





The International Forum to Advance First Responder Innovation

Capability Gap 7 “Deep Dive” Analysis

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International Forum to Advance
FIRST RESPONDER INNOVATION

Homeland Security

Science and Technology

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International Forum to Advance
FIRST RESPONDER INNOVATION

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Introduction

Background

The International Forum to Advance First Responder Innovation (IFAFRI) is an organization of government leaders from across the globe, focused on enhancing and expanding the development of affordable and innovative technology for first responders worldwide.

IFAFRI does this by:

1. Working with the global first responder community to define a list of common, high priority capability gaps;
2. Providing a platform for international collaboration on innovative research and development (R&D) initiatives and solutions;
3. Characterizing the global first responder markets, to inform and guide industry and academia about market opportunities and to incentivize these actors to develop and produce innovative technology solutions to first responder capability gaps; and
4. Providing information about relevant and available first responder technologies to the first responder community, while not endorsing any specific technology, product, or manufacturer.

In order to respond more safely, efficiently, and effectively to everyday and catastrophic incidents, first responders around the world need technologically advanced tools and equipment that are affordable and innovative. However, there is no centralized mechanism for first responders to identify and discuss shared needs and requirements. In addition, overall purchasing of tools and equipment is fragmented into smaller quantities, which provides little incentive for industry to commercialize innovative technologies. Therefore, the lack of consolidated requirements for first responders, along with fragmented purchasing, results in an inadequate amount of affordable, new technology being available for first responder use.

The purpose of this document is to characterize the markets and identify technology solutions relevant to IFAFRI's Capability Gap 7: *The ability to conduct on-scene operations remotely without endangering responders.* IFAFRI is publishing this information to identify potential areas of R&D where there may be opportunity for industry and academia to develop innovative solutions. Further, it is intended to provide industry and academia with key data points and analysis that will inform their decision on entering or expanding into related markets.

IFAFRI Membership

IFAFRI is currently composed of members from 13 different countries and the European Commission, including Australia, Canada, Finland, Germany, Israel, Japan, the Netherlands, New Zealand, Singapore, Spain, Sweden, the United Kingdom, and the United States. The figure below illustrates the global composition of IFAFRI.[1]

[1] Note, IFAFRI membership for France and Mexico is pending.

IFAFRI *Common Global Capability Gaps*

This document is focused on the fifth of ten Common Global Capability Gaps identified by IFAFRI. The list of current gaps includes:

Capability Gap 1	The ability to know the location of responders and their proximity to risks and hazards in real time
Capability Gap 2	The ability to detect, monitor, and analyze passive and active threats and hazards at incident scenes in real time
Capability Gap 3	The ability to rapidly identify hazardous agents and contaminants
Capability Gap 4	The ability to incorporate information from multiple and nontraditional sources into incident command operations
Capability Gap 5	The ability to maintain interoperable communications with responders in any environmental conditions
Capability Gap 6	The ability to obtain critical information remotely about the extent, perimeter, or interior of the incident
Capability Gap 7	The ability to conduct on-scene operations remotely without endangering responders
Capability Gap 8	The ability to monitor the physiological signs of emergency responders
Capability Gap 9	The ability to create actionable intelligence based on data and information from multiple sources
Capability Gap 10	The ability to provide appropriate and advanced personal protective equipment

The first four capability gaps on this list were adopted by IFAFRI in 2016. To arrive at this initial set of capability gaps, the IFAFRI membership conducted analyses of first responder capability gaps in their countries. Some of the IFAFRI participants used the methodology presented in the U.S. Department of Homeland Security (DHS) Science and Technology Directorate's (S&T) Project Responder 4 (PR4) report, as a guide in their analyses. Project Responder 4 is the fourth in a series of studies that focuses on identifying capability needs, shortfalls, and priorities for catastrophic incident response. The methodology is based upon discussions with federal, state, and local first responders, as well as technical subject matter experts.

After submission of first responder capability gaps from IFAFRI participants, a comparative analysis of all submitted gaps was conducted. The analysis found a significant level of overlap among the various countries' gaps, which resulted in the proposal and adoption of the first four *Common Global Capability Gaps* in 2016.

Between 2016 and 2018, IFAFRI's Capability Gaps Committee further refined and formalized its process for adding capability gaps to the list. In 2018, individual countries solicited national capability gaps from first responders in their countries and submitted these to the Capability Gaps

Committee. In total, 78 national capability gaps were received from IFAFRI countries. These gaps were then synthesized to eliminate redundancy and provide overarching gaps that aggregate multiple similar gaps when needed, which resulted in a set of 45 gaps. Three of the gaps corresponded to the initial four *Common Global Capability Gaps*, leaving 42 gaps for prioritization. The prioritization process resulted in the addition of the Capability Gaps 5-10 to the *Common Global Capability Gaps* list.

To date, similar "deep dive" analyses have been conducted for each of IFAFRI's *Common Global Capability Gaps*. Each of these documents has been published to the IFAFRI Web site, and is available for download. It is important to note that continued market research will be required to ensure awareness of current efforts and account for new actors in these capability gap areas.

Capability Gap 7

The ability to conduct on-scene operations remotely without endangering responders

The missions that emergency responders perform can place them at risk of bodily harm. Many line of duty injuries and deaths occur because they must perform tasks in hazardous environments. Suppression of wildfires, neutralizing explosive devices, and responding to hazardous materials (HAZMAT) incidents are examples of tasks that can be particularly unsafe. The focus of this capability gap is to identify solutions that can execute emergency response tasks while responders remain at a safe distance. A current example is the use of explosive ordnance disposal (EOD) robots to examine and defuse explosive devices. The operator is able to direct the EOD robot from a safe distance via a controller. Should the device detonate, it is only the robot that is destroyed, and the operator remains safe. Responders are interested in the development of tools or systems that will perform other tasks that can endanger responders.

This gap is distinct from another gap, "the ability to obtain critical information remotely about the extent, perimeter, or interior of the incident," which focuses on the ability to obtain and maintain real-time, continuous surveillance of the incident scene. It is possible that similar platforms (e.g., unmanned vehicles) may be used to address both gaps, however, the focus of this gap is on the execution of tasks. This capability gap calls attention to the need to expand current remotely operated systems for additional hazardous response missions.

While there is a high level of public and private funding for advancing technology for conducting on-scene operations remotely, emergency responders in IFAFRI nations continue to face challenges. Many factors contribute to this lack of progress, such as country size and degree of centralized response functions, but the main obstacle is a lack of a comprehensive, affordable solution.

While there are a number of solutions in use by responders, these solutions still have shortcomings when considering the state of technology today for remote operations. This study uses the list of existing first responder gear in the *Statement of Objectives* (SOO) document for Gap 7. This list encompasses the current methods of remote operations available for first responders. Each method was considered a "technology type" with a corresponding, relevant market. There are three technology types for this capability gap:

- Unmanned ground systems (UGS) (e.g., tactical robots)
- Unmanned marine systems (UMS) (e.g., water rescue)
- Unmanned aircraft systems (UAS)

Methodology

This section provides a brief overview of the processes used to obtain and assess the findings presented in this report.

Research Methods

The data presented in this report was gathered from publicly available information sources, including market reports and company web sites. The study team conducted a global scan of existing and in-development technology solutions with the aim of identifying and assessing the primary market for technologies related to this gap. However, the data presented in this report should not be considered exhaustive. This document does not contain any proprietary data, nor does it endorse or advocate for any of the technology solutions described herein. Further, the study team did not validate any of the manufacturers' claims found in their product descriptions.

Market Quantification

All relevant markets are quantified utilizing overall global revenue figures, unless otherwise noted, for the forecast period 2019-2023. The Compound Annual Growth Rate (CAGR) within each segment is used to measure growth within the forecast period and to extrapolate data when figures were not publicly available.

Market Phase and Factors

Market phase is determined using factors in the Industry Life Cycle Model. The adapted market phase definitions are presented in the following table.[2] Market factors are assessed by examining barriers to entry and market opportunities, as determined through secondary research.

Nascent	New market need with dominant solutions not yet determined; growth begins increasing toward end of cycle
Growth	Dominant solutions begin to emerge; high growth rates
Mature	Often fewer firms than growth phase, as dominant solutions continue to capture the majority of market share and market consolidation occurs; lower growth rates that are typically on par with the general economy
Decline	Further market consolidation; rapidly declining growth rates

Competitive Landscape

This study also examines the competitive landscape within each market, accounting for the total number of firms, along with the number of responder-specific solutions. Total number of firms was estimated using the number of key players given within publicly available market reports for each segment. Responder-specific solutions were identified using a more tailored search. This search included examining the product offerings of key players listed in publicly available market reports to determine their relevance to the capability gap and conducting targeted keyword searches in order to identify solutions from additional companies.

Presentation

This report includes a “Market Overview” that summarizes the overall market and provides the market quantification data for each segment. The report also presents the key findings for each market segment in the “Market Highlights” section, with a one-page summary for each segment. In addition, the “Competitive Landscape” section further categorizes the total number of firms participating in the market by segment and highlights responder-specific solutions currently available or in-development.

Synopsis Overview

IFAFRI has been conducting an ongoing global capability gaps market analysis in order to meet its objectives characterizing global first responder markets to inform and guide industry and academia. The key objective of this study is to characterize the markets relevant to Capability Gap 7. This synopsis highlights key data and analysis identified as part of this study.

Market Definitions and Segmentation

This study uses the list of existing first responder gear in the *Statement of Objectives 7* (SOO 7) document to further define and segment the relevant markets for Capability Gap 7. For the four types of gear given for this capability gap, it was determined that due to the broadness of this gap, one overarching market was not identified. Thus, multiple markets may represent these technology types. These markets are used for market definition, segmentation and further assessment (see Market Overview and Market Figures section).

Market Quantification

The primary market is quantified utilizing overall revenue figures derived from global markets. Growth is measured using an estimated CAGR. As stated above, a primary market was not identified. Please refer to the Market Overview and Market Figures sections below.

Competitive Landscape

Based upon third-party market research reports, there are 81 key players and innovators identified within the global, primary market for Capability Gap 7. These key global players and innovators appear to offer solutions that address, in part, the ability to conduct on-scene operations remotely without endangering responders. However, none of the solutions identified within this assessment appear to meet all of first responders' target objectives for this gap.

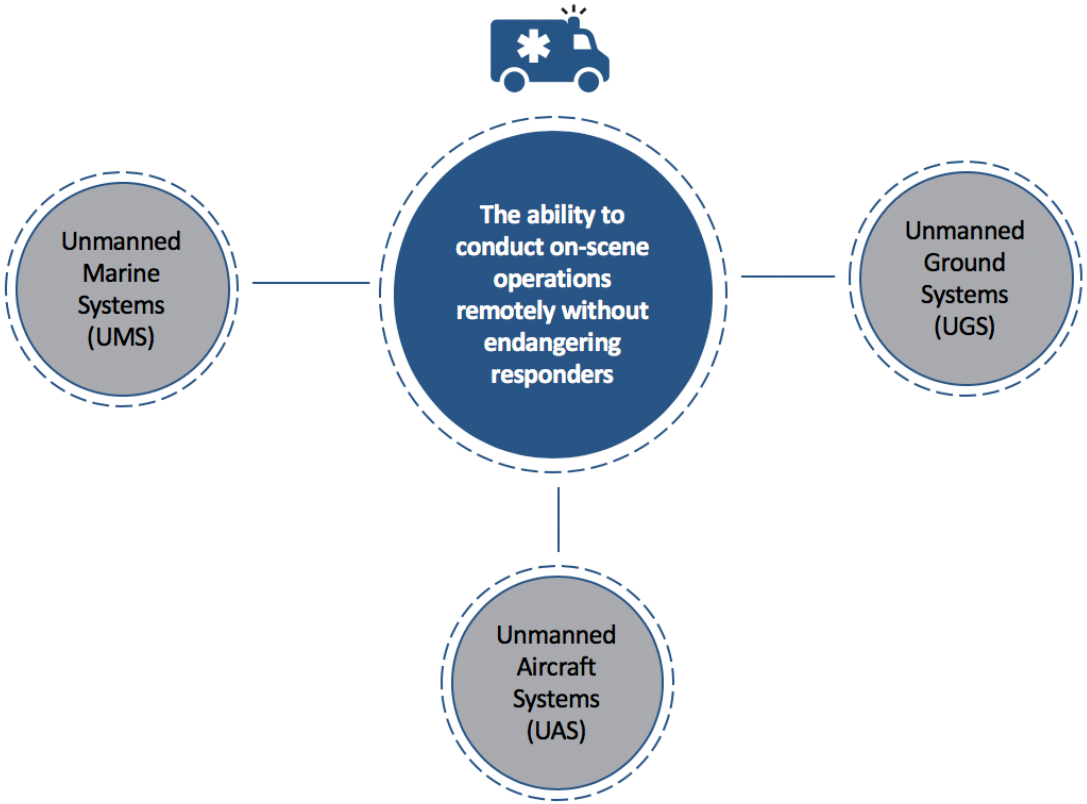
Summary

In summary, although there was no primary market identified, the related markets all appear to be growing. This growth in and of itself presents a great opportunity for new solutions to enter the market. When examining 91 existing solutions and 20 developing solutions in this assessment, none fulfilled all of the objectives for this gap. Therefore, any solutions that address these target objectives and allow the ability to conduct on-scene operations remotely will likely have the greatest commercial potential.

Market Overview

Capability Gap 7 is **the ability to conduct on-scene operations remotely without endangering responders**. This gap is largely focused on the execution of tasks and the need to expand current remotely operated systems for hazardous response missions.

Market Segmentation



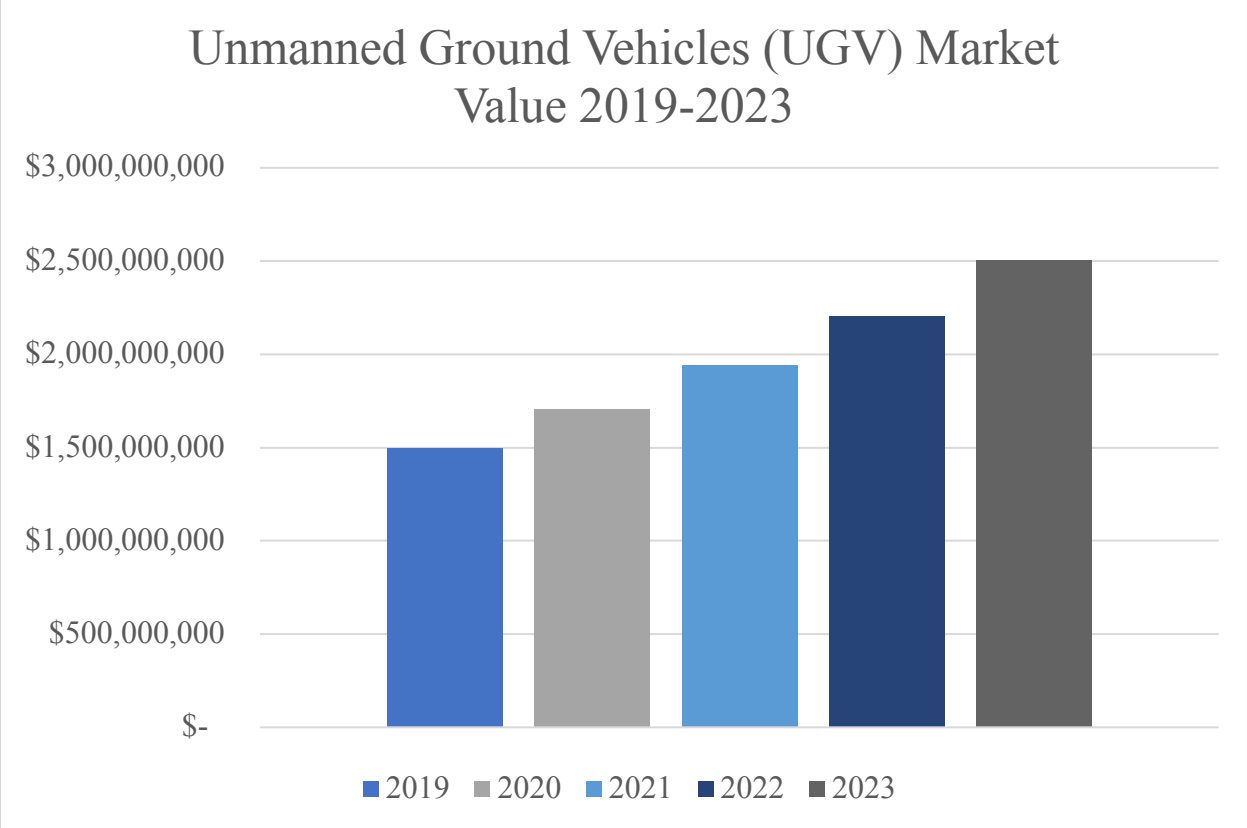
Due to the broadness of this gap, one overarching market was not able to be identified.

Capability Gap 7 – The ability to conduct on-scene operations remotely without endangering responders

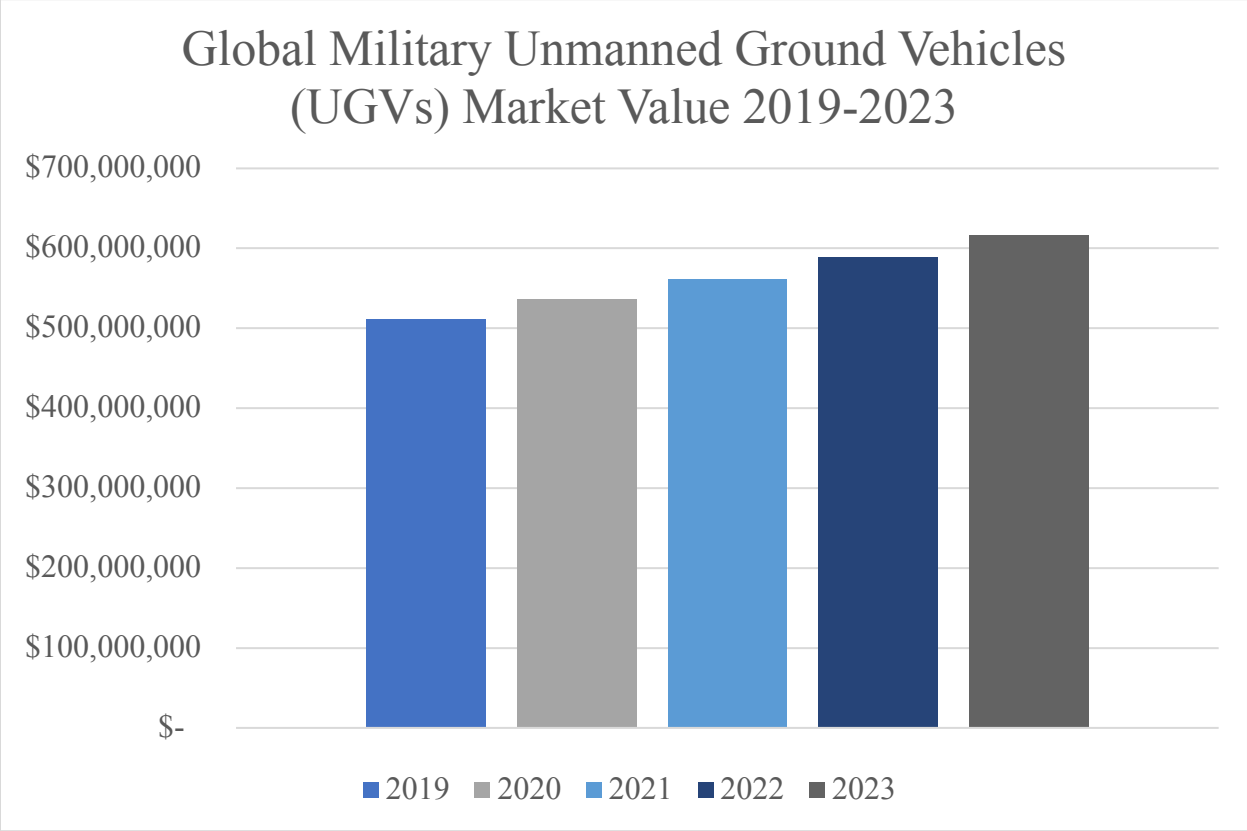
First responders need the ability to consistently execute on-scene maneuvers from a safe distance during an incident. When responders work in areas with limited access to different networks, they face significant challenges to do their jobs more safely and effectively. There are multiple tasks that can be directed from a safe distance to improve the health and safety of emergency responders. Responders would like solutions that are able to perform gross motor tasks (e.g., lifting, pushing, pulling); complete missions in hazardous atmospheres; execute missions in locations that are difficult for humans to reach; and carry out intricate tasks. Having this capability will likely improve responders' abilities to help during incident response.

A myriad of remote operations solutions currently exist within the market. However, not one of these solutions appears to meet all of responders' target objectives, which include providing mission-appropriate capability to remotely carry out emergency response tasks; operating in hazardous conditions; and operate in a beyond line-of-sight capability.

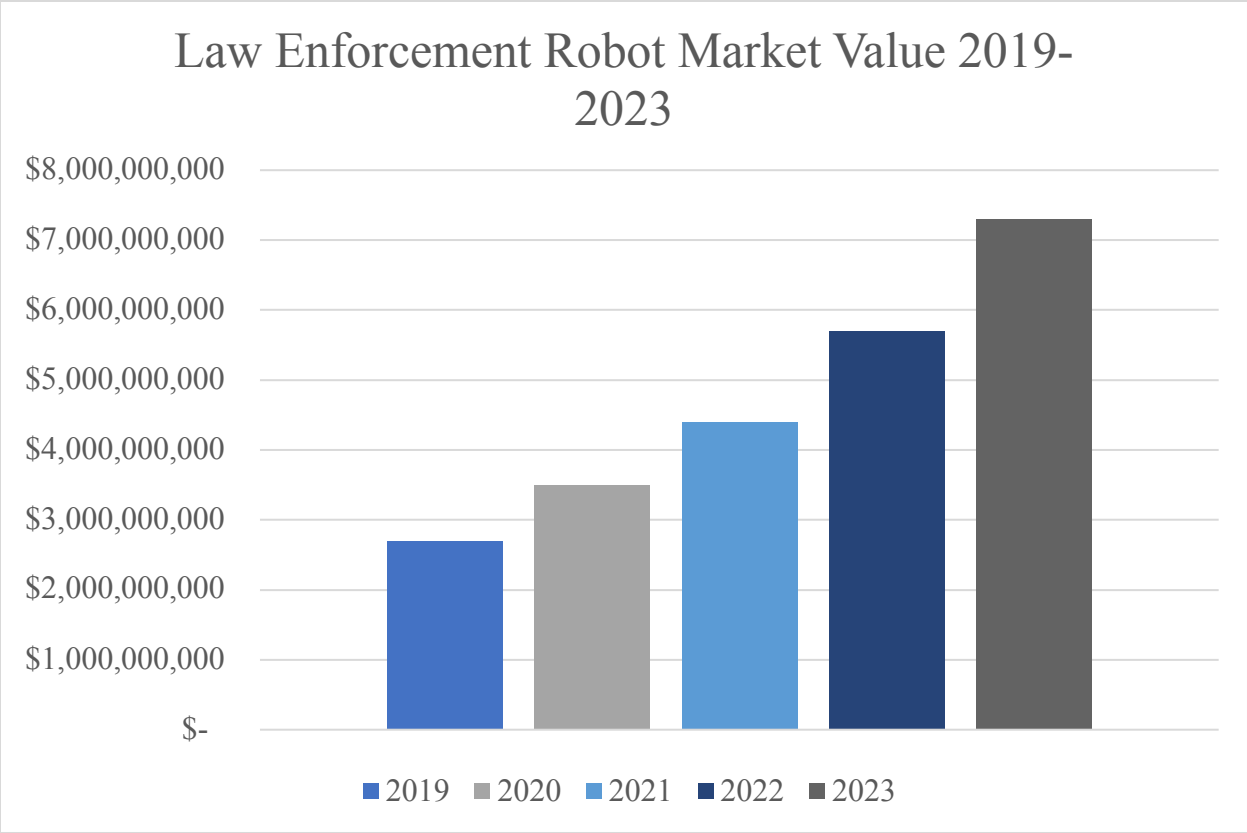
The Unmanned Ground Vehicles (UGV) Market is used to define, quantify and assess the various types of solutions available. This market was worth $1.5 billion USD in 2019 and is projected to grow at a Compound Annual Growth Rate (CAGR) of 13.7 percent through 2023. This equates to a market value of more than $2.5 billion USD in 2023.



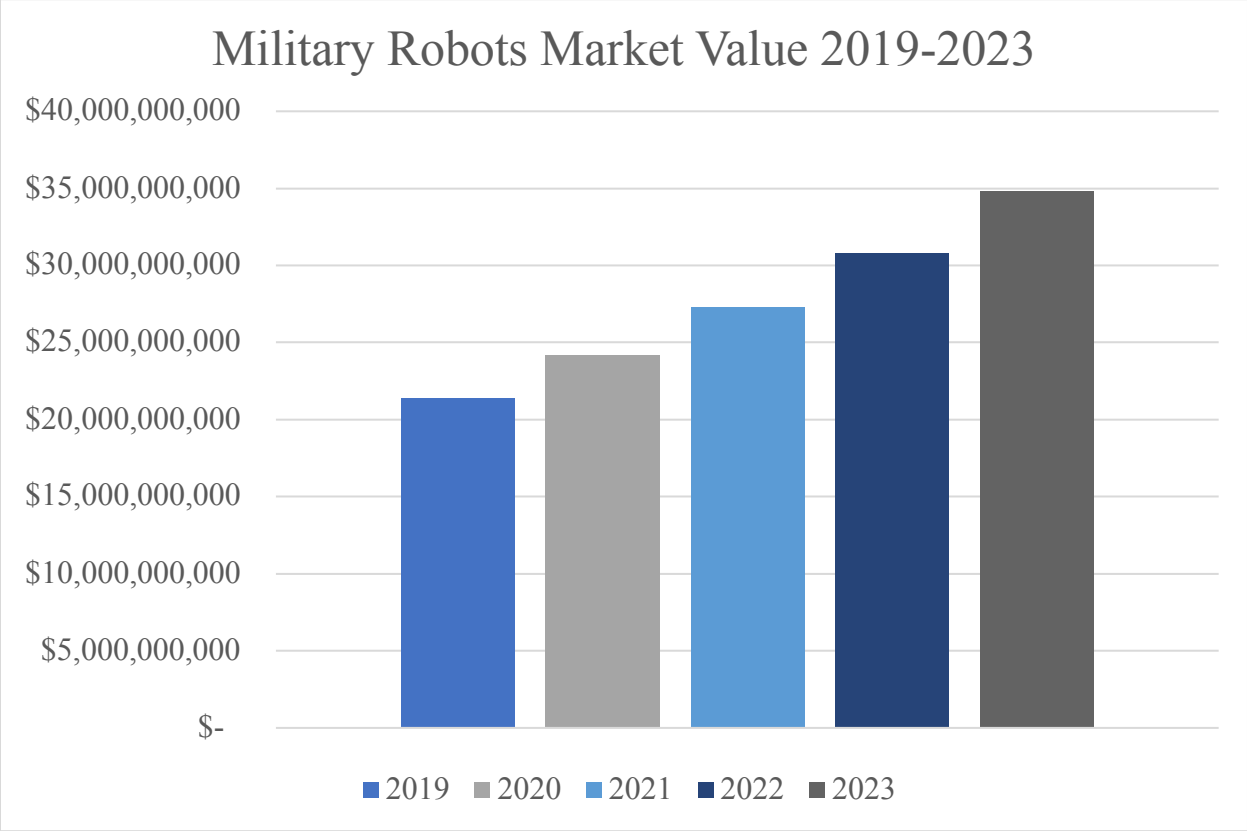
The Global Military Unmanned Ground Vehicles (UGVs) Market is used to define, quantify and assess the various types of solutions available. This market was worth $444.8 million USD in 2016 and is projected to grow at a Compound Annual Growth Rate (CAGR) of 4.8 percent through 2023. This equates to a market value of more than $615.7 million USD in 2023.



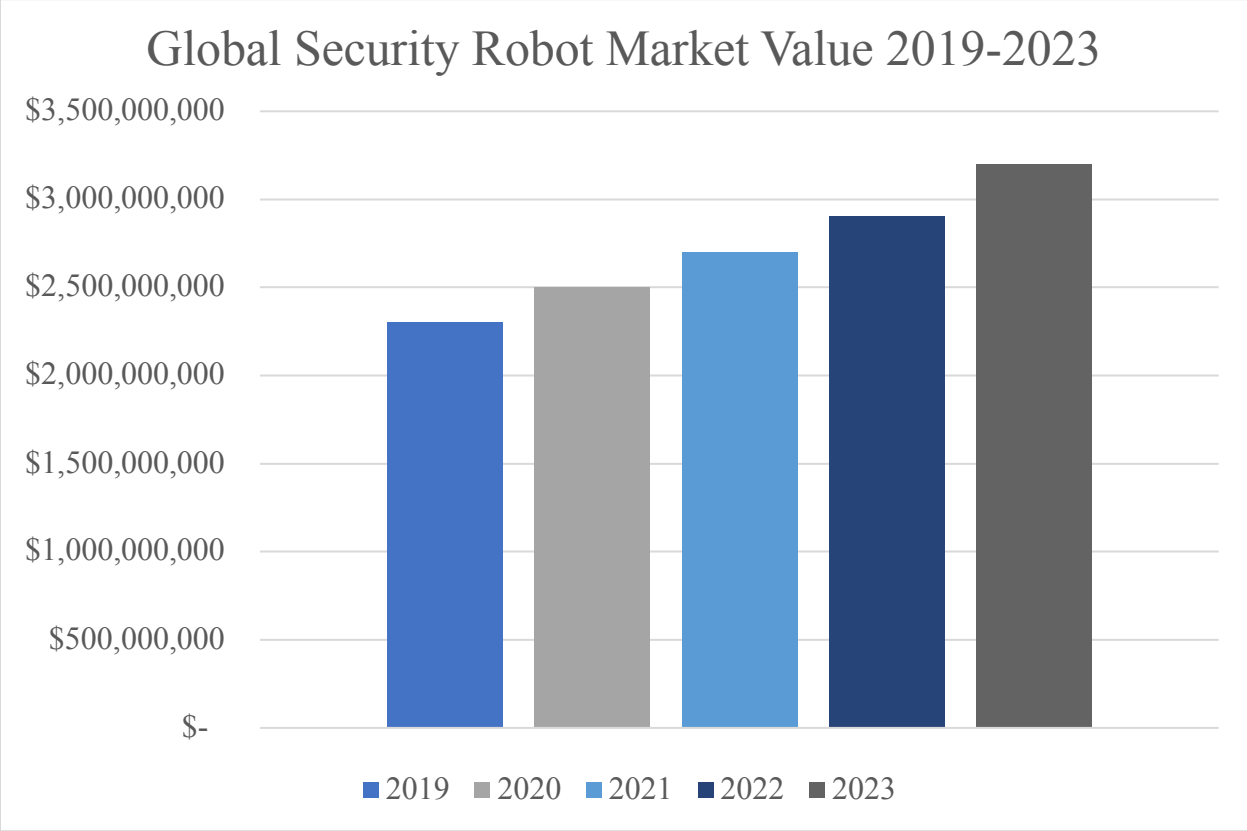
The Law Enforcement Robot Market is used to define, quantify and assess the various types of solutions available. This market was worth $1.0 billion USD in 2015 and is projected to grow at a Compound Annual Growth Rate (CAGR) of 28.2 percent through 2023. This equates to a market value of more than $7.3 billion USD in 2023.



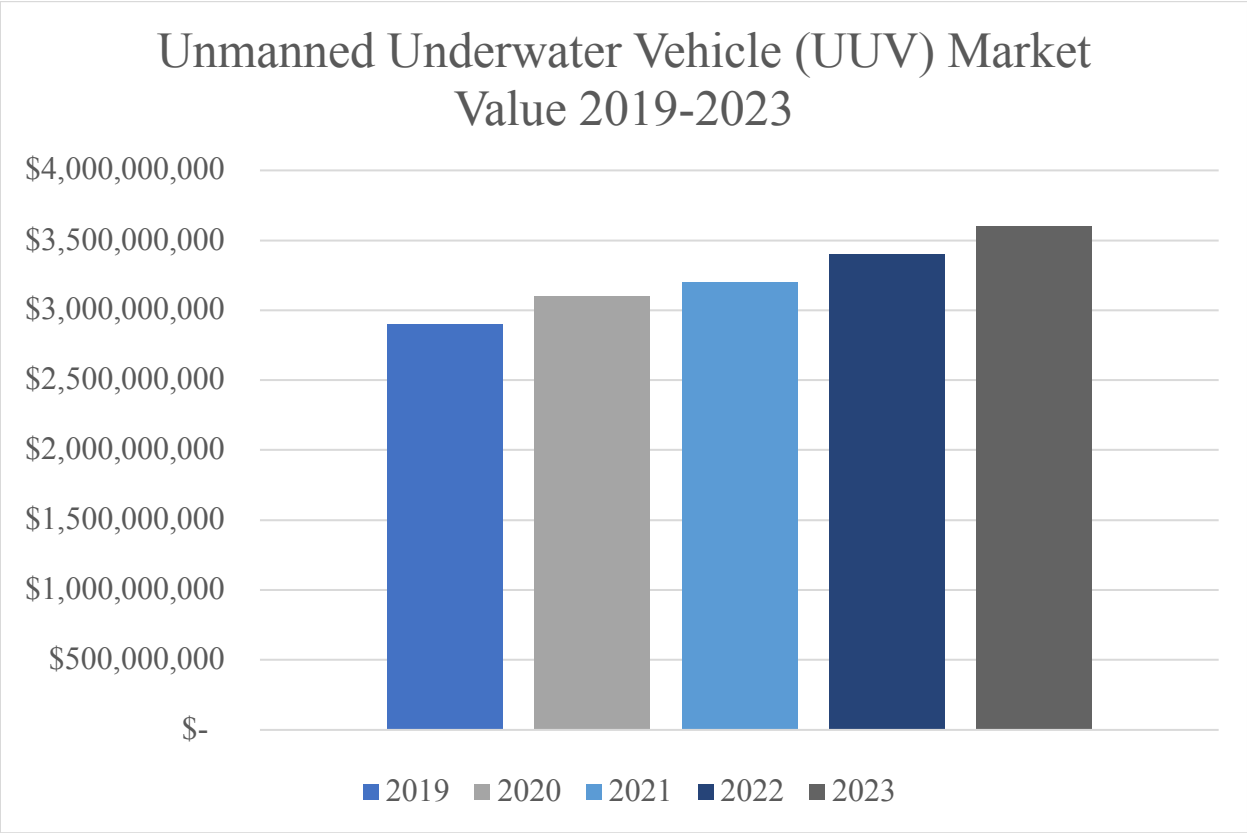
The Military Robots Market is used to define, quantify and assess the various types of solutions available. This market was worth $16.8 billion USD in 2017 and is projected to grow at a Compound Annual Growth Rate (CAGR) of 12.9 percent through 2023. This equates to a market value of more than $34.8 billion USD in 2023.



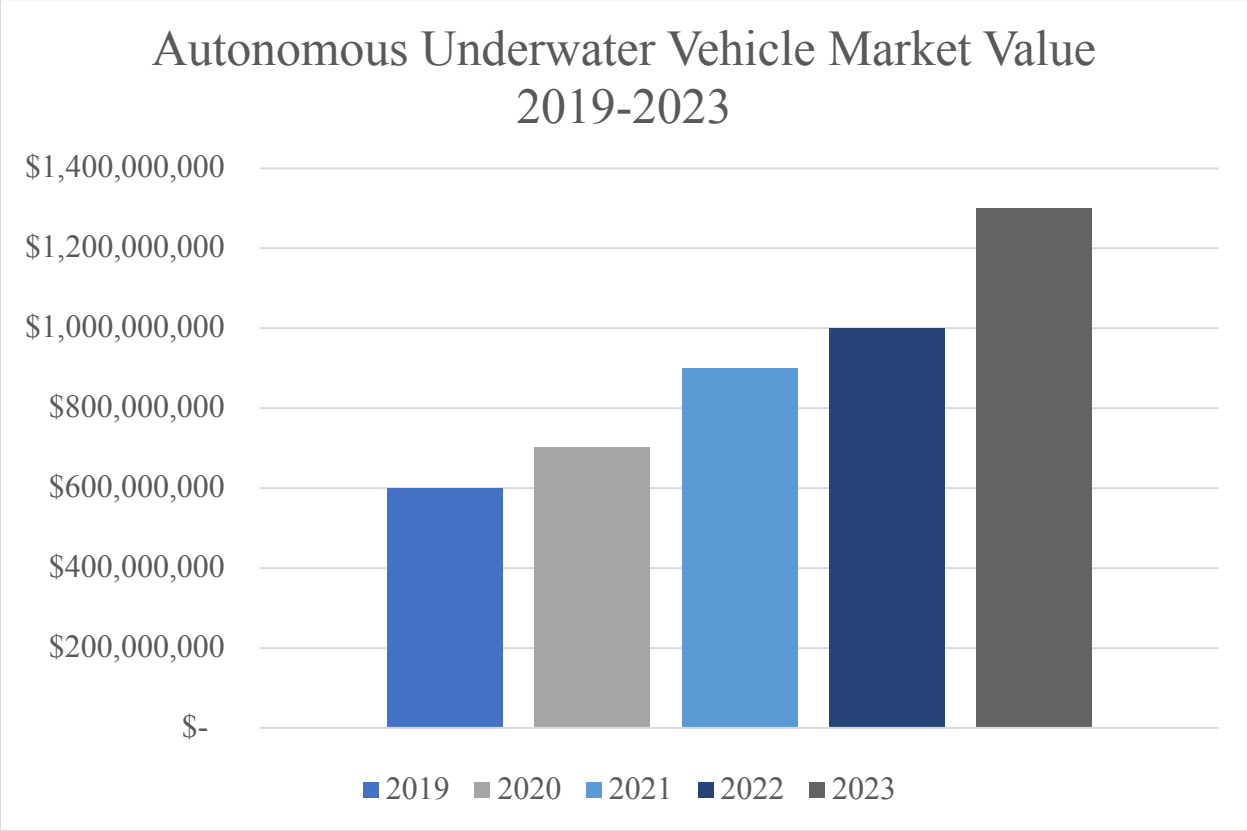
The Global Security Robot Market is used to define, quantify and assess the various types of solutions available. This market was worth $2.1 billion USD in 2018 and is projected to grow at a Compound Annual Growth Rate (CAGR) of 8.3 percent through 2023. This equates to a market value of more than $3.2 billion USD in 2023.



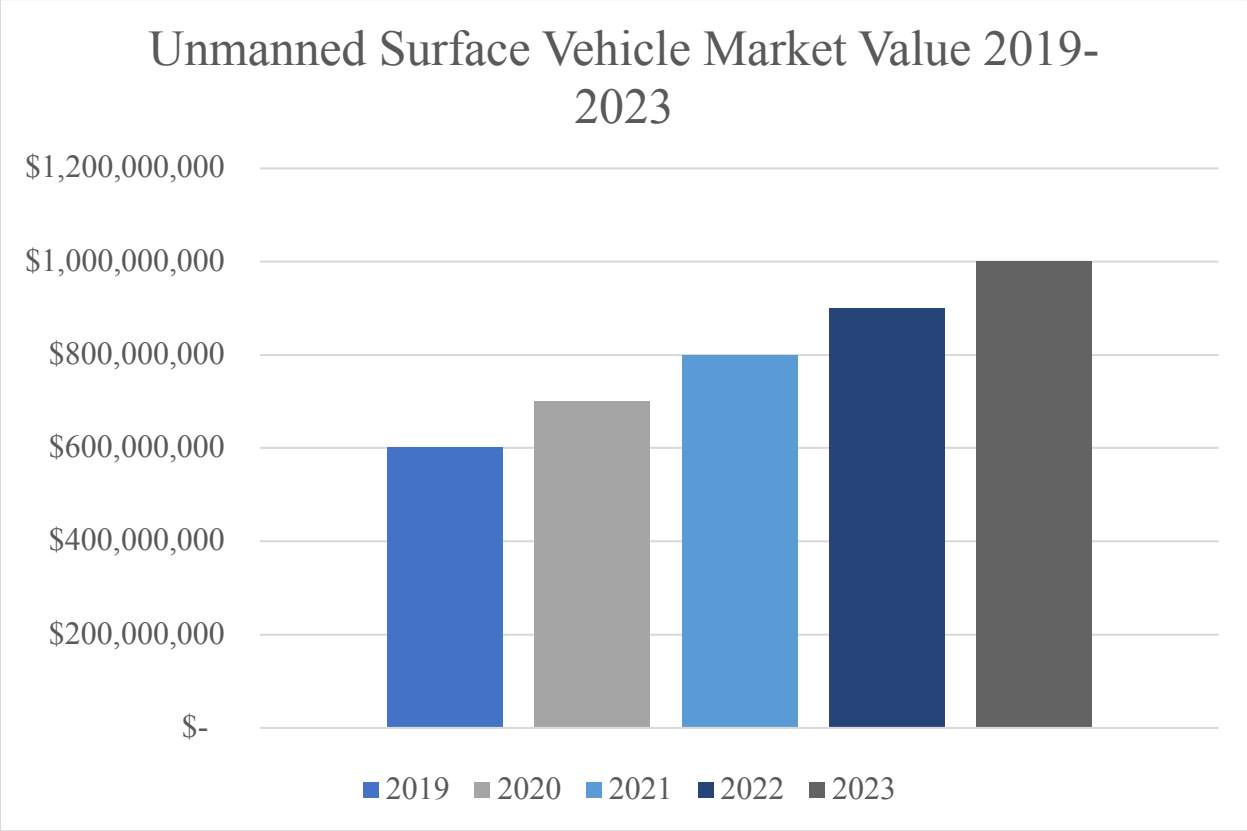
The Unmanned Underwater Vehicle (UUV) Market is used to define, quantify and assess the various types of solutions available. This market was worth $2.6 billion USD in 2017 and is projected to grow at a Compound Annual Growth Rate (CAGR) of 5.3 percent through 2023. This equates to a market value of more than $3.6 billion USD in 2023.



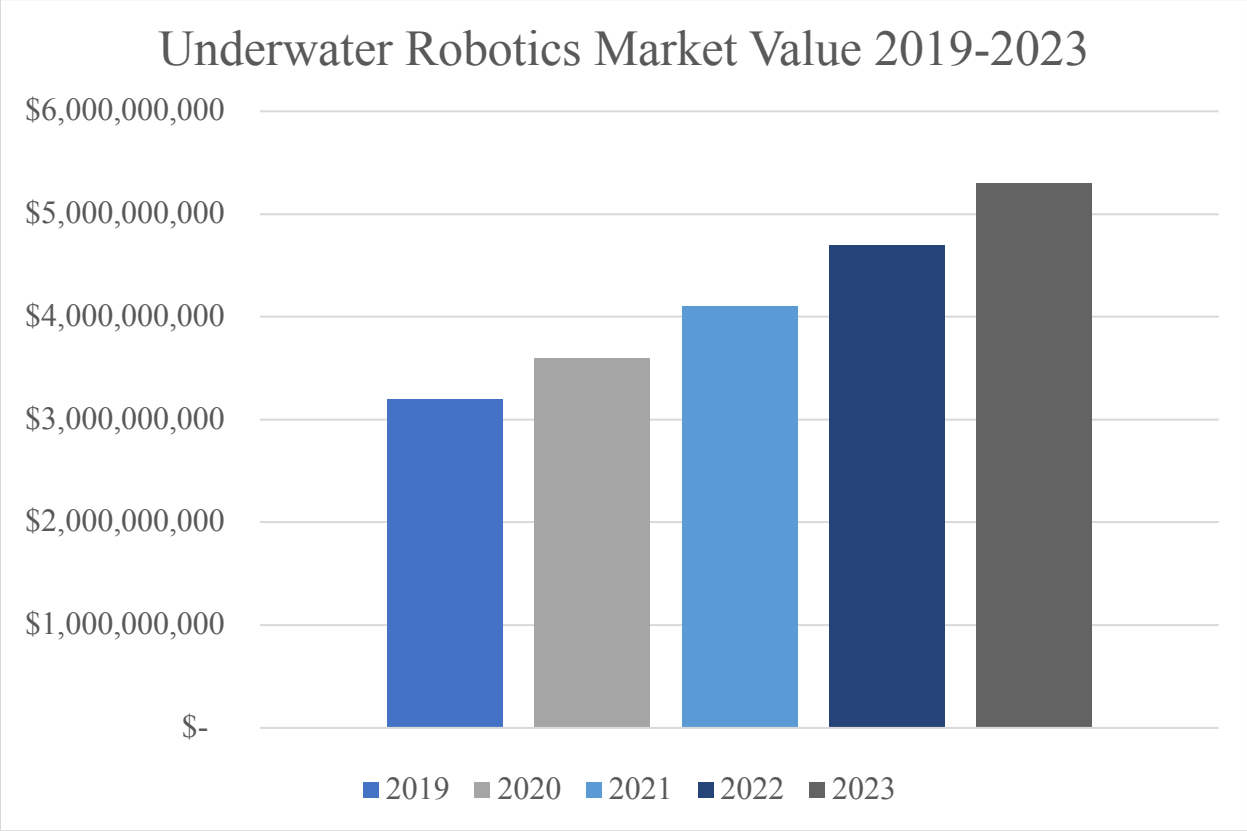
The Autonomous Underwater Vehicle Market is used to define, quantify and assess the various types of solutions available. This market was worth $312.2 million USD in 2016 and is projected to grow at a Compound Annual Growth Rate (CAGR) of 22.3 percent through 2023. This equates to a market value of more than $1.3 billion USD in 2023.



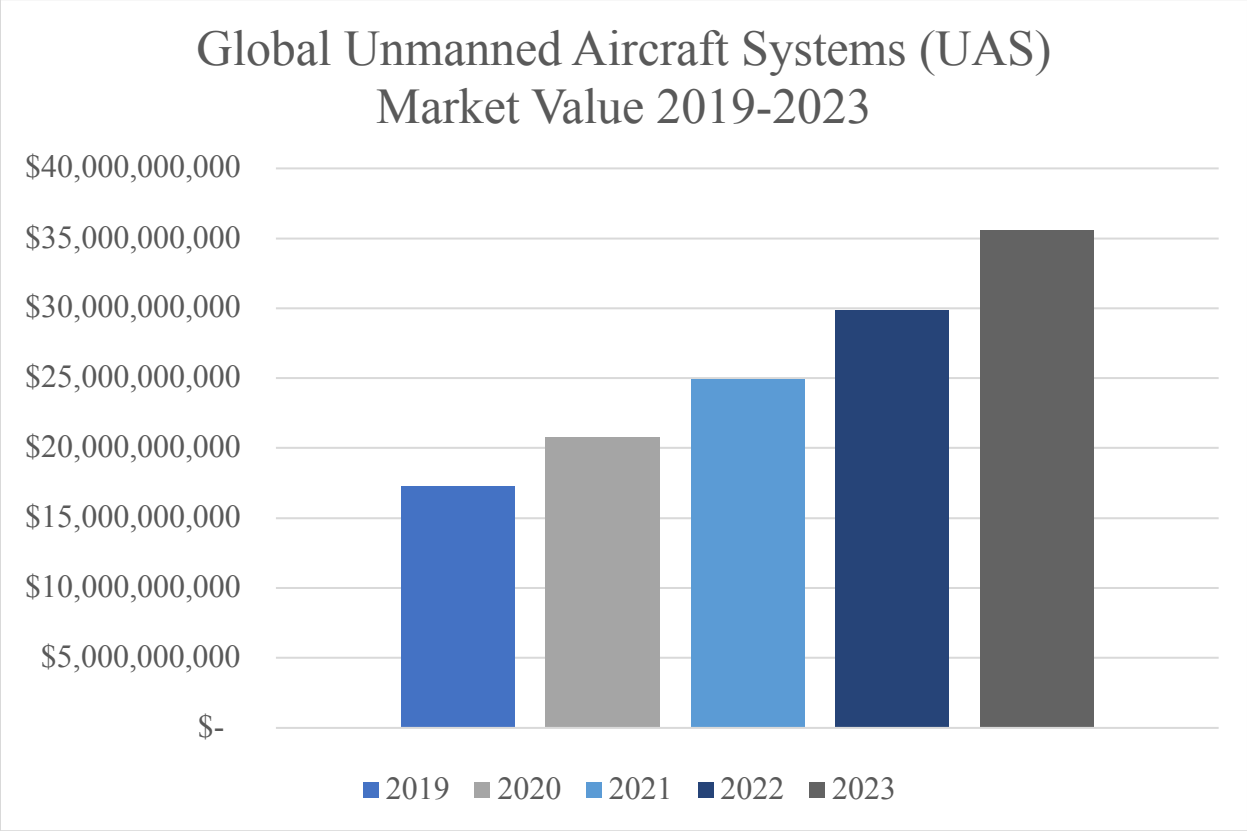
The Unmanned Surface Vehicle Market is used to define, quantify and assess the various types of solutions available. This market was worth $534.0 million USD in 2018 and is projected to grow at a Compound Annual Growth Rate (CAGR) of 13.8 percent through 2023. This equates to a market value of more than $1.0 billion USD in 2023.



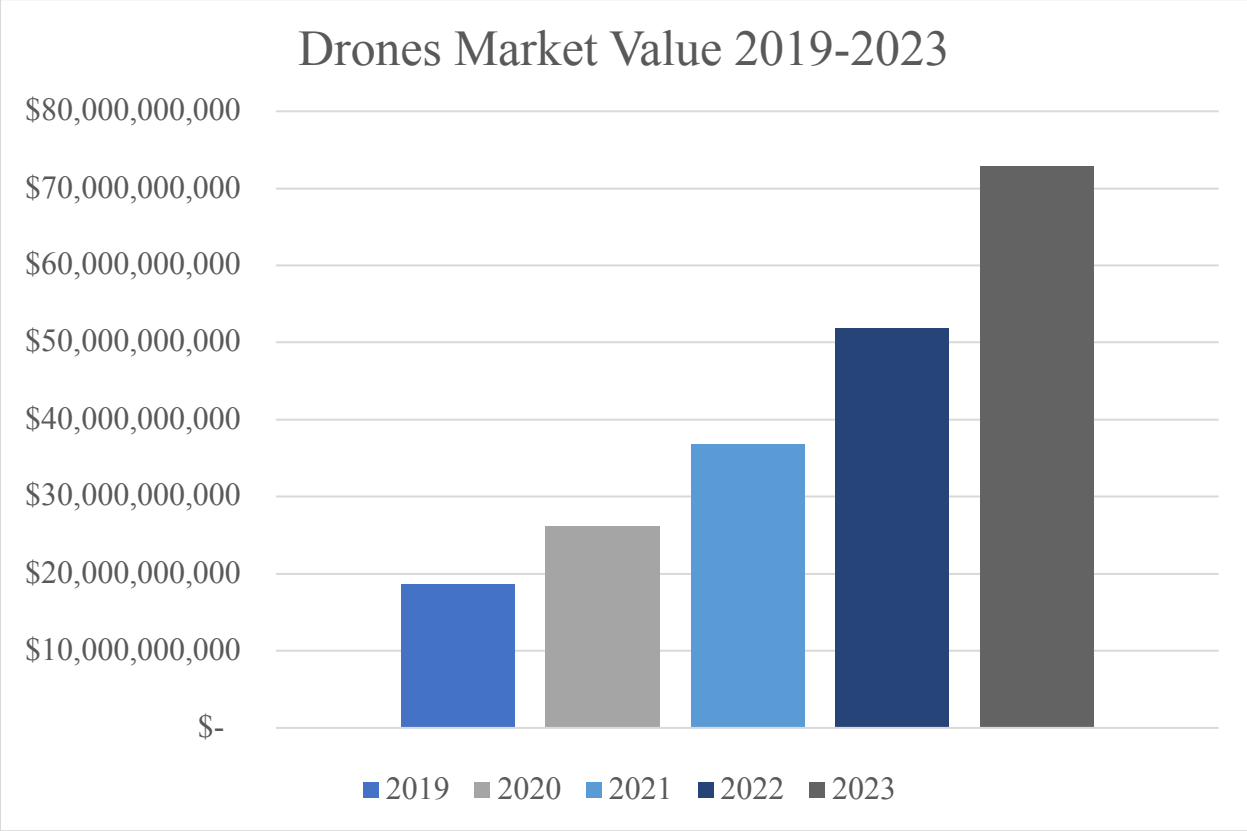
The Underwater Robotics Market is used to define, quantify and assess the various types of solutions available. This market was worth $2.5 billion USD in 2017 and is projected to grow at a Compound Annual Growth Rate (CAGR) of 13.1 percent through 2023. This equates to a market value of more than $5.3 billion USD in 2023.



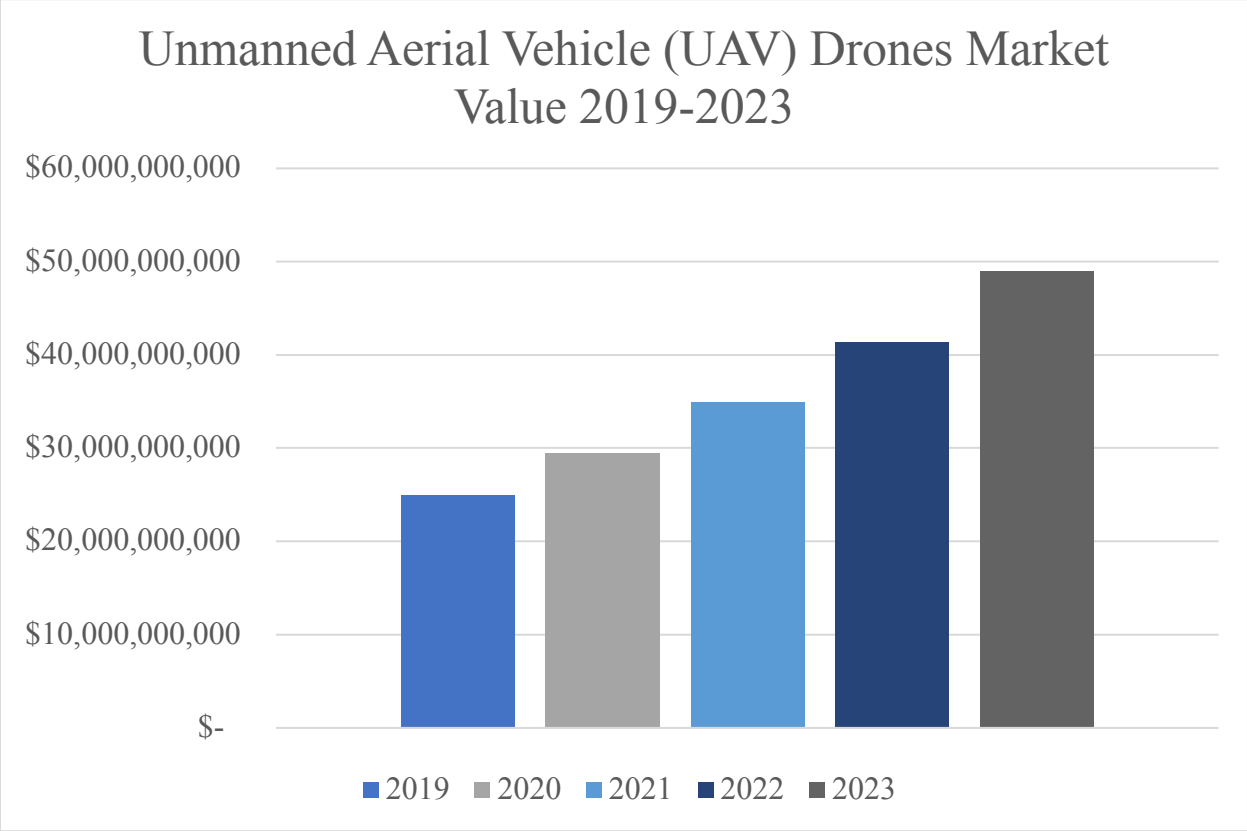
The Global Unmanned Aircraft Systems (UAS) Market is used to define, quantify and assess the various types of solutions available. This market was worth $12.1 billion USD in 2017 and is projected to grow at a Compound Annual Growth Rate (CAGR) of 19.7 percent through 2023. This equates to a market value of more than $35.6 billion USD in 2023.



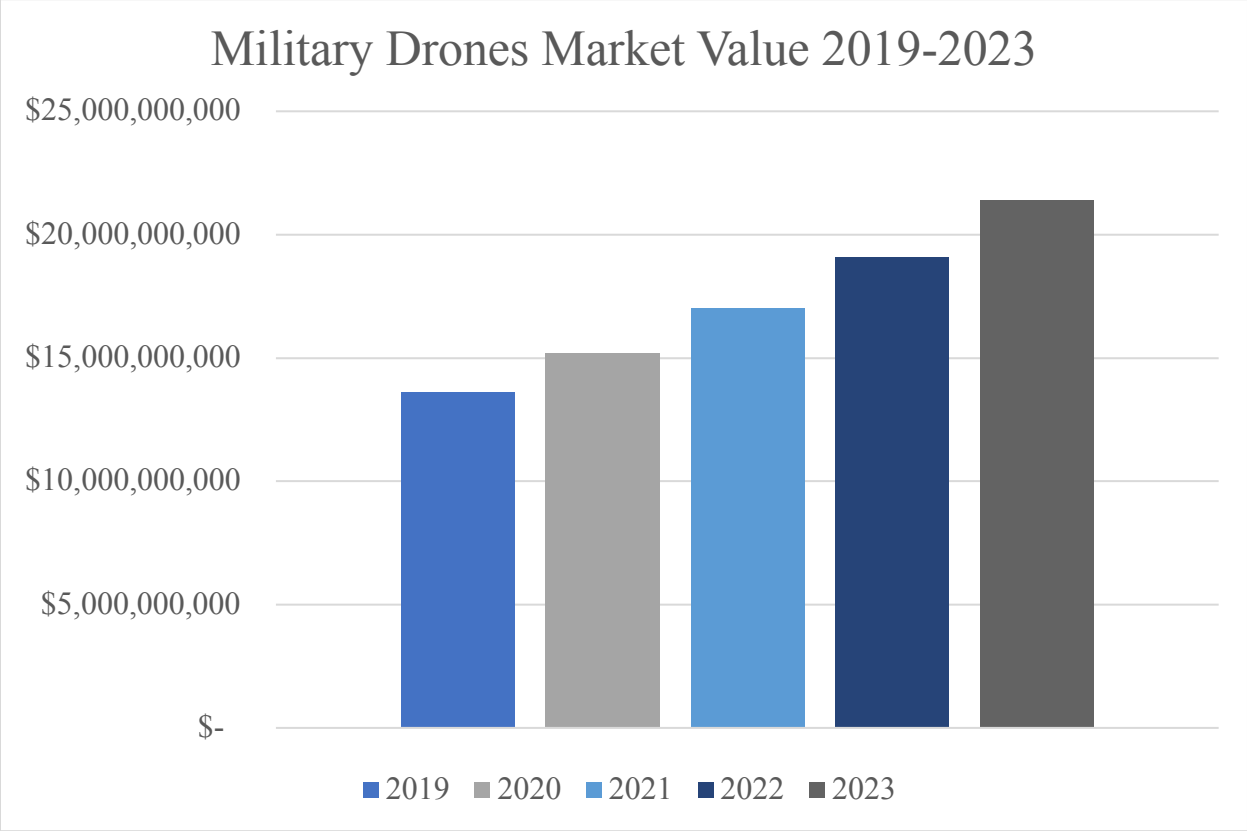
The Drones Market (UAS) Market is used to define, quantify and assess the various types of solutions available. This market was worth $13.2 billion USD in 2018 and is projected to grow at a Compound Annual Growth Rate (CAGR) of 40.7 percent through 2023. This equates to a market value of more than $72.9 billion USD in 2023.



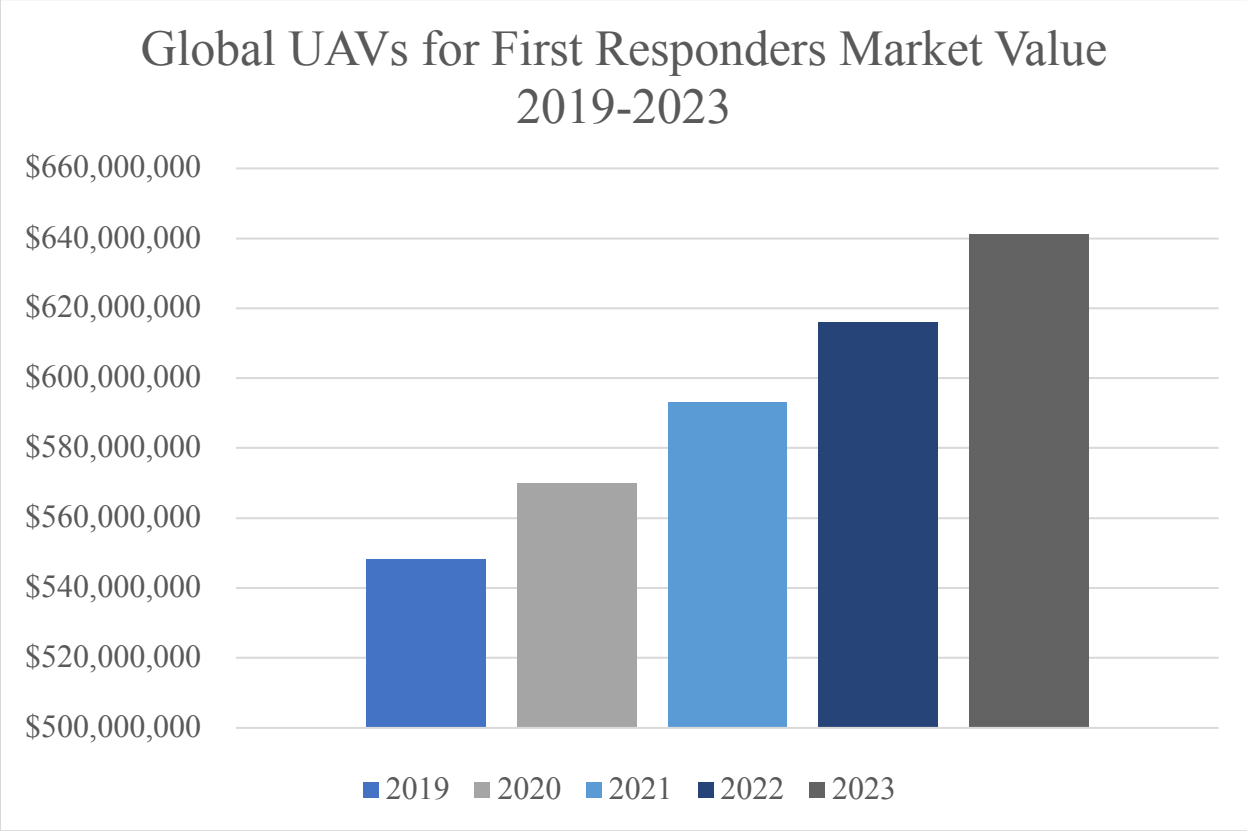
The Unmanned Aerial Vehicle (UAV) Drones Market is used to define, quantify and assess the various types of solutions available. This market was worth $17.8 billion USD in 2017 and is projected to grow at a Compound Annual Growth Rate (CAGR) of 18.3 percent through 2023. This equates to a market value of more than $48.9 billion USD in 2023.



The Military Drones Market is used to define, quantify and assess the various types of solutions available. This market was worth $12.1 billion USD in 2017 and is projected to grow at a Compound Annual Growth Rate (CAGR) of 12.0 percent through 2023. This equates to a market value of more than $21.4 billion USD in 2023.



The Global UAVs for First Responders Market is used to define, quantify and assess the various types of solutions available. This market was worth $487.6 million USD in 2016 and is projected to grow at a Compound Annual Growth Rate (CAGR) of 4.0 percent through 2023. This equates to a market value of more than 641.1 million USD in 2023.



Market Figures

The following table presents the estimated revenue figures for the various sub-markets identified for the Capability Gap 7 market. The colored row represents the primary market used to quantify this gap in this study.

Disclaimer

Note, all figures have been rounded to the nearest hundred thousand. The market forecast period examined is 2019 to 2023. When a market value was not available, it was estimated using the corresponding CAGR given over the forecast period to represent growth or decline. For consistency, data that fell outside of the forecast period has been extrapolated, as denoted by an asterisk (*). A more detailed explanation of how the extrapolated figures were estimated can be found in Appendix B of this report.

Conducting On-Scene Operations Remotely

	Revenue by Year (in $1,000,000 USD)					CAGR
	2019	2020	2021	2022	2023	
*No primary market identified	N/A	N/A	N/A	N/A	N/A	N/A
Unmanned Ground Vehicle (UGV) Market[3]	$1,500.0	$1,705.8	$1,939.9	$2,206.1	$2,508.9	13.7%
The Global Military Unmanned Ground Vehicles Market[4]	$511,314.9	$535,627.8	$561,096.6	$587,776.5	$615,725.1	4.8%
Law Enforcement Robot Market[5]	$2,703.5	$3,466.7	$4,445.2	$5,700.0	$7,309.0*	28.2%
Military Robots Market[6]	$21,410.2	$24,177.1	$27,301.7	$30,830.0	$34,814.3*	12.9%
Global Security Robot Market[7]	$2,306.6	$2,497.9	$2,705.0	$2,929.3	$3,172.1	8.3%
Unmanned Underwater Vehicles (UUV) Market[8]	$2,927.2	$3,082.2	$3,245.6	$3,417.5	$3,598.6	5.3%

Autonomous Underwater Vehicle Market[9]	$571,873.7	$699,687.3	$856,067.2	$1,047.4	$1,281.5	22.3%
Unmanned Surface Vehicle Market[10]	$607,789.3	$691,774.9	$787,365.9	$896,165.8	$1,020.0	13.8%
Underwater Robotics Market[11]	$3,222.7	$3,644.4	$4,121.3	$4,660.6	$5,270.4	13.1%
Global Unmanned Aircraft Systems (UAS) Market[12]	$17,337.9	$20,757.0	$24,850.5	$29,751.2	$35,618.4	19.7%
Drones Market[13]	$18,577.7	$26,146.4	$36,798.6	$51,790.5	$72,890.2	40.7%
Unmanned Aerial Vehicle (UAV) Drones Market[14]	$29,944.9	$29,513.4	$34,918.6	$41,313.7	$48,880.0	18.3%
Military Drones Market[15]	$13,555.7	$15,186.5	$17,013.4	$19,060.2	$21,353.2	12.0%
Global UAVs for First Responders Market[16]	$548,271.1	$570,128.2	$592,856.7	$616,491.3	$641,068.1	4.0%

Market Highlights

The ability to conduct on-scene operations remotely without endangering responders describes the need for certain tasks to be directed from a safe distance to improve the health and safety of emergency responders.

Conducting On-Scene Operations Remotely

Current Capability:

Current solutions related to the ability to conduct on-scene operations remotely without endangering responders are focused on technologies that can execute difficult or unsafe tasks that first responders typically perform. Currently, this type of technology is primarily in the form of unmanned vehicles.

Market Quantification

Market Size (2019):	No primary market identified	**Compound Annual Growth Rate (2016-2023):**	No primary market identified

Competitive Landscape

Number of Firms:	81	**Number of Responder-Specific Solutions:**	61

Market Phase

No primary market identified

Market Factors

The figure below summarizes the market factors associated with the collection, integration, and validation of data from multiple sources.

Opportunities

- ✓ High demand for unmanned ground and aerial vehicles (UGVs/UAVs) across North American and European regions
- ✓ Internal and external security threats, territorial disputes and modernization initiatives
- ✓ Vision of an army with fewer soldiers and more autonomous robots and remote controlled UGVs
- ✓ Rapid advancements in technology
- ✓ Rising demand for safety in the workplace
- ✓ Increase in unmanned underwater vehicle (UUV) demand and rising adoption of underwater robotics technology across military and commercial exploration applications
- ✓ Surge in government spending to promote efficient defense devices such as drones
- ✓ Increase in terrorist attacks

Barriers

- x Restrictions and regulations on drone usage/airborne surveillance (e.g., FAA regulations)
- x Lack of proper air traffic management for unmanned aerial vehicles (UAV) and issues with safety and security of UAVs
- x Concerns related to the database memory of artificial intelligence in military unmanned vehicles can lead to unwanted target for the weapons
- x Privacy issues regarding data usage
- x High cost of technology

Competitive Landscape

A total of eight firms were recognized as key global market players within the markets listed above, including:

- AeroVironment, Inc. (United States)
- Boeing (United States)
- DJI (China)
- ECA Group (France)
- Elbit Systems, Inc. (Israel)
- Israel Aerospace Industries, Ltd. (Israel)
- Lockheed Martin Corporation (United States)
- Northrop Grumman Corporation (United States)

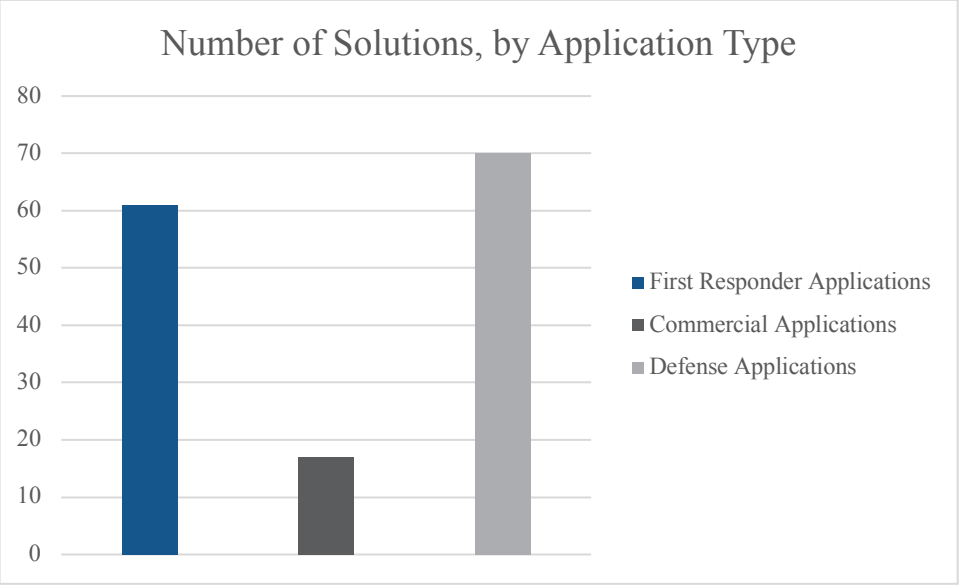
Within this study there are a total of 91 existing solutions and 20 research and development (R&D) initiatives with relevance to Capability Gap 7 identified. This landscape is non-exhaustive, as the number of solutions is vast and ever-changing at a rapid pace.

Among the existing and developing solutions identified, 61 solutions (67 percent) appear to have first responder applications and 18 solutions (90 percent) appear to be in development for first responder use. These numbers may indicate that industry is as aware that a first responder need exists within this technology space. However, when examining how existing solutions meet responders' needs related to this capability gap, it does not appear that any existing solution meets all of responders' target objectives. These objectives include:

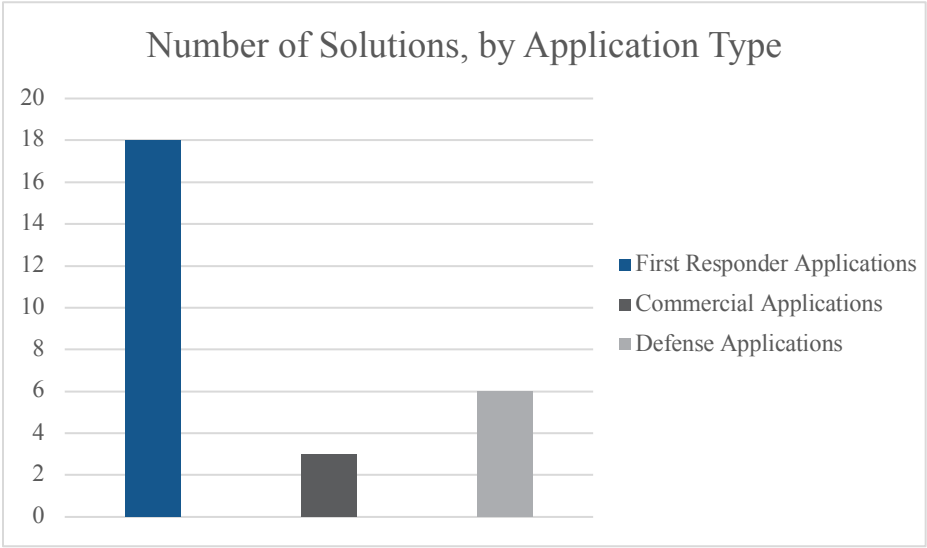
1. Provide mission-appropriate capability to remotely carry out emergency response tasks;
2. Operate in hazardous conditions; and
3. Operate in a beyond line-of-sight capability.

It appears that the greatest gap exists for operation in hazardous conditions. Most of the existing solutions are more focused on preventing self-harm and detecting targets.

While the greatest number of existing solutions (70) identified in this assessment appear to have defense applications, 61 solutions have first responder applications and 17 have commercial applications.



There is also a total of 20 R&D initiatives related to Capability Gap 7 identified in this assessment. Among the developing solutions identified, industry is involved in the development of seven solutions, academia is involved in the development of twelve solutions, and government is involved in the development of three solutions. 18 developing solutions are focused on first responder applications, three are focused on commercial applications and six are focused on defense applications.



Based upon the data presented, the majority of all existing and developing solutions appear to be targeting first responder applications. Therefore, industry is aware that a first responder need exists within this technology space.

Looking more closely at these solutions, the ability of any identified existing or in development solutions would not meet all the needs of responders' target objectives cited previously. More specifically, the ability for responders to conduct on-scene operations remotely is particularly underserved. This presents any opportunity for industry to develop solutions that can fit all of the target objectives, with a special focus on objective two.

For questions or comments about the information presented in this assessment, please contact IFAFRI at info@internationalresponderforum.org.

First Responder-Specific Technology Solutions

The following section presents a selection of the first responder-specific technology solutions that align with responder requirements for this gap. The responder requirements are identified in the IFAFRI-developed Capability Gap 7 Statement of Objectives (SOO) document. None of the solutions identified during this study meet all of the requirements detailed in the SOO document. However, those presented below offer increased levels of integration or newer features than what is generally used by response agencies currently. There are a large number of potential solutions that exist or are in-development and therefore this section should not be considered exhaustive. Further, additional concepts exist in academic literature but these are not included in this study. A complete list of responder-specific technology solutions identified during this study can be found in Appendix B of this report.

The data and information provided in this section is publicly available from manufacturers' web sites. The study team did not validate product claims made by the manufacturers.

Unmanned Marine System (UMS)

Deep Trekker, Inc.

Deep Trekker, Inc. manufactures remotely operated vehicles (ROVs) that are primarily marine systems (i.e., for oceans, seas, lakes or rivers). Its solutions are applicable for aquaculture, oil and energy, infrastructure, underwater discovery, commercial salvage, military first responders, and marine survey shipping. The company claims its ROVs are portable, affordable and easy-to-use.[17]

The **Deep Trekker Law Enforcement Underwater ROV** is used for underwater surveillance and inspection. The solution allows for efficient and precise search and rescue investigations instead of sending divers down (or conjunction with divers). This also increases responder safety. Whereas using divers for search and rescue entails significant time and deployment restrictions, the Deep Trekker ROV offers efficient deployment time (about 30 seconds). Further, it is able to search deeper (about 1000 feet) and in more dangerous areas than divers. The drone batteries last up to eight hours and it can be submerged for long periods of time; whereas a diver can only be submerged for 30 minutes to one hour. According to Deep Trekker, Inc., one of the most innovative advancements of the Deep Trekker ROV is its integration with various sonar platforms. The ROV is portable and offers easy-to-use technology.[18]

Figure 1: Deep Trekker ROV

Unmanned Aircraft Systems (UAS)

DJI

DJI is a Chinese manufacturer of commercial unmanned aerial systems (UAS). Notably, it is the largest drone manufacturer in the world, comprising of two-thirds of the UAS global market.[19] Research findings indicate that responder communities across the world have leveraged many DJI technologies. However, it may also be important to note that various government agencies and oversight authorities have instituted restrictions due to the company's foreign ownership and related national security concerns. For instance, the U.S. Army banned DJI devices in the field. That said, since it is a prominent vendor in this space, it is important to highlight some of its solutions as they relate to this Capability Gap. A few of DJI's first-responder related solutions are listed and described below:

DJI states its **Inspire 1 v. 2.0.** is a drone that features an on-board camera that streams high definition (HD) video back to the police headquarters in real-time. It can also stream video to responders' cellphones. Inspire 1 v. 2.0 is controlled by a trained critical incident manager who communicates with officers in the field, giving them information about the incident. DJI states some of the key features of **Inspire 1 v. 2.0.** include the following:[20]

Figure 2: DJI Inspire 1 v.2.0

- Upgraded image processing system;
- Goes from 0 to 50mph in five seconds;
- Has a dual battery system;
- FlightAutonomy allows it to have two directions of obstacle avoidance and sensor redundancy;
- Has multiple intelligent flight modes, including Spotlight Pro; and
- Upgraded video transmission system

Price: $2,999[21]

DJI offers its **Matrice 200 Series** drones which offer a thermal aerial solution for first responders. The drones are quadcopters that have motors paired with 17-inch propellers which help ensure stable flight in strong winds. The company has also developed an open API for their flight software. This enables the drones to have route automation and control. All of the Matrice 200 Series drones can be unfolded and folded quickly and may be applicable for power line inspection, search and rescue, wind turbine inspection, bridge inspection, and firefighting, among others.[22] Drones in this series have also been used

Figure 3: DJI Matrice 200 Series Quadcopter

to deliver medical and rescue supplies to stranded victims. Information regarding pricing does not appear to be publicly available.

The **Mavic 2 Enterprise Dual** is DJI's first foldable enterprise thermal drone, ideal for thermal imaging pilots. It offers FLIR infrared and Red, Green, and Blue light (RGB) cameras which make situational awareness very easy. It has applications in firefighting, search and rescue and police activity. DJI states some of the key features of the Mavic 2 Enterprise Dual include the following:[23]

Figure 4: DJI Mavic 2 Enterprise Dual

- Powerful image transmission & timestamping;
- Long flight times;
- Safety awareness and data security; and
- Ready for attachments

Price: $2,949

FLIR® Systems, Inc.

FLIR® Systems, Inc. designs, develops, manufactures, markets and distributes technologies that focus on enhancing perception and awareness. It offers thermal imaging, visible-light imaging, video analytics, measurement and diagnostic, and advanced threat detection systems solutions. FLIR® serves a number of applications in the government & defense, industrial, and commercial markets. It appears to offer several solutions related to this Capability Gap, some of which are listed and described below:

FLIR® partnered up with DJI, a Chinese technology company, to provide the **FLIR® Aerial First Responder Kits** (i.e., basic and advanced). The Kits provide drone-based thermal imaging by equipping a DJI unmanned aerial system (UAS) with a FLIR® thermal imaging camera. They are particularly suited for firefighting support as they give incident commanders the ability to see through smoke and keep track of their firefighters in large fires. The Kits are also applicable for rapidly deployed search and rescue missions, day or night. FLIR® states some of the key features of the Aerial First Responder Kits include the following:[24]

Figure 5: FLIR Aerial First Responder Kit

- Offers airborne thermal imaging support;
- Ability to see through smoke and track personnel in complex fire scenes;
- Offers expanded search and rescue operations, day and night;
- Ability to monitor roof conditions to reduce risk to firefighters;
- Includes an integrated, easy-to-fly aircraft that provides an application for live video, camera control and digital recording; and
- Provides a complete package that includes everything needed to start flying within minutes

Information regarding pricing does not appear to be publicly available.

Lockheed Martin Corporation

Lockheed Martin Corporation states it is a global security and aerospace company that is principally engaged in the research, design, development, manufacture, integration and sustainment of advanced technology systems, products, and services. Its operating units are organized into aeronautics, missiles and fire control, rotary and mission systems, and space. The majority of Lockheed Martin's business is with the U.S. Department of Defense and U.S. federal government agencies.[25] The company offers a few first-responder specific solutions related to this Capability Gap:

Lockheed Martin offers its **Indago UAS** which is a quadrotor drone that has applications in precision agriculture, firefighting, first response, and mapping, surveying and inspections. It weighs less than five pounds and is a man-packable unit that does not require any tools for assembly. Lockheed Martin states some of the key features of the Indago UAS include the following:[26]

- Man packable, compact folding design;
- Setup in 60 seconds, airborne in 2.5 minutes;
- Whisper quiet, rugged, all-weather capability;
- Configurable Failsafe behaviors;
- Operation via hand controller and/or full Virtual Cockpit™ GCS;
- Hot-swappable payload options for ISR, search & rescue, inspection and agriculture;
- Industry-leading image stabilization with vision tracking

Information regarding pricing does not appear to be publicly available.

Singapore Police Force (SPF)

The Singapore Police Force (SPF) states it is a uniformed organization under the purview of the Ministry of Home Affairs. Its mission is to prevent, deter and detect crime to ensure the safety and security of Singapore. Its broad areas of Police work include frontline policing, counter and e-services, investigation, community engagement and public security & order.[27]

SPF has deployed drone-equipped surveillance vehicles in an effort to better manage pre-planned security events, search mission and situations requiring aerial assistance. These vehicles are called Sky Aerial Response Command (Sky ARC). Sky ARC's each carry up to three drones. The drones are equipped with thermal imaging, can detect human presence, and are also capable of flying up to an altitude of a few hundred meters to feed information and transmit images back to an integrated command and control system. SPF appears to be rolling this out on a one-year pilot program to enhance its operational effectiveness.[28]

Figure 6: SPF's Sky ARC Drone

Information regarding pricing does not appear to be publicly available.

FLIR® Systems, Inc.

FLIR® Systems, Inc. designs, develops, manufactures, markets and distributes technologies that focus on enhancing perception and awareness. It offers thermal imaging, visible-light imaging, video analytics, measurement and diagnostic, and advanced threat detection systems solutions. FLIR® serves a number of applications in the government & defense, industrial, and commercial markets. It appears to offer several solutions related to this Capability Gap, some of which are listed and described below:

Figure 7: FLIR FirstLook

FLIR® states the **FLIR® FirstLook** is a throwable, rugged, and expandable robot that provides immediate situational awareness, performs persistent observation and investigates dangerous and hazardous material while keeping its operator at a safe stand-off distance. It can maneuver in places where other robots cannot and in a variety of environments, climbing obstacles, overcoming curbs, turning in place and self-righting when tipped over. The robot can be controlled through a variety of controllers, including the uPoint® Multi-Robot Control System which features a touchscreen-based tablet controller that allows an operator to select from across a family of connected robots. It has applications in building clearing, close-in scenarios, Chemical, Biological, Radiological, Nuclear (CBRN)/Hazardous material (HAZMAT) detection, surveillance/reconnaissance, and remote inspection. FLIR® states some of the key features of the FLIR® FirstLook include the following:[29]

- Throwable, rugged and maneuverable;
- Highly maneuverable (e.g., climbing obstacles, righting itself);
- Controllable from the uPoint® Multi-Robot Control System; and
- Superior Communications (through MPU5 radio operating on the Wave Relay® MANET)

Information regarding pricing does not appear to be publicly available.

FLIR® offers its **Kobra™**, a robot that was designed for strength, power and payload support. It has a lift capacity of 330 lbs. and stretches up to a height of eleven feet, six inches. The robot can be used indoors or outdoors, and it can climb stairs and right itself. It is able to be stowed away as it easily folds down. Explosive ordnance disposal (EOD), remote inspection, surveillance/reconnaissance and CBRN/HAZMAT detection are its applications. It appears to be ideal for counter-vehicle borne I.E.D. missions due to its height. FLIR® states some of the key features of Kobra™ include the following:[30]

Figure 8: FLIR Cobra

- Powerful, yet compact;
- Superior mobility in tough terrain;
- Situational awareness;
- Rugged; and
- Superior communications

Information regarding pricing does not appear to be publicly available.

The **FLIR® PackBot®** is a robot that performs bomb disposal, surveillance and reconnaissance, CBRN detection and HAZMAT handling operations. The robot can easily climb stairs and navigate narrow passages. It is man-transportable, and it is able to relay real-time video, audio, and sensor data while the operator remains at a safe stand-off distance. One person can deploy the PackBot® in under two minutes and it can easily fit in a car's trunk. It is applicable for EOD, remote inspection, surveillance/reconnaissance, and CBRN/HAZMAT detection. PackBot® is also controlled from the uPoint® Multi-Robot Control System and uses the MPU5 radio operating on the Wave Relay® MANET, which allows robots, operators, and observers to work together seamlessly. FLIR® states some of the key features of the PackBot® include the following:[31]

Figure 9: FLIR PackBot

- Man-transportable;
- Mobile;
- Powerful multi-sensor capability;
- Controllable from the uPoint® Multi-Robot Control System; and
- Superior communications

Information regarding pricing does not appear to be publicly available.

The **FLIR® SUGV** is a single-person lift robot with dexterous manipulation for dismounted and mobile operations, according to FLIR®. This is said to provide EOD technicians and other responders with a highly mobile robot that can climb up stairs and manipulate objects. The robot is small enough that it is carried and deployed from packs when mobile. It is equipped with wide-angle color, infrared (IR) and zoom cameras. It has applications in dismounted and mobile operations, EOD, surveillance/reconnaissance, and remote inspection. SUGV is also controlled from the uPoint® Multi-Robot Control System and uses the MPU5 radio operating on the Wave Relay® MANET, which allows robots, operators, and observers to work together seamlessly. FLIR® states some of the key features of the SUGV include the following:[32]

Figure 10: FLIR SUGV

- Portable and rapidly deployable;
- Strong, dexterous manipulation;
- Powerful multi-sensor capability;
- Controllable from the uPoint® Multi-Robot Control System; and
- Superior communications

Information regarding pricing does not appear to be publicly available.

Howe & Howe Technologies, Inc.

Howe & Howe Technologies, Inc. states it is a world leader in extreme vehicle fabrication and one of the foremost creators of advanced robotic platform solutions and applications. It supplies the U.S. government, national utility companies and Hollywood movie makers.[33] The company offers two first-responder specific solutions related to this Capability Gap:

The **Thermite RS2-T2** is an industrial firefighting robot that Howe & Howe Technologies states is the smallest, most compact robotic firefighter on the market. Its small size allows it to operate in confined industrial environments such as oil refineries while still delivering a massive amount of water and foam to the fire. Howe & Howe Technologies also states this solution is extremely durable. Information regarding pricing does not appear to be publicly available.

Figure 11: Howe & Howe Tech Thermite

The **Thermite RS1-T3 (1,250 GPM)** is an industrial firefighting robot that is said to provide safety and inside access to firefighters working on containing and defeating fires of any magnitude or origin. It can tow full hoses and dispense up to 1,250 gallons per minute. This tool is not intended to replace first responders but rather aid them in safely and efficiently combating industrial and HAZMAT fires. Information regarding pricing does not appear to be publicly available.

ICOR Technology, Inc.

ICOR Technology, Inc. is a company that manufactures robots, tools and equipment for explosive ordnance disposal (EOD) and Special Weapons and Tactics (SWAT) teams. Its robots are used in

more than 30 countries and have become the national training standard in some police training programs.[34] The company provides several first-responder specific solutions related to this Capability Gap:

The **CALIBER® MK4** is an EOD robot that offers towing and dragging capabilities, speed, agility and dexterity. It can lift 200 lbs., making it the most powerful of all of the CALIBER® robots. Its Command & Control Unit provides automatic pre-set positioning, resulting in quick deployment times. The robot also has a 3-dimensional (3D) avatar that offers real-time positional feedback on the actual position of the unit. ICOR Technology states some of the key features of the CALIBER® MK4 include the following:[35]

Figure 12: ICOR CALIBER MK4

- Multi-use;
- Cost efficient/modular;
- Maneuverable;
- Command & control unit; and
- Extended mission time

Information regarding pricing does not appear to be publicly available.

The **MK3 CALIBER®** is a medium-sized robot designed for remote handling and Render Safe Procedures of IEDs and other explosive ordnances, reconnaissance missions, two-way communication and deliver/retrieval tasks. The robot has two robotic arms, making it unique from other robots, and has six color cameras. Currently, it is in use by law enforcement agencies worldwide.[36] ICOR Technology states some of the key features of the MK3 CALIBER® include the following:

Figure 13: ICOR MK3 CALIBER

- Multi-use;
- Cost efficient/modular;
- Multiple weapons;
- Maneuverable;
- Command & Control Unit; and
- Extended mission time

Information regarding pricing does not appear to be publicly available.

The **CALIBER® T5** is a small and lightweight, two-man portable EOD robot. Its most applicable to serving EOD and SWAT teams in inspecting and retrieving of suspicious devices from narrow passages of buses, trains and planes. It has a turreted claw that provides advantages of both remote handling capabilities of a robotic claw and rend-safe and breaching capabilities of a disruptor. Its robotic arm has five degrees of movement including a turret, shoulder, elbow, wrist and claw rotating joint. ICOR Technology states some of the key features of the CALIBER® T5 include the following:[37]

Figure 14:JCOR CALIBER T5

- Mobility;

- Maneuverable;
- Weapons system;
- Command & Control Unit; and
- Extended mission time

Information regarding pricing does not appear to be publicly available.

The **Mini-CALIBER®** is a lightweight and one-man portable EOD robot. It is quick to deploy and simple to operate. The robot has rubber tracks and articulating front and rear flippers that allow it to climb stairs. Its extendible rotating claw arm allows it to open door handles. The robot is best suited for providing fast action to search rooms, stairwells, and other confined spaces. ICOR Technology states some of the key features of the Mini-CALIBER® include the following:[38]

Figure 15: ICOR Mini-CALIBER

- Man portable;
- Mission configurable;
- Various payloads;
- Mobility;
- Command & Control Unit; and
- Multiple missions

Information regarding pricing does not appear to be publicly available.

QinetiQ Group PLC (United Kingdom)

QinetiQ Group PLC is a defense technology company that offers solutions in air, land and critical infrastructure, maritime, C4ISR (command, control, communications, computers, intelligence, surveillance and reconnaissance, cyber and digital resilience, space, weapons, robotics and autonomy, and training and advisory services. It offers several first-responder specific solutions related to this Capability Gap, some of which are listed and described below:

QinetiQ offers its **Dragon Runner® 20**, a specialized and mobile unmanned ground vehicle (UGV) designed to provide safety and support to small dismounted operations for reconnaissance, security, inspection and IED missions. The robot keeps the Military, law enforcement and other first responders away from danger, it supports infantry counter-mine missions and all facets of ground operations, protects against EOD and IED missions, provides situational awareness and ultimately helps to save lives. It is small enough that it can be carried by hand but still able to lift up to 10 pounds. It has a robotic arm with a rotating shoulder, wrist and grippers and it is equipped with four cameras. QinetiQ states some of the key features of Dragon Runner® 20 include the following:[39]

Figure 16: QinetiQ Dragon Runner 20

- Rugged and flexible;
- Lightweight and reliable;
- Multi-mission;

- Interrogation capable;
- Enhanced radio frequency (RF) operating capabilities;
- Day and night cameras; and
- Two-way communications

Information regarding pricing does not appear to be publicly available.

QinetiQ's **Robotic Applique Kit (RAK) 3** transforms conventional vehicles into UGVs either temporarily or permanently. It can be used for route clearance, unmanned combat vehicles, and commercial equipment. The kit provides safety to soldiers and first responders while keeping them at a stand-off distance from threats. QinetiQ states some of the key features of the Robotic Applique Kit (RAK) 3 include the following:[40]

Figure 17: QinetiQ RAK 3

- Combat-proven technology;
- Open system architecture integrates with third party and government-owned payloads, software and platforms;
- Interoperability Profile (IOP) interface provides broad payload support to adapt to new threats, missions and platforms;
- Temporary or permanent installation;
- Optionally-manned functionality;
- Reliable fail-safe safety system for mission critical functionality;
- Universal cross-compatible hardware;
- Adaptable hardware; and
- Flexible design

Information regarding pricing does not appear to be publicly available.

TALON® is a mid-size tactical robot that is widely deployed for IED and EOD, reconnaissance, communications, CB`RN, HAZMAT, security, heavy lift, defense and rescue missions. TALONs were used at Ground Zero after the 2001 World Trade Center attack, in Iraq and Afghanistan, to search for the Boston Marathon bombing suspect, and in a variety of other situations worldwide. The robot is the first Interoperability Profile (IOP) fielded robotic system that has successfully gone through Army Test and Evaluation Command (ATEC) testing. It can climb stairs and operate in challenge environments and adverse weather conditions. It keeps the military, law enforcement and other first responders at a stand-off distance from threats and provides real-time information and situational awareness. QinetiQ states some of the key features of TALON® include the following:[41]

- IOP and SAE JAUS AS5 compliant;
- Easy to maintain and repair;
- Highly mobile;
- Rugged and reliable;
- Configurable for combat engineers, EOD, CBRN;
- Heavy-lift, multiple degree-of-freedom manipulator arm;
- Flexible controller options;
- User-defined graphical interface and programmable manipulator presets;
- Autonomy and mapping;
- High-definition (HD) video; and
- Powerful, secure, digital encrypted communications

Figure 18: QinetiQ TALON

Information regarding pricing does not appear to be publicly available.

RoboteX®, Inc.

RoboteX®, Inc. is a technology company that designs robots. RoboteX states it designs focus on safety and ease-of-use, and that it works directly with end users to include capabilities that are most important to them. Further, it states it develops robots that are affordable, high-quality, and focused on solving critical real-world problems. The company does not develop its technology through government research grants, and it believes that its line of personal safety robots will become a standard tool for first responders globally.[42] The company offers its AVATAR® line of robots that are applicable to first responders and related to this Capability Gap:

The **AVATAR® EOD Robot** is an unmanned robot that has the ability to remove explosive devices without putting personnel in harm's way. It features an extendable, five-axis robotic manipulator arm and is compatible with a remote Percussion-Actuated Nonelectric (PAN) disrupter. Specifically, it integrates with the CarbonFire 10 PAN Disrupter which is a market-leading laser sight and disrupter, according to RoboteX®. The robot can climb stairs and has dual infrared (IR) and light-emitting diode (LED) lights and a rugged drop-resistant chassis. RoboteX® states some of the key features of the AVATAR® EOD Robot include the following:[43]

Figure 19: RoboteX AVATAR EOD Robot

- CarbonFire 10 PAN disrupter mounts easy onto the manipulator arm using only a few bolts;
- Allows EOD and bomb tech teams to safely engage suspicious packages from a distance using a remote-controlled robot system;
- Easily climbs stairs with optional high angle stabilizer bars;
- Enables enhanced visibility of dangerous objects with robot's built-in cameras; and

- Remote/stand-off activation of the CarbonFire 10 unit possible with a variety of initiator systems.

Information regarding pricing does not appear to be publicly available.

RoboteX® offers its **AVATAR® Hazmat Robot** which is an unmanned robot that can inspect a situation for HAZMAT teams, potentially saving time and money and keeps first responders out of harm's way. The robot is equipped with the AVATAR® Gas and Radiation Detector Mount which is an integrated mount that houses any detector in the MultiRAE® (radiation detectors by RAE® Systems) family on top of the AVATAR®, according to RoboteX®. Data from the detector is displayed on the controller's screen. RoboteX® states some of the key features of the AVATAR® Hazmat Robot include the following:[44]

Figure 20: RoboteX AVATAR Hazmat Robot

- Quickly and easily deployable;
- Navigates various terrain including stairs, sand, clothing, grass, etc.;
- Saves time and money in the case of a false alarm; and
- Keeps first responders out of harm's way by allowing them to check readings from a distance.

Information regarding pricing does not appear to be publicly available.

The **AVATAR® Tactical Robot** allows SWAT and technical response teams to quickly and safely inspect dangerous situations. It also keeps responders out of harm's way. Tactical teams use the AVATAR® Robots as a standard operational tool and many departments across the United States and globally are using the AVATAR® robots. RoboteX® states some of the key features of the AVATAR® Tactical Robot include the following:[45]

Figure 21: RoboteX AVATAR Tactical Robot

- Quickly and easily deployable;
- Navigates various terrain including stairs, sand, clothing, grass, etc.;
- Two-way audio; and
- Video recording capability

Information regarding pricing does not appear to be publicly available.

SuperDroid (SDR) Tactical Robots, Inc.

SuperDroid (SDR) Tactical Robots, Inc. states it designs, builds, assembles, programs and tests customizable robots. It provides autonomous programmable robots and robot kits, tactical robots, SWAT robots, and custom robots.[46] The company offers several first-responder specific solutions related to this Capability Gap:

The **HD2 "Mastiff"** is a heavy-duty surveillance tactical robot with a multi-axis arm. It has the ability to climb over most obstacles, including stairs. It features optional cameras, and LED lighting and its arm allows the operator to open doors, provide assistance in scaling obstacles, moving debris, inspecting suspicious items, and EOD at a safe stand-off distance. This solution has applications in hostage and hazardous surveillance, remote room clearing & opening doors, remote manipulation & surveillance and EOD and HAZMAT.[47]

Figure 22: SDR HD2 Mastiff

Pricing:[48]

- Basic Configuration: $32,500 (estimated price)
- Standard Configuration: $40,000 (estimated price)
- Advanced Configuration: $45,0000 (estimated price)

The **HD2-S "Doberman"** is a heavy-duty surveillance and tactical robot used for remote surveillance. It features a tracked design that allows it to climb over most obstacles like stairs. SuperDroid Tactical Robots states the robot will push, pull, or plow over large objects and climb over virtually any obstacle during remote surveillance. The robot is equipped with cameras and LED lighting. Its applications include tracked chassis for climbing stairs and obstacles, remote surveillance, hostage and hazardous surveillance and clearing rooms remotely.[49]

Figure 23: SDR HD2-S Doberman

Pricing:[50]

- Basic Configuration: $14,000 (estimated price)
- Standard Configuration: $19,500 (estimated price)
- Advanced Configuration: $23,500 (estimated price)

The **LT2/F "Bulldog"** is a light tracked surveillance robot with a multi-axis robotic arm that can be used for clearing rooms, removing suspicious packages, remote surveillance and more. Its robotic arm may also be removed, if needed for different missions and clearance requirements. Removal of the arm also enables it to drive under low clearance obstacles such as cars and beds. The robot is capable of climbing household stairs and other obstacles. It was developed specifically for first responders but may be used by anyone and can also be customized with HAZMAT sensors. Its applications include hostage and hazardous surveillance, remote room clearing & opening doors, remote manipulation & surveillance, and EOD & HAZMAT.[51]

Figure 24: SDR LT2/F Bulldog

Pricing:[52]

- Basic Configuration: $29,500 (estimated price)

- Standard Configuration: $37,500 (estimated price)
- Advanced Configuration: $43,000 (estimated price)

The **LT2/LT2-F "Bloodhound"** is a light surveillance robot that is capable of climbing aggressive stairs and obstacles. It includes rear flipper/stabilizer arms to prevent roll over on steep pitches. According to SDR Tactical Robots, these are its best-selling tactical solutions. The robot is small enough that it can be deployed by one person but can still navigate through rough terrain. Its applications include low clearance inspection, stair climbing, climbing obstacles, hostage and hazardous surveillance and clearing rooms remotely.[53]

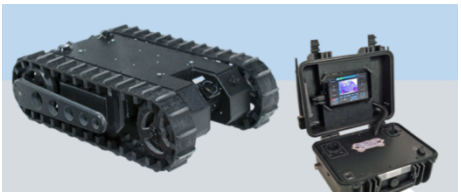


Figure 25: SDR LT2/LT2-F Bloodhound

Pricing:[54]

- Basic Configuration: $11,500 (estimated price)
- Standard Configuration: $18,000 (estimated price)
- Advanced Configuration: $22,000 (estimated price)

The **MLT "Jack Russell"** is a compact tactical surveillance robot. It is small and lightweight so it can easily fit into a bag or pack and be rapidly deployed in the field. It has LED lights, an on-board microphone, and comes with a storage/transport case. There are two configurations of the MLT Jack Russel: the MLT-F and the MLT-PT. The primary difference between the two appears to be that the MLT-PT does not have a rear flipper arm. Its applications include quiet and quick surveillance, tactical deployment, entry into difficult areas, scanning a wide area, hostage and hazardous surveillance and clearing rooms remotely.[55]

Figure 26: SDR MLT Jack Russell

Pricing:[56]

- Basic Configuration: $8,000 (estimated price)
- Standard Configuration: $11,500 (estimated price)
- Advanced Configuration: $13,000 (estimated price)

The **UM4 "Retriever"** is an unmanned surveillance robot that features a camera/video system, control system and charging station. According to SDR Tactical Robots, it is portable, agile, discrete and tough. The robot has a built-in infrared (IR) camera that allows users to see in total darkness. Its applications include quiet and quick surveillance, hostage and hazardous surveillance, clearing rooms remotely, remote surveillance and entry into difficult areas.[57]

Figure 27: SDR UM4 Retriever

Pricing:[58]

- Basic Configuration: $6,100 (estimated price)
- Standard Configuration: $9,500 (estimated price)
- Advanced Configuration: $11,500 (estimated price)

German Aerospace Center (DLR)

The German Aerospace Center (DLR) states it is the national aeronautics and space research center of the Federal Republic of Germany. Its research and development work focus on aeronautics, space, energy, transport, digitization, and security. It has also been given the responsibility for planning and implementation of the German space program.[59]

DLR has developed PHYLAX, a laser system for contactless detection of explosives. PHYLAX stands for personal hybrid laser-based explosive detection and it is specifically designed to protect people and critical infrastructure. Currently, the system is designed to aid in checking for explosives on people and objects at airports and major events; however, PHYLAX is portable and suitable for outdoor use as well. According to the researchers, in the future, PHYLAX will be able to screen people as the walk past the system, at a distance of roughly two meters, without making contact and within seconds. The researchers are currently working on advancing the technology and carrying out initial system tests.[60]

Information regarding pricing does not appear to be publicly available.

Johns Hopkins University

Johns Hopkins University is a school of higher education that was America's first research university. It has an enrollment of over 23,000.[61]

Johns Hopkins University Applied Physics Laboratory (APL) has developed **Robo Sally**, an advanced prosthetic bomb disposal robot. The robot, made with prosthetic arms and legs, is intended to provide the operator with the ability to perform necessary actions, manipulations, and tasks at safe stand-off distances in harmful or dangerous scenarios such as EOD or investigation of chemical or biological threat. The latest version of the robot can be controlled through a variety of control modalities, from "joysticks" to human motion mapping. The APL team now wants to reduce Robo Sally's cognitive load by leveraging recently developed autonomous and semiautonomous manipulation and mobility techniques, according to APL. This would allow the robot to better detect and move around obstacles. Further, by using the robot's computer-eye, an operator could tell the robot to pick up an object, grab a tool, or move something. Currently, Robo Sally could be used for bomb disposal, chemical leaks, and security checkpoints among other tasks. In the future, the APL team sees Robo Sally as "nurse Sally", providing aid to wounded soldiers and replacing battlefield medics.[62]

Figure 28: An early version of John Hopkins University's Robo Sally

Information regarding pricing does not appear to be publicly available.

Massachusetts Institute of Technology (MIT)

Massachusetts Institute of Technology (MIT) is a school of higher education that focuses on advancing knowledge and educating students in science, technology, and other areas of scholarship. Its enrollment is over 11,000 students.[63]

MIT has developed the **Cheetah 3 Robot** that can both climb stairs, avoid obstacles and recover its balance without the help of cameras or visual sensors. This is all thanks to two new algorithms developed by MIT: a contact detection algorithm, and a model-predictive control algorithm. MIT states this new design may be used for exploring disaster zones and other dangerous or inaccessible environments. The robot weighs roughly 90 pounds. Researchers presented the robot's vision-free capabilities in October 2018 at the International Conference on Intelligent Robots, in Madrid, Spain. MIT stated that within the next few years, it envisions the robot carrying out tasks that would otherwise be too dangerous or inaccessible for humans. The research was supported, in part, by Naver, Toyota Research Institute, Foxconn, and Air Force Office of Scientific Research.[64]

Figure 29: MIT Cheetah 3

Information regarding pricing does not appear to be publicly available.

MIT has also developed the **Mini Cheetah**, which is known as the first four-legged robot to do a backflip. It is lightweight and has a high-power design. It can bend and swing its legs wide, enabling it to walk either right-side up or upside down. The robot can also trot over uneven terrain (about twice as fast as an average person's walking speed) and it can right itself when pushed over. The robot only weighs about 20 pounds and interestingly, research claims that it is designed to be "virtually indestructible". The researchers presented the Mini Cheetah's design in May 2019 at the International Conference on Robotics and Automation and currently, they are building more machines, aiming for a set of 10. They are hoping to loan each of these 10 out to other labs for testing opportunities. Researchers also intend to form a Mini Cheetah research consortium of engineers, who can invent, swap, and maybe even complete with new ideas.[65]

Figure 30: MIT's Mini Cheetah

Information regarding pricing does not appear to be publicly available.

Orebro University

Orebro University states it is a modern, broad-based university with international prominent research. It has an enrollment of 15,100 students and 1,350 staff study and work at Orebro as well.[66]

Orebro University researchers have developed a robot that can assist firefighters and rescue units deployed to a critical situation. The robot is called **SmokeBot**, and as it enters into fiery buildings with firefighters, it can spot things that firefighters may not be able to, discover gas leaks and plot maps of areas it has been. Orebro University states the robot collects data about accidents and disaster situations with extremely limited visibility, which improves the safety of rescue operations. SmokeBot is developed in close cooperation with rescue units in Dortmund, Germany. It is hoped for that in the future, SmokeBot can become a part of rescue services. However, at this time, it takes about 15-30 minutes for it to collect data on the accident location which means that it cannot yet be used for the most critical situations.[67]

Figure 31: Orebro University's SmokeBot

Information regarding pricing does not appear to be publicly available.

Unmanned Aircraft Systems (UAS)/Unmanned Maritime Systems (UMS)

Harvard University

Harvard University is a school focused on excelling in teaching, learning, and research, and on developing leaders in a variety of disciplines. The University, has an enrollment of over 20,000 students, including undergraduate, graduate, and professional students. Notably, it is the oldest institution of higher education in the United States.[68]

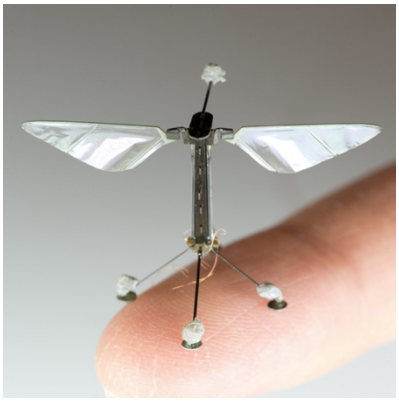


Figure 32: Harvard's RoboBee

Harvard researchers are developing autonomously flying microrobots, called **RoboBees**, that have potential applications in crop pollination, search and rescue missions, surveillance, and high-resolution weather, climate and environmental monitoring. A RoboBee is about half the size of a paper clip, weighs less than one-tenth of a gram, and flies using "artificial muscles" compromised of materials that contract when a voltage is applied, according to researchers from Harvard's Wyss Institute. The RoboBee development is divided into three main parts: The Body, Brain, and Colony. The development of the body consists of constructing robotic insects to fly on their own, brain development is concerned with "smart" sensors and control electronics, and the Conoy's focus is about coordinating the behavior of many independent robots, so they act as an effective unit. These could significantly help first responders, especially in disaster response and search and rescue.[69]

Information regarding pricing does not appear to be publicly available.

Unmanned Ground Systems (UGS)/Unmanned Maritime Systems (UMS)

Toshiba Corporation & the International Research Institute for Nuclear Decommissioning (IRID)

Toshiba Corporation is a Japanese organization that focuses on manufacturing information technology (IT) and communications equipment and systems, electronic components and materials, power systems, industrial and social infrastructure systems, consumer electronics, home appliances, medical equipment, office equipment, as well as lighting and logistics.[70]

The International Research Institute for Nuclear Decommissioning (IRID) is a Japanese research institute that focuses on research and development of technologies for nuclear decommissioning, promoting cooperation with international and domestic organizations on nuclear decommissioning, and developing human resources for research and development. It has 18 member organizations, including Toshiba Corporation.[71]

Toshiba Corporation and IRID have developed a submersible robot that is small and resilient enough to enter and inspect the damaged primary containment vessel (PCV) of Fukushima Daiichi Nuclear Power Station Unit 3. The robot, named "Manbo" (means "Little Sunfish") is only 13 centimeters in size, has front and rear facing cameras and LED lights. It is powered and controlled remotely through a wire and operators are able to control its progress. A solution like this could increase the safety of first responders, if able to be used in an emergency situation. The robot was set to be deployed in the summer of 2017, pending the training of operators.[72] It is unclear if the solution was deployed.

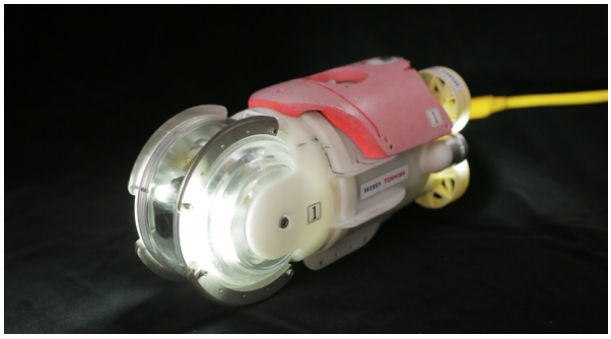


Figure 33: Toshiba & IRID's Manbo

Information regarding pricing does not appear to be publicly available.

Appendix A

The following section includes tables that list the potential first responder-specific solutions, both existing and in-development, as identified in this analysis activity. It is likely that there are additional potential solutions in the market and therefore, this section should not be considered exhaustive.

Conducting On-Scene Operations Remotely		
Existing Solutions		
Solution	**Solution Provider(s)**	**Country**
Aerones Firefighting Drone	Aerones	United States
ALLIGATOR	Shark Robotics	France
AT-802F Initial Attack Air Tanker	Dauntless Air	United States
AT-802F Fire Boss	Dauntless Air	United States
ATRAX	Shark Robotics	France
AVATAR EOD Robot	RoboteX	United States
AVATAR HAZMAT Robot	RoboteX	United States
AVATAR Tactical Robot	RoboteX	United States
CALIBER MK4	ICOR Technology	Canada
CALIBER T5	ICOR Technology	Canada
Carrier Hx8 Drone	Harris Aerial	United States
COLOSSUS	Shark Robotics	France
Daksh	Defense Research Organization (India)	India
Deep Trekker ROV	Deep Trekker	Canada
DJI Matrice 200 Series	DJI	China
DJI Mavic 2 Enterprise Drone	DJI	China
DJI Mavic 2 Enterprise Dual Thermal Drone	DJI	China
Dragon Runner 20	QinetiQ North America	United States
Dragon Runner 10	QinetiQ North America	United States
Elios	Flyability	Switzerland
FIRSTLOOK	FLIR Systems, Inc.	United States
FLIR Aerial First Responder Advanced Kit	FLIR Systems, Inc.	United States
FLIR Aerial First Responder Basic Kit	FLIR Systems, Inc.	United States
Flying UAV Laboratory	Research International	United States
High Altitude Long Endurance (HALE)	Boeing	United States

HD2 "Mastiff"	SuperDroid (SDR) Tactical Robots	United States
HD2-S "Doberman"	SuperDroid (SDR) Tactical Robots	United States
Indago UAS	Lockheed Martin	United States
Inspire 1 First Responder Thermal Kit	DJI	China
Inspire 2	DJI	China
Integrator	Boeing	United States
K-MAX	Kaman Aerosystems	United States
KOBRA	FLIR Systems, Inc.	United States
LT2/F "Bulldog"	SuperDroid (SDR) Tactical Robots	United States
LT2/LT2-F "Bloodhound"	SuperDroid (SDR) Tactical Robots	United States
Mark 5A-1	Northrop Grumman	United States
Micro Tactical Ground Robot Explosive Ordnance Disposal (MTGR EOD)	Roboteam	Israel/United States
Mini-CALIBER	ICOR Technology	Canada
MK3 CALIBER	ICOR Technology	Canada
MLT "Jack Russell"	SuperDroid (SDR) Tactical Robots	United States
MVF-5	DOK-ING	Croatia
PACKBOT	FLIR Systems, Inc.	United States
Parrot Behop-Pro Thermal Drone	Parrot Business Solutions	France
RHYNO PROTECT	Shark Robotics	France
Robotic Applique Kit (RAK)	QinetiQ North America	United States
Robotic Applique Kit (RAK) 3	QinetiQ North America	United States
Skyfront Perimeter Hybrid-Electric UAV	Skyfront	United States
Sky Aerial Response Commands (ARC)	Singapore Police Force	Singapore
SUGV	FLIR Systems, Inc.	United States
T7 Multi-Mission Robotic System	L3 Harris	United States
TAF35	EmiControls	Italy
TALON	QinetiQ North America	United States
TALON CBRN, HAZMAT Robotic Kit	QinetiQ North America	United States

tEODor (telerob Explosive Ordnance Disposal and observation robot)	Telerob	Germany
Thermite RS2-T2	Howe and Howe Tech	United States
Thermite RS1-T3 (1,250 GPM)	Howe and Howe Tech	United States
Throwbot 2 (TB2)	ReconRobotics	United States
UM4 "Retriever"	SuperDroid (SDR) Tactical Robots	United States
U-RANGER USV	L-3 Calzoni	Italy
Zoe	Acecore Technology & Flycam UAV	Netherlands
Yuneec H520 UAV System	Yuneec	China

In-Development Solutions		
Solution	**Solution Developer(s)**	**Country**
737 Fireliner Air Tanker	Coulson Aviation	Canada
Autonomous Flying Microbots (RoboBees)	Harvard University	United States
BDRP (aka Robo Sally)	Johns Hopkins University	United States
Cheetah 3	Massachusetts Institute of Technology (MIT)	United States
Growing Vine Robot	Stanford University	United States
Human-Sniffing Sensors	Universities of ETH Zurich, Innsbruck, and Cyprus	Austria, Switzerland, and Cyprus
Hyundai Elevate	Hyundai	South Korea
"Listening Drone"	Cabinet Office of Japan	Japan
Manbo ("Little Sunfish") Robot	Toshiba Corporation & the International Research Institute for Nuclear Decommissioning (IRID)	Japan
Mechanical Roach	University of California at Berkeley	United States
Mini Cheetah	Massachusetts Institute of Technology (MIT)	United States
Nuclear Waste Storage Tunnel Platform	University of Nevada	United States
PHYLAX	German Aerospace Center	Germany
Rega Rescue Drone	Rega	Switzerland
Sky Aerial Response Commands (ARC)	Singapore Police Force	Singapore
Smokebot	Orebro University	Sweden

Water Cannon Robot and Hose Extension Robot	Mitsubishi Heavy Industries, Ltd.	Japan
Whole-body Adaptive Locomotion and Manipulation (WALK-MAN)	European Commission	Belgium

Appendix B

The following section includes notes (where applicable) regarding extrapolation methods for some of the revenue figures presented in the "Market Figures" section of this report. In addition, there are instances when the CAGR cited by a third-party data source does not equate to the market figures presented. In these cases, the CAGR as calculated based upon the market figures presented is utilized.

- Law Enforcement Robot Market
- Market figures and a CAGR were available for the time period 2015 through 2022. A CAGR of 28.2 percent was used to estimate the revenue values for 2023.
- Military Robots Market
- Market figures and a CAGR were available for the time period 2017 through 2022. A CAGR of 12.9 percent was used to estimate the revenue values for 2023.

Glossary

Compound Annual Growth Rate (CAGR)	The average annual growth rate when compounding is taken into account; its formula is as follows: CAGR = (FV/PV)^(1/n)-1, where FV is the future or ending value, PV is the present or starting value, and n is the number of years between PV and FV.
First Responder	Those individuals who, in the early stages of an incident, are responsible for the protection and preservation of life, property, evidence, and the environment, including fire service, law enforcement, and emergency medical services.
Project Responder 4	The fourth in a series of studies that focuses on identifying capability needs, shortfalls, and priorities for catastrophic incident response. The methodology is based upon discussions with federal, state, and local first responders, as well as technical subject matter experts.

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