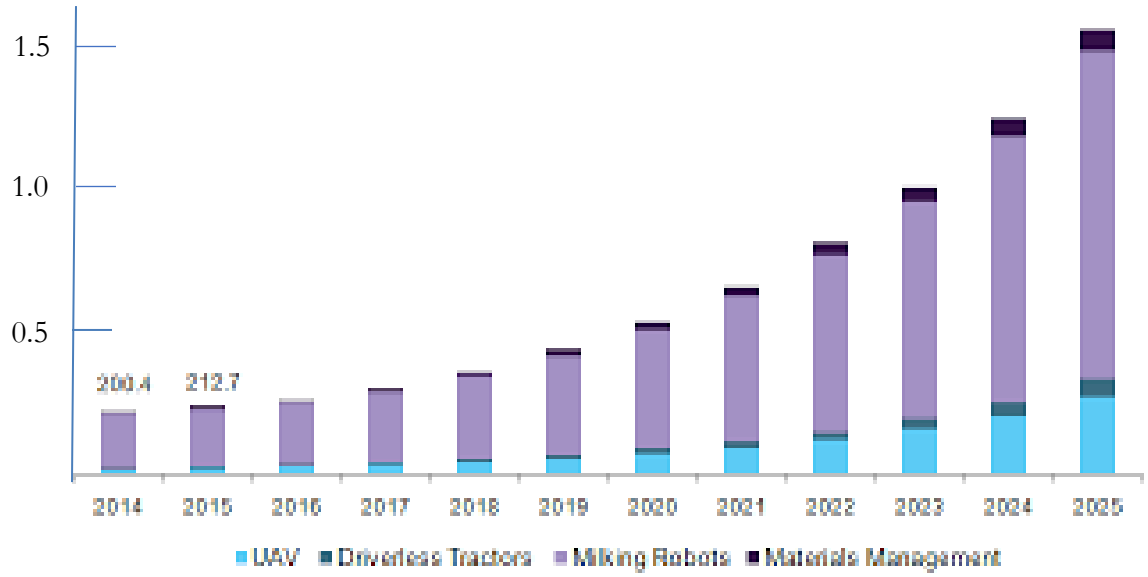
Field/Agriculture & Forestry Segment

Robotics is/has been applied in agriculture because autonomous systems and data analytic tools provide precision and eliminate rote labor in agricultural tasks while minimizing environmental footprints, meeting increase demand for food volume, lower costs and provide better safety. Two market studies of the robotics agriculture & forestry market size provide an indication of what robotics can do for agriculture:

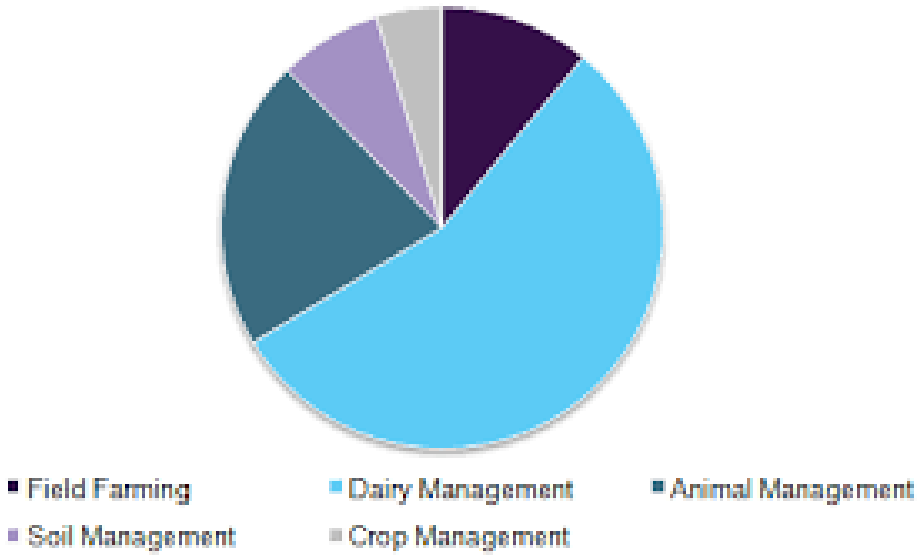
- A market study by Grand View Research states that the global agricultural robots market was $1.05 billion in 2015 (when the US represented 31.5% of the global market); and owing to electronics technologies such as the global positioning system and geographic information systems that allow for increased use of precision agriculture (better decisions on fertilizing, planting and harvesting) and the higher productivity from employing robots, the market is projected to reach $8.83 billion by 2025. The major market segments within agriculture & forestry that are successfully implementing robotics are unmanned aerial vehicles that monitor field conditions, driverless tractors that can plant/seed, and tillage, milking robots that voluntarily milk animals – the dominant segment in this market, and materials management. Because of the high cost of equipment such as driverless tractors, fruit harvesters, and weeding robots, most farms have adopted a leasing equipment model. Within this market there are ethical concerns with respect to ownership of the data captured by ground robots as a number of software providers sell data to third parties. This is a continuing issue for the community.

The figure below shows the US agriculture & forestry robotics market in terms of these segments.

US Agriculture & Forestry Robots Market by Product, $ Billion



Global Agriculture & Forestry Robots Market by Application, 2015, %



- A market study by MarketsandMarkets states the 2020 market size was $4.6 billion; and the market is projected to grow at a CAGR of 34.5% from 2020 to 2025 (The Grand View Research study projected a CAGR of 24.7%), resulting in a projected 2025 global market of $20.3 billion. The factors fueling the growth of this segment are those stated above.

The difference in the projected global 2025 market - $8.8 billion versus $20.3 billion – is a result of the differences in projected CAGRs. ***To be conservative, the segment's projected 2025 global market size of $12.4 billion will be used in projecting the total global robotics market.***

Key players in this segment include Deere & Company (USA), Trimble (USA), AGCO Corporation, (USA), AgJunction (USA), DJI (China), BouMatic Robotics (Netherlands), Lely (Netherlands), DeLaval (Sweden), Topcon (USA), Agribotix LLC (USA), Autonomous Solutions (USA), and AgEagle Aerial Systems (USA). Abundant Robotics (USA) and Iron Ox (USA) are two emerging companies in the agricultural robots market that need to be watched. In addition, the State of Colorado has over 70 agritech startup companies; and Colorado State University is playing a large role in the state's agritech evolution.

In summary, the Professional Service Robotics Sector market is projected as:

Professional Service Robotics Segments	Projected 2025 Market Size, $ Billion
Logistics	$12.4
Healthcare/Medical	23.8
Military & Defense	23.2
Field: Agriculture & Forestry	12.4
Total	***$71.8***

Personal & Domestic Service Robotics Sector

Sources reviewed include:

- **Personal Robots Market Research Report – Global Industry Analysis and Growth Forecast to 2030**, Prescient & Strategies Intelligence, September 2020, Report SE 10647
- **Consumer Robotics Market and Region – Global Opportunities**, GMI Research, February 2020, Report UP142A-00-1119
- **Cleaning Robot Market Size and Segment Forecasts, 2019-2025**, Grand View Research, December 2019, Report GVR-3-68038-937-1
- **Robotic Vacuum Cleaner Market Size and Forecast**, Verified Market Research, June 2020, Report 42640
- **Service Robotics Market Size & Forecast, 2017-2024**, Global Market Insights, March 2018, Report GMI 130
- **Assistive Robotics Market – Global Forecast to 2024**, MarketsandMarkets, August 2019, Report SE 7298
- **Rehabilitation Robotics Market & Regional Forecasts to 2027**, Emergen Research, September 2020, Report ER 00167
- **Rehabilitation Robots Market Size and Regional Forecast 2019-2026**, Fortune Business Insights, September 2019
- **Global Entertainment Robots Market, Industry Trends and Forecast to 2027**, Data Bridge Market Research, July 202
- **Global Entertainment Robots Market Research Report – Forecast till 2027**, Market Research Future, July 2019, Report MRFR/SEM/2149-CR

The Sector comprises cleaning robots; healthcare exoskeleton systems that address the needs of those with disabilities and/or have had amputations caused by stroke, orthopedic disorders or accidents; social robots that provide for the care of elderly people as well as serve as companions; entertainment robots including toy robots and hobby system robots; and educational robots. All of the segments except for cleaning robots are in the early stages of commercialization. Therefore, the markets for some segments have not been reviewed in market studies.

Published projections for the size of the Personal & Domestic Service Robotics market include:

- **Personal Robots – Global Analysis and Growth Forecast to 2030**, Prescient & Strategic Intelligence, September 2020, Report SE10647
  The global market is stated to have reached $21.5 billion in 2019; and is projected to reach $51.5 billion by 2030, at a CAGR of 7.8%. The projected 2025 market size is, thus, $35.4 billion; however, the report mentions that, because of the coronavirus, this sector experienced negative growth in 2020.
- **Consumer Robotics Market by Region – Global Opportunities & Forecast, 2020-2027**, GMI Research, February 2020
  The global market is stated to have reached $4.12 billion in 2019; and is projected to reach $32.8 billion by 2027, at a CAGR of 30.7%. The projected 2025 market size is, thus, $19.2 billion.

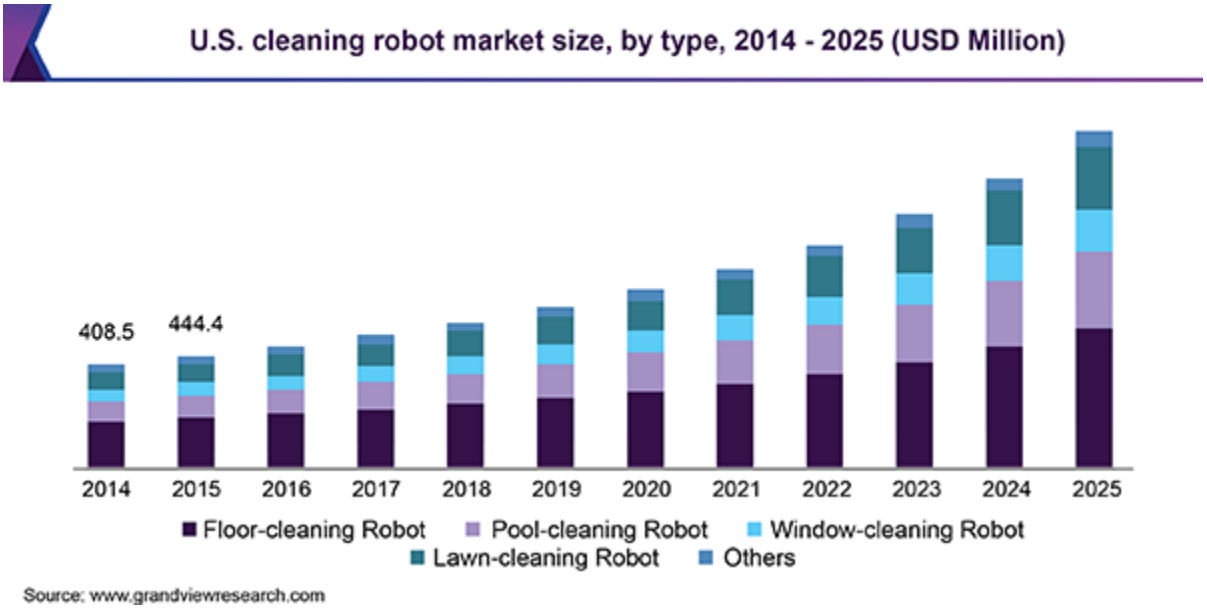
- **Service Robotics Market Size & Forecast, 2017-2024**, Global Market Insights, March 2018, Report GMI130
  The Internet available information on this study is minimal and only states that the Personal & Domestic Service Robots market is one third of the Professional Service Robots market.

The difference in the 2025 projected market sizes is a result of the chosen CAGRs, which are called into question in the older GMI report (see above). Thus, ***for the 2025 Personal & Domestic Service Robotics market size, the best estimate is taken as $23.9 billion (one third of the Professional Service Robotics market size in 2025).***

Cleaning Robots Segment

Three market size studies were reviewed for the Cleaning Robots market:

- **Cleaning Robot Market Size and Segment Forecasts, 2019-2025,** Grand View Research, December 2019, Report GVR-3-68038-937-1
  The global market was valued at $2.5 billion in 2018 and it is projected to reach $6.2 billion by 2025, at a CAGR of 14.6%.
  The report includes the US cleaning robot market size per sub-segment for 2014 to 2025 that is shown below; note that the floor cleaning robot sub-segment is projected to be 42% of the 2025 US market.



- **Robotic Vacuum Cleaner Market Size and Forecast**, Verified Market Research, June 2020, Report 42640
  The global market was valued at $2.48 billion in 2019 and it is projected to reach $8.85 billion by 2027, at a CAGR of almost 17.2%. This would project the 2025 market to be $6.44 billion.

- **Household Robots Market and Global Forecast to 2024**, MarketsandMarkets, June 2019, Report SE 7203
  The global market was valued at $3.3 billion in 2019 and it is projected to reach $9.1 billion by 2024, at a CAGR of almost 22.4%. This would project the 2025 market to be $11.1 billion.

In summary, this segment is taken to be the lower number of the two studies: $6.3 billion in revenues by 2025.

The key players in this segment are Ecovacs Robotics (China), ILIFE Robotics Technology (USA), iRobot Corporation (USA), LG Electronics (South Korea), Maytronics (Israel), Milagrow Business and Knowledge Solutions Limited (India), Neato Robotics (USA), Nilfisk Group (Denmark), Pentair plc (Ireland/USA), Samsung Electronics (South Korea), AB Electrolux (Sweden), Dyson (UK), Xiaomi Corporation (China), Beijing Roborock Technology (China), SharkNinja Operation LLC (USA), Cecotec Innovaciones SL (Spain), Panasonic Corporation (Japan), Kevac Srl (Italy), Sharp Electronics Corporation (Japan), Philips Innovation Services (Netherlands), Mamibot Manufacturing USA (USA), Stanley Black and Decker (USA), Bosch (Germany), and Miele (Germany).

Rehabilitative and Assistive Robotics/Exoskeleton Segment

The Rehabilitative and Assistive Robotics segment includes therapeutics robots, assistive robots, exoskeleton robots and similarly named sub-segments. Stationary robots are expected to hold the largest share of the assistive market that are used mostly in households and medical applications. This segment meets the needs of people who need assistance doing their everyday activities because they have suffered strokes, spinal cord injuries, brain traumas or are suffering from multiple sclerosis, Parkinson's disease, palsy, or similar handicaps.

The biggest constraint on this segment is the high cost of robotic rehabilitation devices. Nevertheless, some sub-segments are growing at annual rates of over 50%.

Out of seven market reports reviewed, three were considered useful for projecting the market for rehabilitative and assistive robots:

- **Assistive Robotics Market – Global Forecast to 2024**, MarketsandMarkets, August 2019, Report SE 7298
  The global market included physically assistive robots, handicap assistive robots, and stationary robots mostly used in households. As such, it is the most comprehensive of the 3 studies. It stated the 2019 global market as $4.1 billion; and projected the market to reach $11.2 billion by 2024, a CAGR of 22.3% for the period.

- **Rehabilitation Robotics Market & Regional Forecasts to 2027**, Emergen Research, September 2020, Report ER 00167
  The global market in 2019 was valued at $2.3 billion; and it was projected to grow to $9.45 billion by 2027, a CAGR of 20.5%.
- **Rehabilitation Robots Market Size & Regional Forecast 2019-2026**, Fortune Business Insights, July 2019, Report FBI101013
  The global market in 2018 was valued at $0.53 billion; and it was projected to grow to $92.62 billion by 2026, a CAGR of 22.1%.

Because of its greater market depth, the MarketsandMarkets report is considered the best for projecting this market segment: 2025 market projected to reach $13.7 billion by 2025.

Key players in this segment include Myomo (USA), Bionik (USA), Hocoma AG (Switzerland), AlterG Inc (USA), Motek Medical B V (Netherlands), Reha Technology AG (Switzerland), Cyberdyne (Japan), Man&Tel Co Ltd (Korea), ReWalk Robotics Ltd (USA), Kinova Robotics (Canada), Focal Meditech (Netherlands), Blue Frog Robotics (France), SoftBank Robotics (Japan), Ekso Bionics (USA), Ubtech Robotics (China), Barrett Technology (USA), Hyundai (South Korea), DreamFace Technologies (USA), Double Robotics (USA), Fourier Intelligence (China), CT Asia Robotics (Thailand), F&P Robotics (Switzerland), Axosuits (Romania), Japet Medical Devices (France), Hanson Robotics (Hong Kong), Motorika (USA), Rex Bionics (New Zealand), and ABILITY AG (Switzerland).

Entertainment Robotics Segment

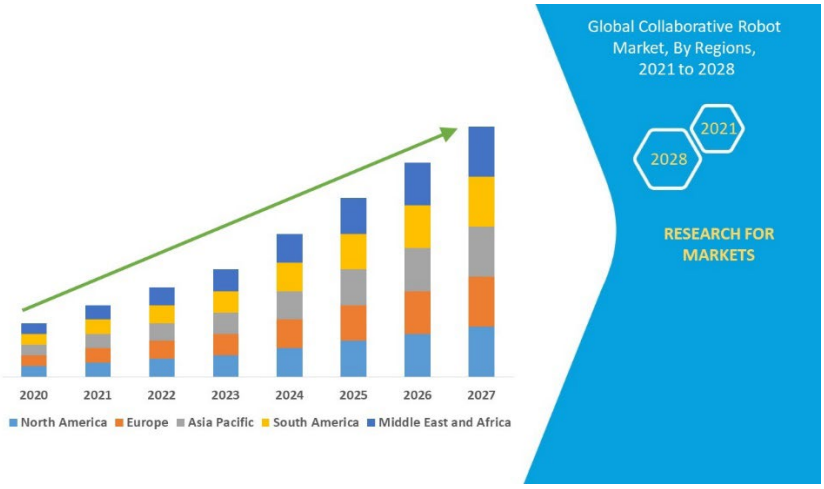
The global entertainment segment includes robot toys, educational robots, and robot companion pets. The market is being driven by developments in artificial intelligence, increasing demand for animatronics robots, and both the younger and older populations. The constraints on this segment include the R&D expense and technical complexity of human-machine interfaces associated with developing the robots.

Two market studies were reviewed to determine the size of this segment's size:

- **Global Entertainment Robots Market, Industry Trends and Forecast to 2027**, Data Bridge Market Research, July 2020
  The global market in 2020 was determined to be $2.25 billion and the projected 2025 to be $6.27 billion. The CAGR during the period of the study was taken as 22.88%.
- **Global Entertainment Robots Market Research Report – Forecast till 2027**, Market Research Future, July 2019, Report MRFR/SEM/2149-CR
  The global market in 2016 was determined to be $0.98 billion and the projected 2023 to be $3.72 billion. The CAGR during the period of the study was taken as 23.06%. The calculated 2025 market size is $5.63 billion.

Therefore, the segment's 2025 revenue is taken as $5.95 billion.

The following figure, taken from Data Bridge Market Research report, shows that the market is fairly evenly distributed in the world.



Key players in this segment include Kuka (Germany), Hasbro (USA), MATTEL (USA), SPHERO (USA), Blue Frog Robotics (France), Robobuilder (Korea), Sony Corporation (Japan), USRobotics (USA), Shibaura Machine Co Ltd (Japan), WooWee Group Limited (Canada), Innovation First International (USA), fischertecknik GmbH (Germany), and The Lego Group (Denmark).

In summary, the Personal & Domestic Service Robotics Sector is projected at:

Personal & Domestic Service Robotics Segments	Projected 2025 Market Size, $ Billion
Cleaning Robots	$6.3
Rehabilitative & Assistive Robots	13.7
Entertainment Robots	5.95
Total	***$25.95***

Global Robotics Market

Sources reviewed include:

- **[Op-ed] Robots Jump into the Mobility Industry**, Hyundai Motor Group, January 2021
- **Global Robotics Market Research Report – Forecast till 2024**, Market Research Future, September 2019, Report MRFR/SEM/3310-CR

- **Global Robotics Market Analysis, Trends and Forecast 2018 to 2025**, Fior Markets, January 2020
- **Robotics Market – Global Industry Analysis and Forecast 2017-2025**, Transparency Market Research, October 2017, Report TMRGL 32000
- **Robotics Technology Market by Component, Global Opportunity Analysis & Industry Forecast, 2020-2027**, Allied Market Research, October 2020
- **Collaborative Robot Market – Global Forecast to 2026**, MarketsandMarkets, March 2020, Report SE 4480

The sector conclusions reached above need to be compared to published studies on the total. Four market studies of the global robotics industry provide one estimate for this total growth in the robotics industry to 2025:

- Hyundai Motor Group Study: published in January 2021, the report provides market projections for each of the robotics market sectors for 2020 – 2025. Per this study, the global market was $35 billion in 2020 and is projected to reach $179 billion by 2025, with a CAGR of 32% during 2020 to 2025.
- Market Research Future Study: published in September 2019, provides only an estimate of the total robotics market size: $42.6 billion in 2018, projected to increase to $181 billion by 2024 with a CAGR of 28.52% during 2018-2024. The 2025 market size would then be $233 billion.
- Fior Markets Study: published in January 2020 only provides the total robotics market size: $37.8 billion in 2017, projected to increase to $158 billion by 2025 with a CAGR of 19.11% during 2018-2025
- Transparency Market Research Study: published in November 2018 only provides the total robotics market size: $35.2 billion in 2016, projected to increase to $147 billion by 2025 with a CAGR of 17.0% during 2017-2025

In summary, the Market Research Future Study – projecting the 2025 market $233 billion - is an outlier among the four studies. Therefore, ***the total 2025 robotics industry market is projected to be in the range of $147 billion to $181 billion (or $164 ±17 billion).***
The global robotics market estimate reached through the sector segment analysis earlier is $182.8 billion for the 2025 global robotics market:

Projected 2025 Global Robotics Market
Five-Year Market Increase of 84%

Sector	Segment	2025 Global Market, $ Billion	Percent of Total Market
Industrial		***$85.00***	***46%***
Professional Service	Logistics	$12.40	7%
	Healthcare/Medical	23.80	13%
	Military & Defense	23.20	13%
	Agriculture	12.40	7%
	Total	***$71.80***	***40%***
Personal & Domestic Service	Cleaning	$6.30	3%
	Exoskeleton	13.70	8%
	Entertainment	6.00	3%
	Total	***$26.00***	***14%***
Total 2025 Robotics Market		***$182.80***	

Even though this overall market estimate is similar to that reached from a review of the global market studies, the sector results are very different. Therefore, the sector analysis is taken as the best estimate of the 2025 global robotics market.

Appendix B: The Evolving Robotics Industry

In Spring 2021, the Hampton Roads Alliance, on behalf of the Cities of Hampton, Newport News and Norfolk, and in collaboration with Norfolk based SVT Robotics and its consultant, The Gaston Group. commissioned the Virginia Tech Center for Excellence and Community Engagement to conduct a study to assess the feasibility and opportunities for a Regional Hampton Roads Robotics Innovation Hub. The project was to focus on:

1. A market analysis to assess the global robotics market trends and demand for different applications that a robotics innovation hub may provide
2. A regional situation analysis to complement the larger market analysis and determine regional needs and support for an innovation hub
3. Proposing a vision for establishing a robotics innovation hub in Hampton Roads that would address the needs of the region and be financially and programmatically sustainable. This vision would include a proposed organizational and management structure/staffing.
4. A roadmap for establishing such an innovation hub over a three-year period, including physical site requirements and budgets

Evolution of Robotics Industry

Although robots have been the subject of study since the time of the Greek empire, the science of robotics only came about in the 20th century; and what we think of today as the robotics industry started with the first industrial robot developed by George Devol in the mid-1950s which entailed a robotic arm device for transporting die castings in a General Motors plant in New Jersey. At about the same time, the German firm Kuka developed an automated welding line for appliances as well as a multi-spot welding line for Volkswagen. Automated welding became a significant application of industrial robots since they produced high-quality welds. Over the remaining decades of the 20th century, electro-mechanical drivers and vision sensors were added to robots. And by the 1990s, robot controls and synchronization were employed to load pretzels in bags (this used the first packaging robot) and for image-guided surgery. These and other applications help give a definition to robotics as an interdisciplinary field that integrated computer science and engineering with the goal being to design machine that could help, assist and possibly replace humans in manufacturing and service applications.

Until the 21st century, most robots were designed to provide, through automation, higher speed and greater accuracy in industrial operations. Such robots typically need to be confined to highly controlled environments, many times via caging. The introduction of cognitive computing into the robotics industry – generally called Industry 4.0 Collaboration - included adding artificial intelligence, machine learning and automated reasoning capabilities as well as advanced sensory and perception capabilities to robots. In response, the industry is currently moving to next generation robots that can sense and think and, in response, act; i.e., they can and do act autonomously. By their very

nature and function, such robots typically cannot be isolated from humans. The following table shows the differences between traditional robots and the next generation of robots (called collaborative robots or Cobots).

Traditional Robot	Cobot
Ideal for large companies manufacturing high volumes of same products for long periods	Designed for low volume, high mix production
Requires extensive programming skills & weeks for set up	Easy to deploy with simple programming; inexperienced users can set up in minutes
Programmed for unchanging environment & same movement with minimal need to adapt	Flexible to adapt to changing environment and workpieces
Typically requires safety guarding to keep human workers out of robot's work area	Humans can work alongside robot
Repeats same actions for years	Focus shifts to end-of-arm tooling to increase robot utilization
Expensive robots, system integration & operator training	In-house integration and ease-of-use speed integration promise increased uptime & ROI

These intelligent robots are becoming an increasing portion of the total robotics market. They employ four design principles integral to Industry 4.0:

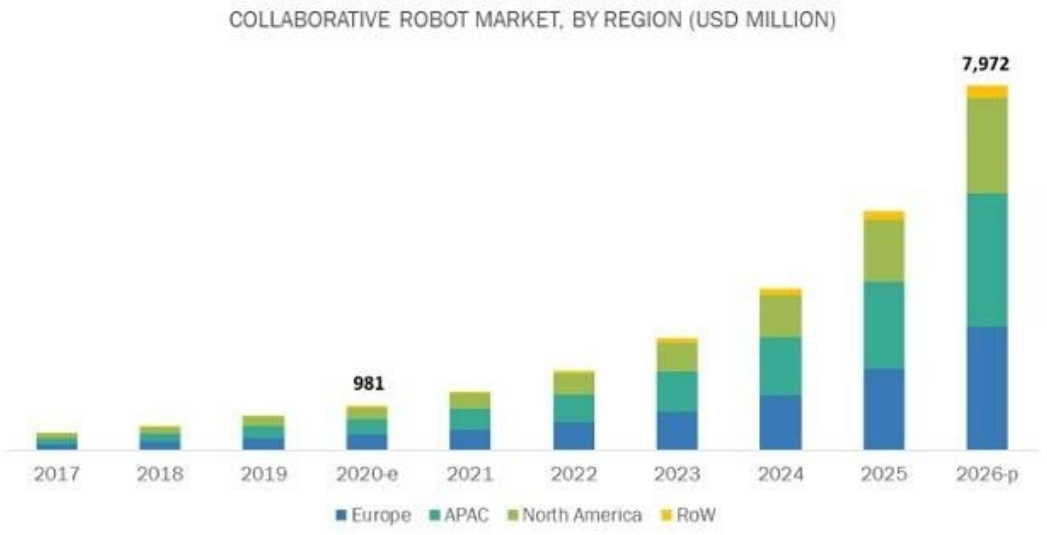
1) Interconnection: the ability of machines, devices, sensors, and people to connect and communicate with each other
2.) Information transparency: provide operators with comprehensive information to make decisions
3.) Technical assistance: the technology facility of systems assist humans in decision making and problem solving; and the ability to help humans with difficult and unsafe tasks
4.) Decentralized decisions: the ability of cyber physical systems to make decisions on their own and to perform their tasks as autonomously as possible

The introduction of intelligent robots is also being accompanied by the introduction of soft robots: robots constructed from highly compliant materials that increase the flexibility and adaptability of possible robot actions. Industry 4.0 robots also offer coordination between robots and a changing environment.

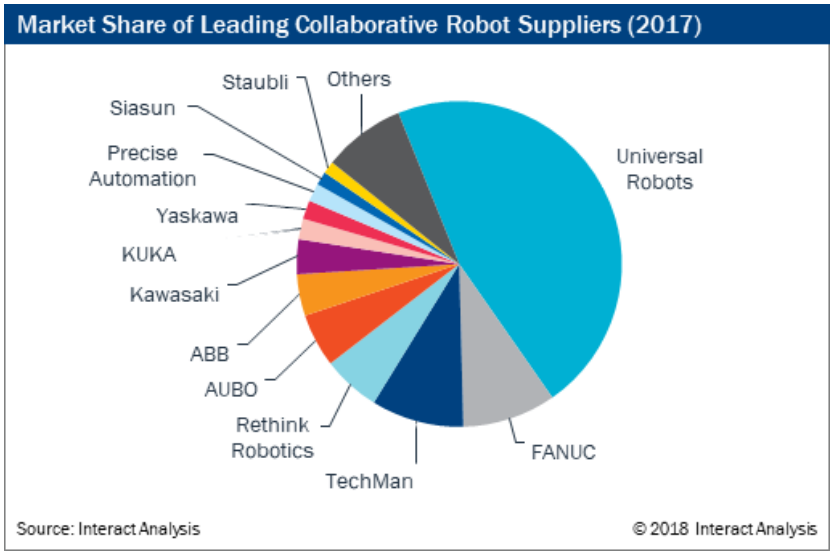
Cobots typically have lower upfront costs and are easier to program. They are also typically small and lightweight so they can be deployed easily into existing manufacturing facilities. That means

they can increase productivity, improve quality and respond more nimbly to changing customer demands.

The North American market for collaborative robots is projected to reach $2.09 billion by 2026 while the global 2026 market is projected to reach $7.97 billion and have a Compound Annual Growth Rate (CAGR) of 41.8% from 2020 to 2026, as shown in the figure below. As the figure shows, the Asian-Pacific region is projected to capture the largest portion of the Cobot market during the period.



The leading COBOT suppliers in 2017 were provided in an article by A Sharman in Interactive Analysis. As shown, Universal Robots of Denmark was the lead supplier at that time.



Cobots with a payload capability of up to 5 Kg are expected to hold the largest share of the near-term market. They handle applications such as pick & place and palletizing. Using them eliminates common errors and damage that typically result when humans perform these tasks. The use of Cobots also eliminates the risk of contamination within processing operations associated with the food & beverage and healthcare industries. They, on the other hand, cannot work today at the speed or accuracy of traditional robots nor can they handle the higher payloads that occur in many industrial operations. The figure below shows some applications of intelligent collaborative robots currently available.

Size of Robotics Industry

Robotics products are typically divided into two main sectors:

1. Industrial Robots, which are stationary robots used in manufacturing processes for purposes of automation. The main benefit of these robots is higher speed and more accuracy than can be obtained from human labor. Typical industries using such robots include automotive, light manufacturing, heavy manufacturing, and food processing. The following are some of the applications of industrial robots:

    - Assembly: robots are capable of automating assembly tasks in factories
    - Material removal: includes grinding, polishing, cutting, and sanding, which are processes well suited for robots due to the need for high precision
    - Material joining and welding, especially arc welding

- Loading and unloading, palletizing, and dispensing material and components during a manufacturing process
- Packaging: this is most popular in the food processing industry; it involves performing repetitious tasks that could create ergonomic risks for humans

Current markets using industrial robots include automotive, electrical/electronics, metal/heavy machinery, chemical – rubber - plastics, and food.

2. Service Robots, which are mobile robots designed to assist or service humans in a wide variety of tasks. They operate through control systems that allow them to respond to their environments.

   Service robots have become established over the last few decades; and they are typically subdivided into professional and personal segments.

   - Professional Service Robots are designed for applications in industry, especially where dirty, dangerous, or unique environments exist. They are employed in logistics, healthcare/medical, military & defense, field or agriculture & forestry, construction, and inspection & maintenance operations.
   - Personal Service Robots are domestic robots performing tasks that service humans at home. They include cleaning and domestic tasks, lawn mowing, rehabilitative & assistive robots also called exoskeleton systems, education, and entertainment.

Industrial Robotics Market Segment

The Industrial Robotics Sector has been growing since the 1960's when automotive OEMs introduced robots into their weld shops. A second growth spurt started in about 2000 when dramatic developments in technology were introduced to industrial applications in response to rising labor costs and increasing labor turnover and shortages. This was also a period when robotic costs were decreasing. Many industries discovered that:

- It was simpler to incorporate robots into their facilities now that talent with the requisite skill set was available
- New, simpler integration of end effector, simpler I/O, and appropriate communication software made robotics easier to implement within existing plant structures
- New interfaces allowed even complex programming tasks to be implemented without using expert suppliers or engineering departments

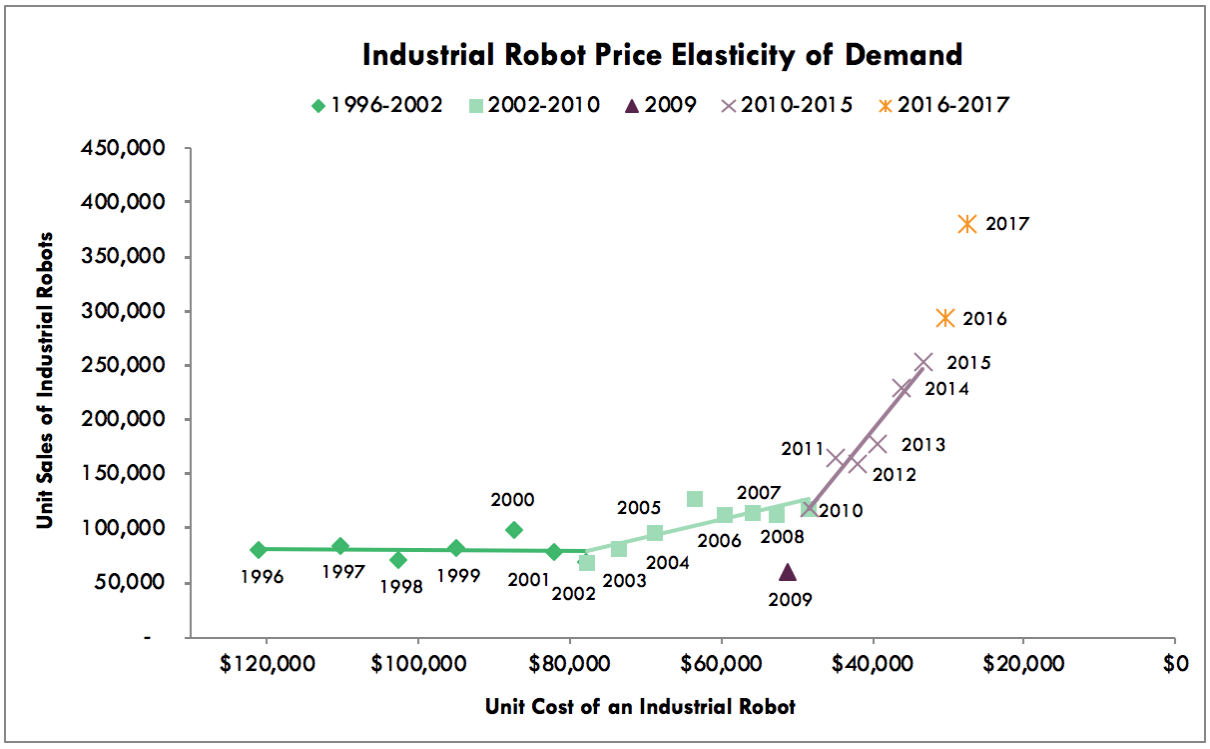
These changes also made it easier for small and medium-sized companies to consider employing robotics in their businesses. This resulted in a major new customer base for the robotics industry.

A 2019 industry study by McKinsey & Company found that, as is typical when new technologies are introduced, the cost of the robotics systems were the key challenge to their greater use. The following diagram from a 2019 article by S Korus of ARK Invest shows industrial robot prices started to dramatically decrease about 2000. As shown, prices today are about 25% of what they were in 2000.

The main drivers triggering investment in robotics and automation solutions in the Industrial Robotics Sector are:

- Reduced cost of production
- Improved product quality
- Increased productivity
- Improved capabilities of robots
- Enabling higher flexibility in production
- Reinforcing/increasing the safety of plant operations

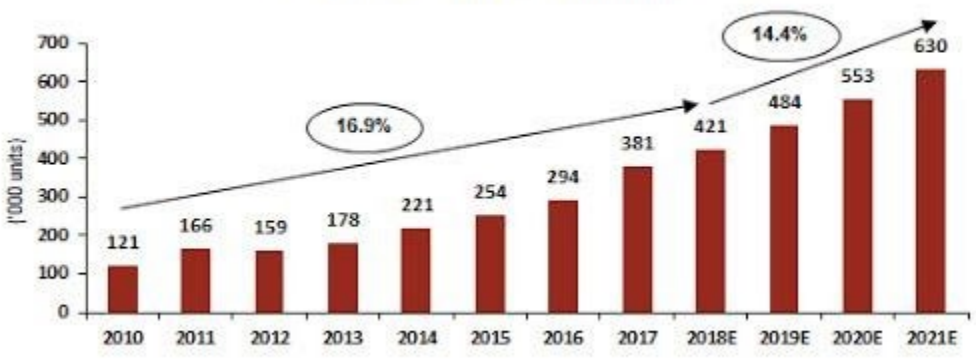
with the net result that automotive companies are employing robots to provide greater production flexibility, electronics companies to provide higher product quality, and pharma companies to provide greater plant flexibility.



Source: ARK Investment Management LLC, 2019 | ark-invest.com; Data from: United Nations Economic Commission for Europe; International Federation of Robotics; Sirkin, Hal, et al. "How Robots Will Redefine Competitiveness." BCG, 23 Sept. 2015, https://arkinv.st/2VLo0Jt.

In response, industrial robots have seen a continually increasing rate of adoption, as shown in the figure below from a 2018 ICICI Securities report. Note that the compound Annual Growth Rate (CAGR) decreased from 16.9 % to 14.4% over the years shown.

Estimated Annual Worldwide Sales of Industrial Robots,



As a result of all these advantages, the International Federation of Robotics has found that industry is now installing many types of robots:

Type of Robot	Percent of Installed Base
Traditional Industrial Robot	27%
Autonomous Ground Vehicle	23%
Collaborative Robot	17%
Service Robot	4%
Cells for Loading/Unloading Machines	20%
Other Automation Solutions	8%

The most common applications of industrial robots are materials handling (including picking & packaging, pelletizing, and machine tending), assembly, and welding. Of the industries employing robots, the electrical/electronics industry seems to be the most sophisticated in terms of robot adoption.

Three market studies for the Industrial Robotics Industry have been published that covered the period to 2024 (at least).

- Global Market Insights: **Industrial Robotics Market Size & Forecast, 2017-2024**

  The global market was stated as exceeding $35 billion in 2016 and was projected to reach $80 billion by 2024, with a Compound Annual Growth Rate (CAGR) of 10% over 2017 – 2024

- MarketsandMarkets: **Industrial Robotics Market – Global Forecast to 2024**

  The global market for 2019 was stated as $48.7 billion and was projected to reach $75.6 billion by 2024, with a CAGR of 9.2% over 2020-2024

- Fortune Business Insights: **Industrial Robots Market Size, Share and Global Trend; and Geography Forecast till 2026**

  The global market for 2018 was stated as $18.78 billion and was projected to reach $59.99 billion by 2026, with a CAGR of 15.7% over 2020-2027. This implies that the Industrial Robotics Market would be $44.8 billion in 2024.

As is typical for such market studies, the market size includes peripherals, software and system engineering. ***The robot itself typically accounts for 30% of the total cost when installing robots while accessories account for 25% and auxiliary hardware, software & programming, and installation account for 45%.***

Based on these studies, a best estimate on the size of the global Industrial Robotics Market is that it will reach $75 - $80 billion by 2024, with CAGR of 9-10% over the period to 2024.

Appendix C: Summary of Interviews with New Venture Companies and Service Providers in Robotics Industry

List of company participants

Name	Title	Company	Location
Charles Quinn	Co-Founder & CEO	Greenzie	Atlanta, GA
Christian Fritz	Founder & CEO	*stealth startup*	Palo Alto, CA
Tyler Weaver	Roboticist / Senior Software Engineer	Picknik Robotics (15 FTE)	Boulder, CO
Jack Morrison	Co-Founder & CEO	Scythe Robotics (25 FTE)	Boulder, CO
Ralf Opper	Business Development Manager	Bosch Rexroth ctrlX Automation Group (29k FTEs)	Greenville, SC
Katherine Scott	Developer Advocate	Open Robotics Foundation	San Francisco, CA
Colleen Hahn	VP of Marketing & Communications	Perrone Robotics (<50 FTE)	Crozet, VA

Alberto Moel	VP of Strategy & Partnerships	Veo Robotics	Waltham, MA
Susan Payne	Co-Owner & CFO	SuperDroid Robots (10-100 FTE)	Fuquay-Varina, NC
Mickey Cowden	Owner / Roboticist	Cowden Technologies (<10 FTE)	Blacksburg, VA
Donovan Sydow	Director of Field Operations	iUNU (10-100 FTE)	Seattle, WA
Anonymous	CTO	Chapulin (10-100 FTE)	New York, NY

Core questions

1. What are the main strengths and weaknesses of your local business environment? (e.g. training, funding, talent, sales)?
2. Describe any unique challenges or advantages you experience as a robotics company in your area.
3. Have you considered establishing an office in another city (or relocating entirely)? If so, which city and why?
4. Are you a member of any local or online robotics communities? If so, please name or link to the one most significant to you.

Imagine a mid-sized city on the East Coast starts a robotics innovation hub. In this facility, established companies, startups, and academic programs have private office space and share common labs with state-of-the-art hardware and prototyping tools. They can also participate in joint challenges (e.g. for grants and government contracts). The goal is to grow robotics businesses, foster collaboration, and spark new ideas.

5. What, if anything, might a hub like this provide to your business?
6. Would you apply to join the community in person? Why or why not?

List of service provider participants

Name	**Title**	**Organization**	**Location**
Lena Johnson	Graduate Administrative Assistant	Maryland Robotics Center at the University of Maryland	College Park, MD
David C. Conner	Assistant Professor in the Department of Physics, Computer Science and Engineering	Christopher Newport University	Newport News, VA
George Konidaris	John E. Savage Assistant Professor in the Department of	Brown University	Providence, RI

	Computer Science		
M. Ani Hsieh	Research Associate Professor in Mechanical Engineering & Applied Mechanics	University of Pennsylvania's General Robotics, Automation, Sensing and Perception (GRASP) Lab	Philadelphia, PA
Christopher J. Mordaunt	Professor and Program Head for Mechanical Engineering Technology	John Tyler Community College	Chester, VA
Sherif Abdelwahed	Professor in the Department of Electrical and Computer Engineering	Virginia Commonwealth University	Richmond, VA
Ali Greenberg	Outreach Manager	Lighthouse Labs	Richmond, VA
Elliot McAllister	CEO/CTO	Skyphos Industries Inc. (former Lighthouse Labs Program participant)	Blacksburg, VA
Orkun Ozturk	Marketing Development Representative	NexPCB Accelerator	Ningbo, China
Marty Kaszubowski	Executive Director	Old Dominion University Institute for Innovation & Entrepreneurship (Innovation Center)	Norfolk, VA

Interview Questions for Universities

1. Say I am a student in your program and I want to work in the robotics industry. What courses or other opportunities would you recommend to me?
2. What proportion of your graduates would you estimate go on to work in: academia, established robotics companies, robotics startups, other?
3. Do graduates stay local or move? If they move, where are the biggest hubs?
4. Say I am a student in your program, and I am interested in starting a new robotics venture. What services could your department provide to help me get started? Where would you direct me if I asked for more help with business training, fundraising, or facilities?
5. If new ventures focused on robotics were founded by your graduates, can you provide contact information of them? Any provided should be added to the New Ventures to be Interviewed.
6. What in your opinion prevents more students from starting their own ventures during or after graduate school?

7. What sort of interactions does your robotics program have with robotics companies? Do you consider these valuable for your department? Why or why not?
    a. Do these companies provide projects for student term projects?
    b. Do they provide summer internships to your students?
    c. Do faculty engage as consultants with them?
    d. Do any of these activities results in students starting new ventures or the companies starting new product lines?
8. Imagine a mid-sized city within 300 miles of your location starts a robotics innovation hub. In this facility, established companies, startups, and academic programs have subsidized private office space and share common labs with state-of-the-art robots. What programs or amenities for academic partners might entice your program to participate?
9. What, if any, impacts do you believe the remote working environment that covid-19 has popularized will have on the working and innovation process for the robotics industry?

Interview Questions for Incubators and Accelerators

1. Can you provide some measures you employ to measure success?
2. How many ventures are active at your incubator/accelerator?
3. What services do you provided to your residents?
4. How do new ventures learn about your incubator/accelerator; and get accepted to join your program?
5. What challenges do you face in incubating new ventures in your area?
6. Training/education, funding, facilities, talent, leads—describe how startups in your area get access to each of these. Are there startups in certain industries that aren't served well by the current model?
7. What would you allocate money and funding toward to improve the startup ecosystem in your area?
8. Have you ever turned a good idea away from your program? If so, why?
9. Have you ever referred a startup to a different program, for example, one that made more sense for their industry?
10. Imagine a mid-sized city within 300 miles of your location starts a robotics innovation hub. In this facility, established companies, startups, and academic programs have subsidized private office space and share common labs with state-of-the-art robots. What programs or amenities for incubator/accelerator partners might entice your organization to collaborate?
11. What, if any, impacts do you believe the remote working environment that covid-19 has popularized will have on the working and innovation process for the robotics industry?

Appendix C: List of Robotics Companies in Virginia

*Denotes Hampton Roads Location

Company Name	Location	Robotics Sector/Use	Industry	Website
AC&E, Inc.	Blacksburg	Software	Advanced Manufacturing	http://www.acel.us/
Advanced Marine Vehicles (Tridentis)*	Hampton Roads - Norfolk	Automation	Advanced Manufacturing	http://www.advancedmarinevehicles.com/
Advanced Micro Robotics	Sterling	Hardware	Advanced Manufacturing	
Amazon	Arlington	Hardware & Automation User	Information Technology, Distribution & Logistics	https://www.aboutamazon.com/
Automation Equipment Services Group*	Hampton Roads - Virginia Beach	Hardware	Advanced Manufacturing	https://www.aes-g.com/
Booz | Allen | Hamilton*	Virginia	User	Information Technology	https://www.boozallen.com/
Canon Virginia*	Hampton Roads - Newport News	Hardware User	Advanced Manufacturing	https://www.cvi.canon.com
Continental*	Hampton Roads - Newport News	Hardware User	Advanced Manufacturing	https://www.continental.com/en-us
Cowdin Technologies	Blacksburg	Automation	Advanced Manufacturing	https://cowden.tech/
Dollar Tree*	Hampton Roads - Chesapeake	Hardware User	Business & Shared Services, Distribution & Logistics	https://www.dollartree.com/dt-home-2021
Draper	Reston	Automation	Advanced Manufacturing	https://www.draper.com/
DroneUp*	Hampton Roads - Virginia Beach	Automation	Advanced Manufacturing	https://www.droneup.com/
EVMS*	Hampton Roads - Norfolk	Hardware User	Business & Shared Services (Healthcare)	https://www.evms.edu/
Flexicell, Inc.	Ashland	Automation	Advanced Manufacturing	https://pearsonpkg.com/

General Dynamics*	Virginia		Information Technology, Advanced Manufacturing	https://www.gd.com/
Huntington Ingalls*	Hampton Roads - Newport News	Hardware User & Autonomation	Advanced Manufacturing	https://huntingtoningalls.com/
Hush Aerospace*	Hampton Roads - Virginia Beach	Automation	Advanced Manufacturing	https://www.hush.aero/
IMS Gear*	Hampton Roads - Virginia Beach	Hardware	Advanced Manufacturing	https://www.imsgear.com/en/
Infamous Robotics	Fairfax	Hardware	Advanced Manufacturing	https://www.infamousrobotics.com/index.html
Intellibot	Richmond	Automation	Advanced Manufacturing	https://diversey.com/en/solutions/taski-intellibot-robotics
ivWatch*	Hampton Roads - Newport News	Hardware User	Biotech	https://www.ivwatch.com/
Jewett Automation	Richmond	Automation	Advanced Manufacturing	https://jewettautomation.com/
Liebherr*	Hampton Roads - Newport News	Hardware User	Advanced Manufacturing	https://www.liebherr.com/en/usa/start/start-page.html
Lineage Logistics*	Hampton Roads - Chesapeake		Distribution & Logistics	https://www.lineagelogistics.com/
Lockheed Martin*	Virginia	User	Information Technology	https://www.lockheedmartin.com/en-us/index.html
NASA*	Hampton Roads - Newport News	Automation, Software, Hardware	Government	https://www.nasa.gov/
Perrone Robotics	Crozet	Automation	Advanced Manufacturing	https://www.perronerobotics.com/
Port of Virginia*	Hampton Roads - Portsmouth	Hardware User	Advanced Manufacturing	https://www.portofvirginia.com/
QVC*	Hampton Roads	Hardware User	Distribution & Logistics	https://www.qvc.com/

	- Suffolk			
Rendyr, Inc.	Blacksburg	Hardware	Advanced Manufacturing	https://www.rendyr.com/optic-portable-laser-cutter/overview
Riverside Health*	Hampton Roads - Newport News	Hardware User	Business & Shared Services (Healthcare)	https://www.riversideonline.com/
Robotic Vision Technologies	Great Falls	Automation	Advanced Manufacturing	https://www.roboticvisiontech.com/
Ryson*	Hampton Roads - Yorktown	Hardware	Advanced Manufacturing	https://ryson.com/
Sentara*	Hampton Roads - Norfolk	Hardware User	Business & Shared Services (Healthcare)	https://www.sentara.com/hampton-roads-virginia/
Sentinel Robotics Solutions	Wallops Island	Automation	Advanced Manufacturing	https://srsgrp.com/
Service Robotics & Technologies	Springfield	Software	Distribution & Logistics	https://srtlabs.com/
SimIs*	Hampton Roads - Portsmouth	Software	Information Technology	https://www.simisinc.com/
Simplimatic Automation	Forest	Automation	Advanced Manufacturing	https://simplimatic.com/
Smithfield Foods*	Hampton Roads - Smithfield	Hardware User	Food & Beverage Processing, Distribution & Logistics	https://www.smithfieldfoods.com/
Stihl, Inc.*	Hampton Roads - Virginia Beach	Hardware User	Advanced Manufacturing	https://www.stihlusa.com/
SVT Robotics*	Hampton Roads - Norfolk	Software	Distribution & Logistics	https://www.svtrobotics.com/
Swisslog*	Hampton Roads - Newport News	Hardware	Advanced Manufacturing	https://www.swisslog.com/en-us
Target*	Hampton Roads - Suffolk	Hardware User	Distribution & Logistics	https://corporate.target.com/
Torc Robotics (now	Blacksburg	Automation	Advanced Manufacturing	https://torc.ai/

Daimler Trucks)				
US Air Force*	Virginia	User	Government	https://www.airforce.com/
US Army*	Virginia	User	Government	https://www.army.mil/
US Navy*	Virginia	User	Government	https://www.navy.mil/
VRC Metal Systems*	Hampton Roads - Chesapeake	Hardware User	Advanced Manufacturing	https://vrcmetalsystems.com/

Appendix D: Hub Service Providers

Ecosystem Support Providers	
Regional	
757 Collab (757 Angels & 757 Accelerate)	Old Dominion University - Institute for Innovation & Entrepreneurship
Hampton Roads Innovation Collaborative	Tech Center Research Park
Techstars Hampton Roads	Norfolk Innovation Corridor/Greater Norfolk Corporation
In-company innovation activities: "Dogfish Labs" and "Autonomy Incubator"	Peninsula Technology Incubator
State	
State Accelerators: Lighthouse Labs, RAMP	Center for Innovative Technology (CIT)
Virginia Economic Development Partnership	Virginia Tech