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The rise of robots and the implications for military organizations

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THESIS

THE RISE OF ROBOTS AND THE IMPLICATIONS FOR MILITARY ORGANIZATIONS

by

Zhifeng Lim

September 2013

Thesis Advisor: Gary O. Langford
Co-Advisor: Douglas H. Nelson

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This thesis explores the reasons for the inevitability of the extensive use of robots in military organizations, projects the adoption timeframe for robots in military organizations, proposes how robots might evolve, assesses the impact of robots on military organizations and suggests the way forward for military organizations to facilitate the adoption of robots.

Macro environmental trends suggest that the use of robots is the way forward for military organizations. The thesis projects that the adoption rate of robots will pick up from this point forward and will reach market saturation in a matter of decades. The use of robots has physical, functional, and behavioral implications for military organizations, and their increasing numbers will affect how militaries are organized and alter the existing organizational processes in the long term. Military organizations will benefit from a better understanding of the impact of robots and the resulting challenges. Taking the necessary steps to mitigate the challenges and facilitate the evolutionary transition for the military organizations will allow these organizations to reap the benefits of robots and to operate effectively in the changing macro environment.

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THE RISE OF ROBOTS AND THE IMPLICATIONS FOR MILITARY ORGANIZATIONS

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Submitted in partial fulfillment of the
requirements for the degree of

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LIST OF ACRONYMS AND ABBREVIATIONS

DNA	Deoxyribonucleic Acid
DoD	Department of Defense
F-bots	Free Robots
HAL	Hybrid Assistive Limb
HcSoS	Human-Centric Systems of Systems
IFR	International Federation of Robotics
IHL	International Humanitarian Law
IHRL	International Human Rights Law
OM	Operation and Maintenance
PROC	Procurement
R&D	Research and Development
RDTE	Research Development Test and Evaluation
RoW	Rest of the World
RPV	Remotely Piloted Vehicles
SoS	Systems of Systems
T-bots	Tethered Robots
UAS	Unmanned Aerial Systems
UAV	Unmanned Aerial Vehicle
UGV	Unmanned Ground Vehicle
UN	United Nations
USV	Unmanned Surface Vehicle
UUV	Unmanned Underwater Vehicle

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EXECUTIVE SUMMARY

This thesis explains why the extensive use of robots is inevitable for military organizations, projects the adoption timeframe for robots in military organizations, proposes how robots might evolve, assesses the impact of robots on military organizations and suggests the way forward for military organizations to facilitate the adoption of robots.

The inevitability of robots is fundamentally a result of the need to reduce manpower requirements in military organizations, while sustaining the capability needs of the organizations. The need to reduce manpower is driven by the trends of the macro environment for military organizations, which include the aging demographics and the reduced public tolerance for human casualties. The evolving operational environment that places increasing demands on soldiers and exposes the limitations of human body also supports the adoption of robots.

The adoption timeframe for robots in military organizations is projected to be 50 years. The projection is made by assessing the average adoption timeframe for earlier electronic technologies (i.e., radio, television, computer and Internet). While the precision of the projection is debatable, the projection suffices to provide military organizations with an appreciation of the urgency for attention. As a follow-on for the thesis, further research may be performed to provide a better estimate of the adoption timeframe of robots, tailored to various military organizations.

Robots are not limited to their current forms and will evolve as robotic technologies advance and the potential of robots is uncovered. Looking at the macro environmental trends, this thesis proposes the evolutionary goal for the two general types of robots, T-bots and F-bots. While F-bots would be more effective at replacing humans, development of T-bots will predominate while semantic technologies, necessary for F-bots, are being developed and in the event that the macro environment favors human control over the actions of robots.

As robots evolve and their scale and scope of application increase, the impact on military organizations will change. The long term impact of robots at the organizational level is a streamlining of the human resources within the organization resulting in the reduction in manpower requirements and change in organizational systems and their associated capabilities. The long term impact is driven fundamentally by the changing interactions between systems within military organizations, as a result of the introduction of robots. The changing interactions would manifest as physical, functional and/or behavioral changes, and these changes are observable from the assessment of the impact of currently deployed robots.

Understanding the impact and inevitability of robots, it is in the interest of military organizations to take necessary steps to facilitate the rise of robots and gain from the adoption of robots. In the near term, the priority for military organizations is to establish a clear distinction between humans and robots. This entails a clear segregation of roles that will be used to guide the development of robots. Investment in the research of semantic technologies and technologies that enhance robot human interactions should be made early to spur the development of robots and shorten their adoption timeframe.

Material and manpower resources should be provided for in the near term to support an expected rise in manpower and material resources for the operation and maintenance of robots. In the near term, the application of robots should also be diversified to provide multiple development channels and sustain the overall development of robots. Benefits of robots may also be realized earlier though the diversification of their application.

A longer term focus for military organizations is to legitimize the use of robots both internationally and domestically. The foundations supporting the rise of robots should be reinforced to sustain the increasing use of robots. These foundations include the communication network and the pool of specialists.

Consolidation and reorganization at the organizational level is the eventual means of harvesting the benefits of robots. This has to be recognized down the road and realized in spite of potential resistance.

Social acceptance is also important for the successful integration of robots into military organizations. Military organizations should therefore pace the introduction of robots according to that concern in the public domain.

In conclusion, macro environmental trends suggest that the use of robots is the way forward for military organizations. It is projected that the adoption rate of robots will pick up from this point forward and will reach saturation in a matter of decades. The use of robots has physical, functional and behavioral implications on military organizations, and their increasing numbers will affect how militaries are organized and alter the existing organizational processes in the long term. Military organizations will benefit from a better understanding of the impact of robots and the resulting challenges. Taking the necessary steps to mitigate the challenges and facilitate the evolutionary transition for the military organizations will allow organizations to reap the benefits of robots early and allow the organization to operate effectively in the changing macro environment.

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I. INTRODUCTION

A. THESIS OVERVIEW

There are reasons to believe that robots will have an increasingly dominant role in the military. The surge in the number of drones and mine clearing robots deployed in Afghanistan and Iraq over the past decade (Singer, *Robots at War: The New Battlefield*, 2009b) is one of the tell-tale signs. Intuitively, it is not difficult to accept the increasing trend of military organizations deploying robots. This trend could in part be due to popular sci-fi movies like *Transformers* and *Iron Man* that brought out the infinite potential of robots and made robots seem like the way forward. Not limited in form the way humans are limited by our physical body, robots can be designed with extraordinary power and sensor capability. The essential attraction to robots lies in their ability to augment humans' decision making and support humans in tasks that human bodies are incapable of performing.

Accepting the rise of robots has implications for military organizations. As robots evolve and show increasing applicability, the rising number and extent of their deployment across military organizations, will affect these organizations, physically, functionally and behaviorally, changing their organizational structure and processes.

This thesis identifies the reasons for the inevitability of robot dominance in military organizations, projects the adoption timeframe for robots, proposes how robots will evolve, assesses the impact of robots on military organizations and suggests the way forward for military organizations to facilitate the adoption of robots.

The thesis is broken up into five chapters. Chapter I provides an overview of the thesis and addresses the motivation and objectives of the thesis. This chapter also establishes the definition of robot that is used in this thesis, highlights current investment and development trends for robots and provides examples of existing robots. Chapter II identifies the reasons for the inevitable rise of robots in military organizations by examining the value of robots to military organizations and the macro environmental trends. Chapter III explores the adoption rate of robots in military organizations and projects the timeframe for widespread adoption of robots within military organizations. Chapter III will identify two general types of robots and discuss their evolutionary goal. Chapter IV identifies the near term impact of the introduction of robots, drawing examples from currently deployed robots and discusses the long-term implications of the increasing adoption of robots. Chapter V proposes the way ahead for military organizations to facilitate the rise of robots and concludes this thesis.

B. PURPOSE AND OBJECTIVES

> Disruptive technologies are scientific discoveries that break through the usual product/technology capabilities and provide a basis for a new competitive paradigm. (Kassicieh, Walsh, Al-Romig, McWhorter, & Williams, 2000)

By the definition quoted above, robotics technology can represent a disruptive technology. Robotics technology provides man-made machines, called robots, with the disruptive capability to displace humans from work that humans have traditionally thought not possible by machines. Robots provide organizations with the opportunity to explore solutions for the organizations' needs free from the constraints imposed by the employment of humans. For manpower intensive military organizations, the opportunity presented by robots can potentially be translated to improved operational performance, added capabilities and lower manpower costs.

While the potential benefits of robots to military organizations are clear and attractive, the potential pitfalls should not be overlooked. Failure to recognize the long-term extensive impact of robots early can have detrimental effects on military organizations. These negative effects can range from the inefficient use of resources, evident from the uncoordinated development of Unmanned Aerial Systems (UAS) by various services of the U.S. military (Office of the Under

Secretary of Defense (Acquisition Technology and Logistics), 2011), to the potential rejection of robots by humans within the organization as the livelihood of humans is threatened by robots.

Despite the potentially serious and disruptive consequences of the long term impact of robots on military organizations, not much has been written about these implications. Most researchers have chosen instead to discuss the operational benefits (Shanker, 2013) of specific robots or to focus narrowly on the legality and morality issues surrounding the use of robots in specific context (Volker, 2012). There are many possible explanations for the current lack of discussion on the long -term impact of robots. Possible explanations include the failure to recognize the true potential of robots and their inevitable pervasive application, as well as the false belief that robots are things of a distant future, justifying a delay in discussion. It is not in the interest of this thesis to discuss the reasons for the lack of focus on the long-term impact of robots. The purpose of this thesis is instead to create an awareness of the impact of robots and spur actions to better position military organizations to harness the potential of the disruptive innovation of robots. More specifically, this thesis is concerned with highlighting the impacts that have to be managed through coordinated action at the higher leadership level of military organizations.

With this purpose in mind, this thesis ultimately seeks to spur military organizations to consider the key question of: “What can military organizations do to prepare for the increasingly dominant role of robots?” Given the differing contexts of various military organizations, it is beyond the scope of this thesis to provide a comprehensive answer to this question. This thesis will instead propose general guidelines for military organizations. These guidelines will be shaped by the answers to the following relevant questions:

- Why is the rise of robots in military organizations inevitable?
- How long will it be before robots become ubiquitous in military organizations?
- How will robots evolve and what drives their evolution?

- How do robots affect military organizations, and what are the consequences of their impact?

The answers to these questions will be discussed in the subsequent chapters of this thesis.

C. DEFINING ROBOT

So what exactly are robots? This is not a trivial question, given its numerous definitions and the lack of a universally accepted answer. Yet, it is an important question whose answer would distinguish robots from any other machine that has been around since the industrial revolution and provide the first hint at their significance to the military or even the world at large. This section reviews some of the existing definitions of robots and establishes the definition that is used in communicating this thesis.

Some dictionary definitions of robots are listed below:

- A machine that looks like a human being and performs various complex acts (as walking or talking) of a human being; also : a similar but fictional machine whose lack of capacity for human emotions is often emphasized (Merriam-Webster).
- A machine controlled by a computer that is used to perform jobs automatically (Cambridge Dictionaries).
- A machine capable of carrying out a complex series of actions automatically, especially one programmable by a computer. (Oxford Dictionaries)

The Merriam-Webster definition represents a stereotypical robot that hints at the presence of some form of intelligence (to perform complex acts) but restricts robots to human form. The Cambridge and Oxford definitions emphasize only the presence of automation and lack description of the physical form.

These dictionary definitions represent various layman impressions of what robots are and either limits what robots can be or lack the specificity needed to distinguish robots from automated machines. A more specific, yet encompassing definition is that described by Singer in his book, *Wired for War: The Robotics Revolution and Conflict in the 21st Century*.

> Robots are machines that are built upon what research calls the "sense-think-act" paradigm. That is, they are man-made devices with three key components: "sensors" that detect the environment and monitor changes in it, "processors" or "artificial intelligence" that decide how to respond, and "effectors" that act upon the environment in a manner that reflects decision, creating some sort of change in the world around a robot. When these three parts act together, a robot gains the functionality of an artificial organism. (Singer, 2009c)

From a systems engineering perspective (i.e., functional perspective), this statement is a good definition as it captures the key functions (i.e., detect and monitor environmental changes, make decisions and act upon the environment based on decisions) and prescribes the key components (i.e., sensors, processors and effectors) of a robot, without limiting the robot's physical form. While this more comprehensive definition does suggest the presence of automation in robots, the definition does not require a machine that is able to accomplish a job autonomously to be considered a robot. The implication of this distinction is that a machine that requires some form of human control to accomplish a job may still be considered a robot as long as the machine possesses the key robot functions.

A problem with this more comprehensive definition is that a machine, like a lamp that is able to sense the light intensity of the surrounding and decides to turn on or off the light, or a remote control car that is equipped with a touch sensor in its bumper and is able to change the direction of movement on contact with an obstacle, may be considered a robot. From a layman's perspective, these differences may be difficult to reconcile. This problem with Singer's definition of robot arises from the lack of specification (considering the level of complexity) required in the decisions that robots make. To improve on Singer's definition of robots, this thesis proposes that robots should be capable of making decisions dynamically, and this would manifest as different actions, depending on the context of use.

With the specific definition of robot, a distinction still needs to be made between a military and non-military robot. This thesis focuses on military robots, which would entail robots employed by the military to fulfill a combat, combat support,[1] or combat service support role.[2] Military robots can be broadly categorized based on the domain in which they are deployed: Air, Ground, and Maritime. Aerial military robots include, but are not limited to, all Unmanned Aerial Vehicles (UAVs), which are also referred to as Remotely Piloted Vehicles (RPVs) or drones. Ground military robots include, but are not limited to, Unmanned Ground Vehicles (UGVs) and wearable robots. Maritime military robots include, but are not limited to, Unmanned Underwater Vehicles (UUVs) and Unmanned Surface Vehicles (USVs). Unless otherwise stated, the use of the word 'robots' will generally refer to military robots in this thesis.

D. CURRENT TRENDS

Having established the definition of robots, this section will highlight some of the current development and investment trends on military robots and provide an appreciation of the current scale of military robots employed.

Figure 1 compares the budget forecast for UAV procurement and research and development (R&D), between U.S. and the rest of the world (RoW) (Harrison, 2013). The forecast suggests that U.S. interest in UAVs will be sustained for the next decade, and the interest in UAVs among other countries will increase in the coming decade.

[1] Defined as the fire support and operational assistance provided to combat elements, by the *Department of Defense Dictionary of Military and Associated Terms* (Joint Education and Doctrine Division, 2010)

[2] Defined by the *Department of Defense Dictionary of Military and Associated Terms* (Joint Education and Doctrine Division, 2010) as the essential capabilities, functions, activities, and tasks necessary to sustain all elements of operating forces in theater at all levels of war. Within the national and theater logistic systems, it includes but is not limited to that support rendered by service forces in ensuring the aspects of supply, maintenance, transportation, health services, and other services required by aviation and ground combat troops to permit those units to accomplish their missions in combat. Combat service support encompasses those activities at all levels of war that produce sustainment to all operating forces on the battlefield.

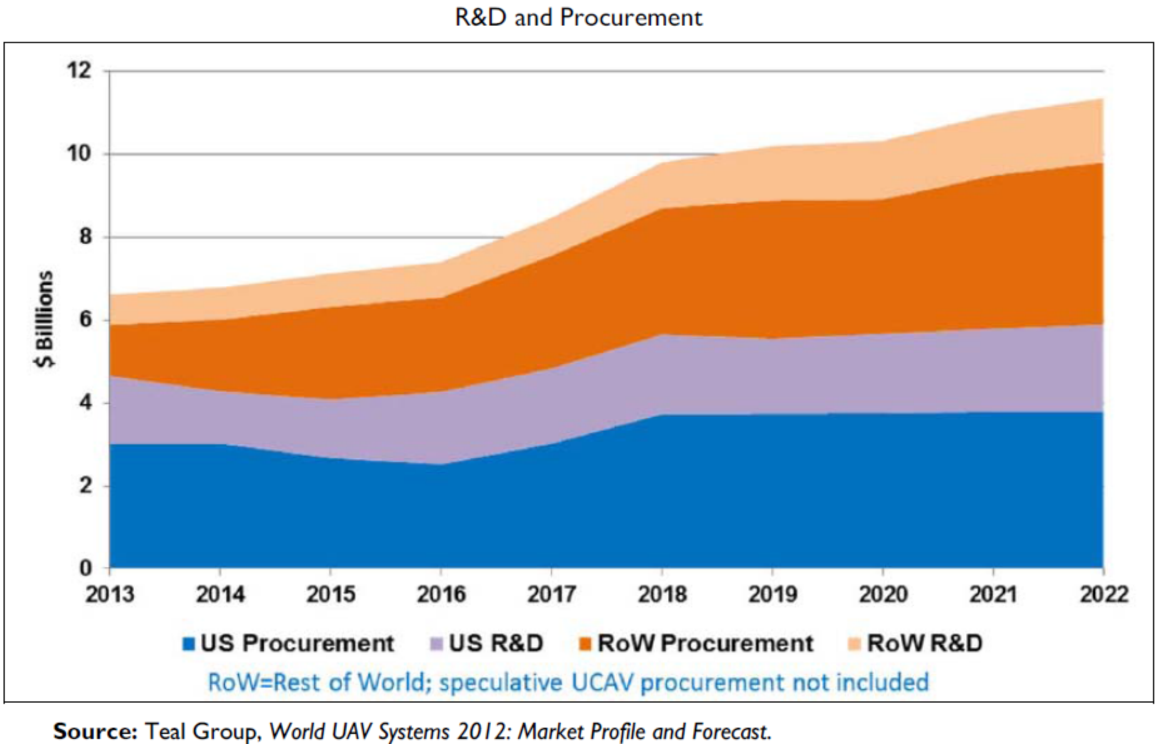

Figure 1. World UAV budget forecast (From Harrison, 2013).

While research and employment of military robots in the form UAVs, began as early as 1917 (Gertler, 2012), the tipping point for the widespread use of military robots by the United States came with the Iraq war. According to Singer (2009b), “When U.S. forces went into Iraq in 2003, they had zero robotic units on the ground. By the end of 2004, the number was up to 150. By the end of 2005 it was 2,400, and it more than doubled the next year. By the end of 2008, it was projected to reach as high as 12,000.” Singer also noted that the U.S. military went into Iraq with just a handful of drones or UAVs, but had over 7,000 of them by 2009 (Singer, 2009a). Robots had demonstrated their utility in combat operations.

Table 1. 2011 president's budget for unmanned systems ($ Mil) (From Office of the Under Secretary of Defense [Acquisition Technology and Logistics], 2011).

Unmanned Funding ($ Mil)							
Fiscal Year Defense Prog		FY11	FY12	FY13	FY14	FY15	Total
Air	RDTE	1,106.72	1,255.29	1,539.58	1,440.57	1,296.25	6,638.40
	PROC	3,351.90	2,936.93	3,040.41	3,362.95	3,389.03	16,081.21
	OM	1,596.74	1,631.38	1,469.49	1,577.65	1,825.45	8,100.71
Domain Total		6,055.36	5,823.59	6,049.48	6,381.17	6,510.72	30,820.32
Fiscal Year Defense Prog		FY11	FY12	FY13	FY14	FY15	Total
Ground	RDTE	0.00	0.00	0.00	0.00	0.00	0.00
	PROC	20.03	26.25	24.07	7.66	0.00	78.01
	OM	207.06	233.58	237.50	241.50	245.96	1,165.60
Domain Total		227.09	259.83	261.57	249.16	245.96	1,243.61
Fiscal Year Defense Prog		FY11	FY12	FY13	FY14	FY15	Total
Maritime	RDTE	29.69	62.92	65.72	48.60	47.26	254.19
	PROC	11.93	45.45	84.85	108.35	114.33	364.90
	OM	5.79	4.71	3.76	4.00	4.03	22.28
Domain Total		47.41	113.08	154.32	160.94	165.62	641.37
Fiscal Year Defense Prog		FY11	FY12	FY13	FY14	FY15	Total
All Unmanned	RDTE	1,136.41	1,318.21	1,605.29	1,489.16	1,343.52	6,892.59
	PROC	3,383.86	3,008.63	3,149.32	3,478.96	3,503.36	16,524.12
	OM	1,809.59	1,869.67	1,710.75	1,823.15	2,075.44	9,288.59
Domain Total		6,329.86	6,196.50	6,465.36	6,791.27	6,922.31	32,705.30

Currently, the focus of unmanned systems development in the U.S. military is in the air domain, as suggested by the budget allocation shown in Table 1. The budget allocation is broken down into research development test and evaluation (RDTE), procurement (PROC) and operation and maintenance (OM) for the various deployment domains.

Table 2. Unmanned aerial systems inventory projection for U.S. military (From Office of the Under Secretary of Defense [Acquisition Technology and Logistics], 2012).

System Designation/Name		Current	FY 12	FY 13	FY 14	FY 15	FY 16	FY 17
			Air Force					
MQ-1B	Predator	163	152	141	130	121	115	110
MQ-9A	Reaper	70	96	135	167	199	229	256
RQ-4B	Global Hawk	23	23	15	15	15	15	15
			Army					
RQ-11B	Raven	5394	6294	6528	6717	6921	7074	7074
RQ-7B	Shadow	408	408	408	408	408	408	408
MQ-5B	Hunter	45	45	45	45	45	45	45
MQ-1C	Gray Eagle	19	45	74	110	138	152	152
			Navy					
RQ-4A	Global Hawk	5	5	0	0	0	0	0
MQ-4C	BAMS	0	0	2	2	5	9	13
MQ-8B	Firescout/VTUAV	5	9	14	18	25	32	37
RQ-21A	STUAS	0	1	2	3	4	4	4
	Scan Eagle	122	122	122	122	122	122	122
X-47B	UCAS-D	2	2	2	2	0	0	0
	UCLASS	0	0	0	0	2	2	4
			Marine Corps					
RQ-7B	Shadow	52	52	52	52	52	52	52
RQ-21A	STUAS	8	8	8	23	48	73	100

Table 2 captures the inventory projection for unmanned aerial systems,[3] UAS, in the U.S. military, and it shows an increasing trend for the next several years. While the rate of increase would subside in the coming years, continued investment in development of unmanned aerial systems can be expected, to improve earlier generations of UAS.

[3] Unmanned aircraft are commonly called unmanned aerial vehicles (UAVs), and when combined with ground control stations and data links, form UAS, or unmanned aerial systems (Gertler, 2012).

E. EXAMPLES OF ROBOTS

This section serves to provide readers with an appreciation of the diversity of existing robots and includes some examples of non-military robots with potential military applications.

Figures 2, 3 and 4 provide an overview of the various unmanned systems that are deployed by the U.S. military. The figures highlight the diversity of unmanned systems as well as their capabilities.

DoD Unmanned Aircraft Systems (As of 1 JULY 2011)

General Groupings	Depiction	Name	(Vehicles/GCS)	Capability/Mission	Command Level
Group 5 • > 1320 lbs • > FL180		•USAF/USN RQ-4A **Global Hawk/BAMS-D** Block 10 •USAF RQ-4B **Global Hawk** Block 20/30 •USAF RQ-4B **Global Hawk** Block 40	•9/3 •20/6 •5/2	•ISR/MDA (USN) •ISR •ISR/BMC	•JFACC/AOC-Theater •JFACC/AOC-Theater •JFACC/AOC-Theater
		•USAF MQ-9 **Reaper**	•73/85* *MQ-1/MQ-9 same GCS	•ISR/RSTA/EW/ STRIKE/FP	•JFACC/AOC- Support Corps, Div, Brig, SOF
Group 4 • > 1320 lbs • < FL180		•USAF MQ-1B **Predator**	•165/85*	•ISR/RSTA/STRIKE/FP	•JFACC/AOC-Support Corps, Div, Brig
		•USA MQ-1 **Warrior**/MQ-1C **Gray Eagle** •USN **UCAS**- CVN Demo •USN MQ-8B **Fire Scout** VTUAV	•31/11 •2/0 •14/8	•(MQ-1C Only-C3/LG) •Demonstration Only •ISR/RSTA/ASW/ ASUW/MIW/OMCM/ EOD/FP	•NA •NA •Fleet/Ship
		•SOCOM/DARPA/USA/USMC A160T **Hummingbird**	•8/3	•Demonstration Only	•NA
Group 3 • < 1320 lbs • < FL180 • < 250 knots		•USA MQ-5 **Hunter**	•45/21	•ISR/RSTA/BDA	•Corps, Div, Brig
		•USA/USMC/SOCOM RQ-7 **Shadow**	•368/265	•ISR/RSTA/BDA	•Brigade Combat Team
		•USN/USMC **STUAS**	•0/0	•Demonstration	•Small Unit
Group 2 • 21-55 lbs • < 3500 AGL • < 250 knots		•USN/SOCOM/USMC RQ-21A **ScanEagle**	•122/13	•ISR/RSTA/FORCE PROT	•Small Unit/Ship
Group 1 • 0-20 lbs • < 1200 AGL • < 100 knots		•USA / USN / USMC / SOCOM RQ-11 **Raven**	•5628/3752	•ISR/RSTA	•Small Unit
		•USMC/ SOCOM **Wasp**	•540/270	•ISR/RSTA	•Small Unit
		•SOCOM SUAS AECV **Puma**	•372/124	•ISR/RSTA	•Small Unit
		•USA **gMAV** / USN **T-Hawk**	•270/135	•ISR/RSTA/EOD	•Small Unit

Figure 2. United States Department of Defense unmanned aircraft systems (As of 1 July 2011) (From Office of the Under Secretary of Defense [Acquisition Technology and Logistics], 2011).

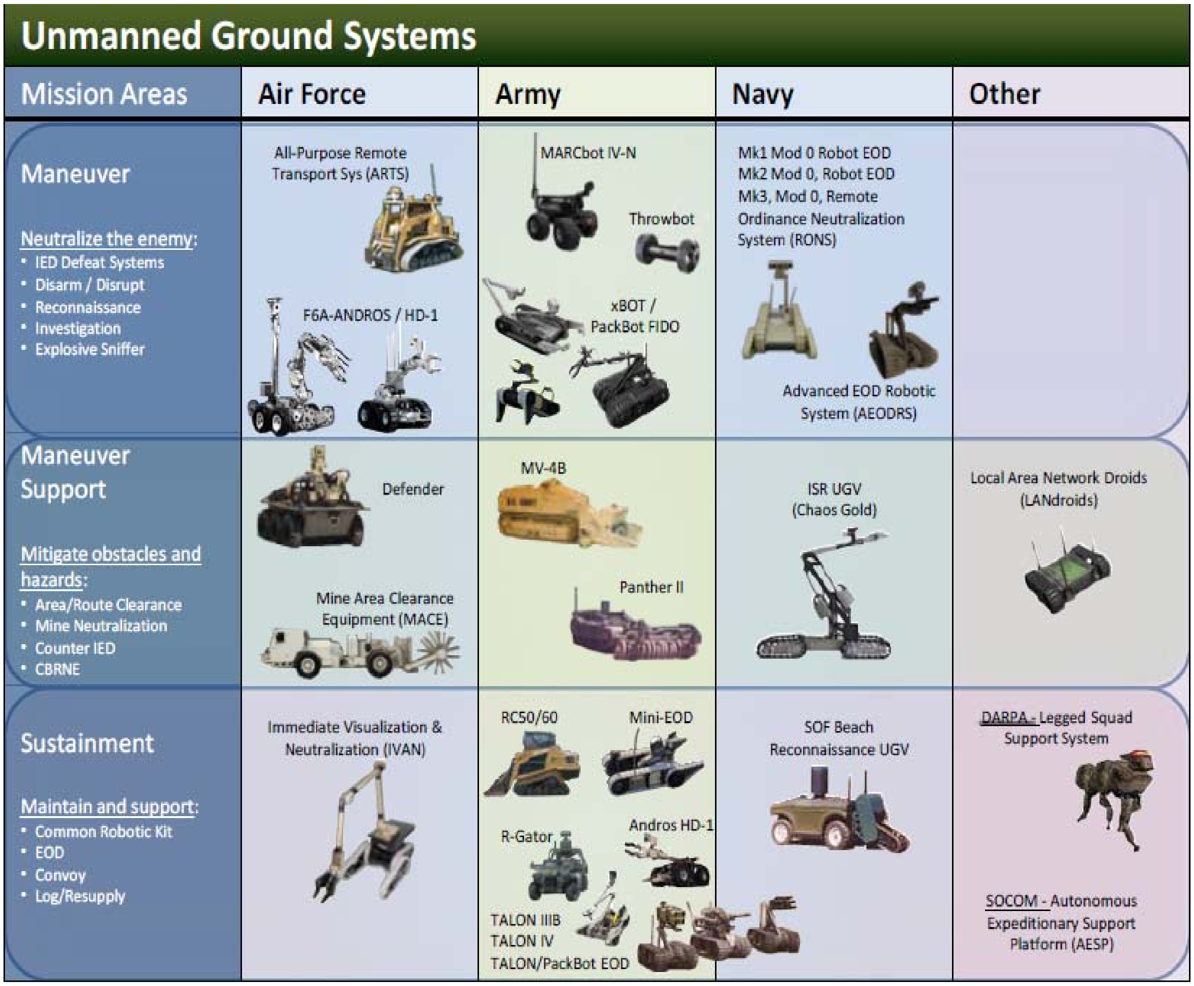

Figure 3. United States Department of Defense unmanned ground systems (From Office of the Under Secretary of Defense [Acquisition Technology and Logistics], 2011).

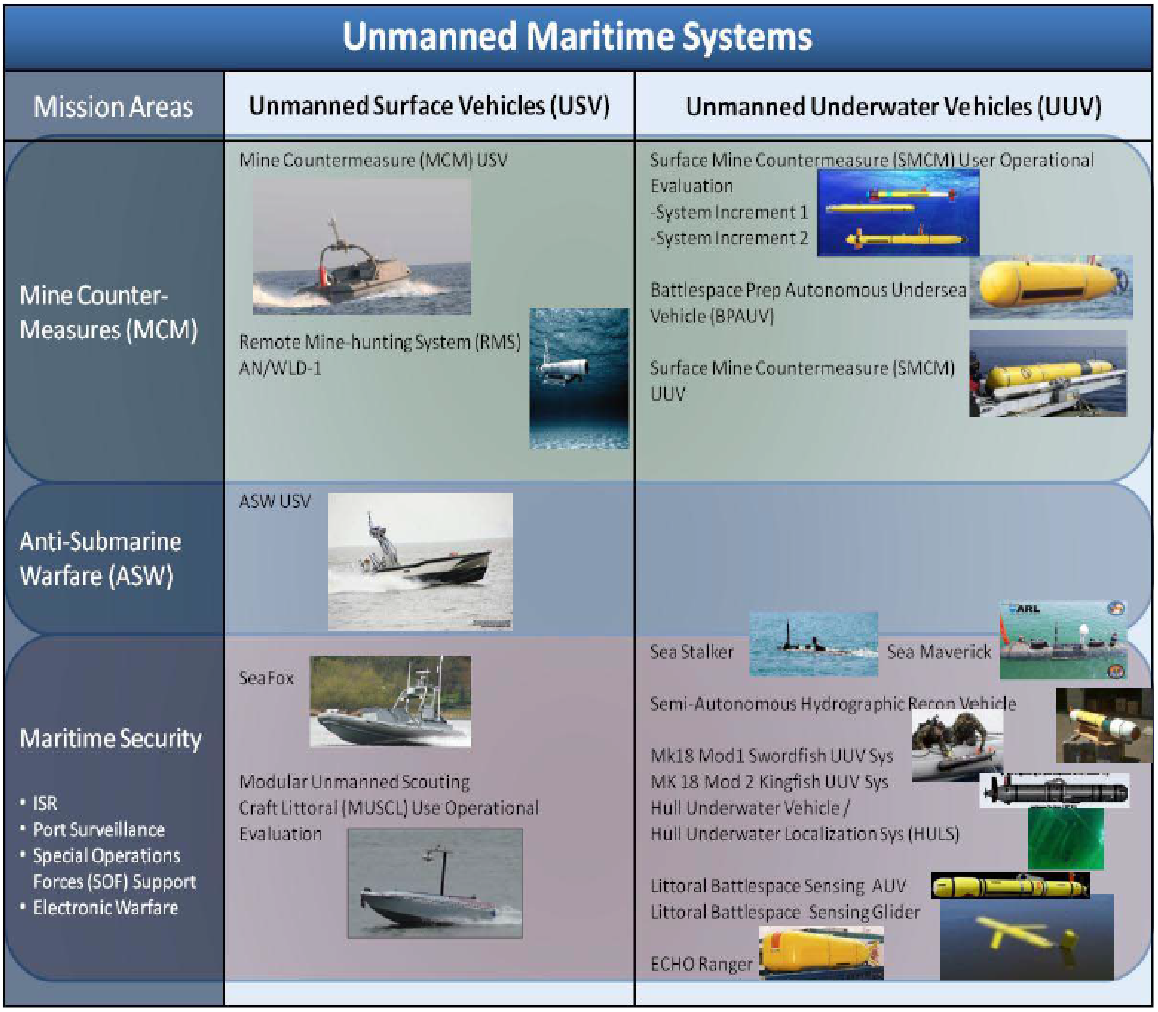

Figure 4. United States Department of Defense unmanned maritime systems (From Office of the Under Secretary of Defense [Acquisition Technology and Logistics], 2011).

Unmanned systems are the predominant robots that are deployed currently by military organizations. They represent the first generation of military robots, which are distinguished by their diverse forms, as the military explores their various options and limited autonomy. These first-generation unmanned military robots still rely significantly on human operators for assessment of the environment and making decisions. Robots that are capable of operating independently from human control are likely to emerge among the future generations of robots. Prototypes of such robots exist and include Boston Dynamics' BigDog that is shown in Figure 5.

Figure 5. Boston Dynamics’ BigDog (From Marcott, 2009).

The BigDog is a robot that is capable of carrying up to 340 lbs. of load and navigating and maneuvering through rough terrain autonomously (Boston Dynamics, 2013). While not a military robot, Google’s driverless car, as shown in Figure 6, can potentially be adapted for military applications.

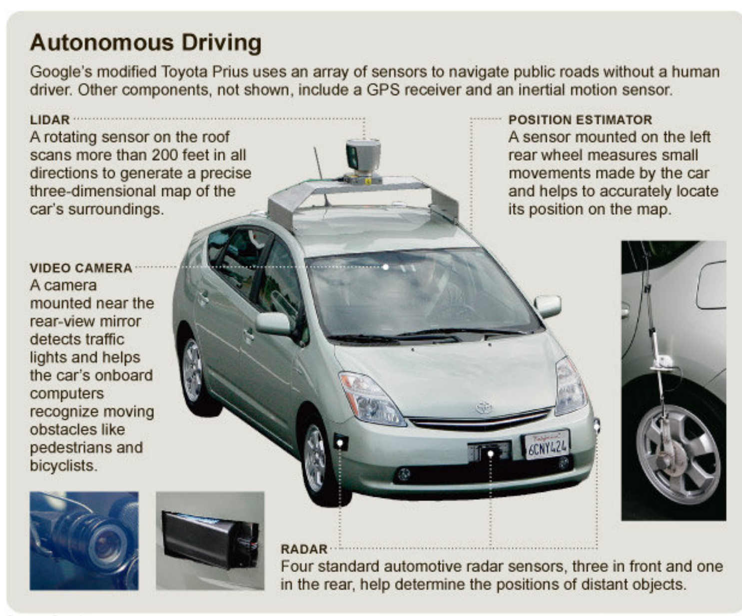

Figure 6. Google’s Driverless Car (From Markoff, 2010).

Humanoid robots, such as Honda’s ASIMO, also have potential military applications. Figure 7 shows a picture of ASIMO.

Figure 7. Honda’s ASIMO humanoid robot (From Honda).

Robots in the form of robotic suit may also emerge among the mix of robots that will be employed by military organizations in the future. Existing examples of robotic suits that can potentially be deployed in military organizations include Cyberdyne’s Hybrid Assistive Limb (HAL-5) and Raytheon’s XOS 2 exoskeleton. Cyberdyne’s HAL-5 is shown in Figure 8.

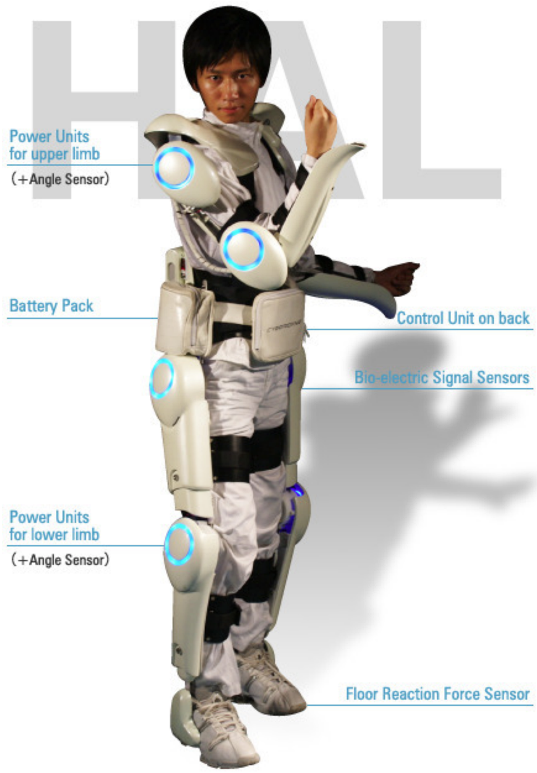

Figure 8. Cyberdyne’s HAL-5 (From Cyberdyne).

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II. WHY ARE ROBOTS INEVITABLE?

Change is often brought about by a combination of “push” and “pull” factors. Pull factors, i.e., those factors that draw people to an idea or new paradigm, are the strengths of robots that attract military organizations to adopt robots. Push factors, i.e., those factors that drive people away from an existing idea to a new idea or paradigm, provide the reasons for change, but the validity and strength of the reasons are subject to change, according to higher order influences. Push factors are the higher order influences that complement the pull factors by reinforcing the validity of pull factors and sustain the change.

Adoption of unmanned systems represents a significant milestone for military organizations and signifies the start to the integration of robots into military operations. This sustained change will be as much a reflection of the physical strength of robots, as it is an indication of the evolving macro environment of military organizations. This chapter discusses why the adoption of robots in the military is an inevitable outcome, by highlighting the strengths of robots that are pulling military organizations towards this option and identifying the trends in the evolving macro environment that are pushing for change. Figure 9 depicts the forces that are fueling the increasing use of military robots.

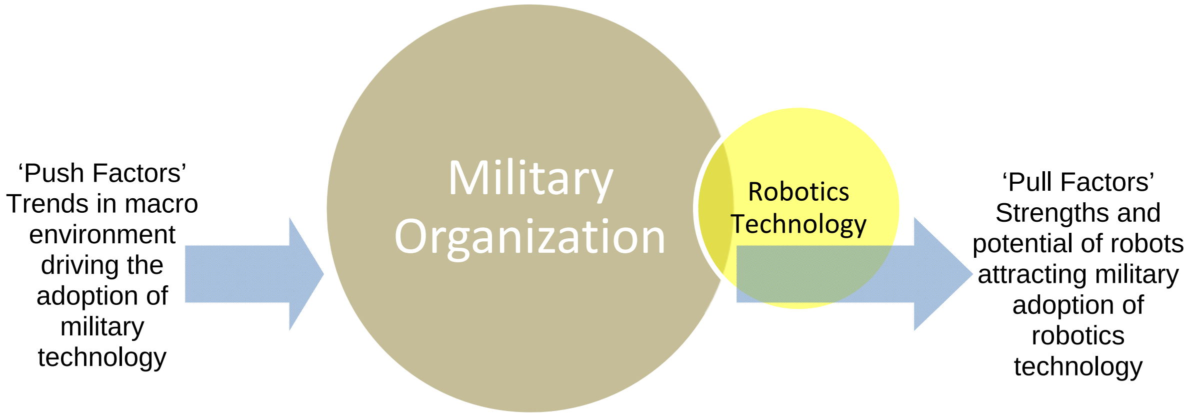

Figure 9. Diagram showing the pull and push factors that are moving military organizations toward robotics technology.

A. THE PULL FACTORS – STRENGTHS OF ROBOTS

While military robots that are currently deployed have limited capabilities and are not able to complete an operation without human intervention, the robots have exhibited numerous operational strengths and potential to allow military organizations to operate more efficiently and effectively. These operational benefits make robots very attractive to the military and form the pull factors for their adoption.

The purpose of robots, as with other technologies that have been adopted, is to make the life of humans easier by supporting what humans do or by replacing humans from their work altogether. Robots create greater value on specific tasks, than humans could on their own. Understanding that the disruptive nature of robots lies in the ability to replace humans, humans would be the best yard stick for measuring the strengths of robots. Identifying the strengths and potential that robots have over humans would therefore shed light on the reason why military organizations want robots.

Physiologically, robots are not subject to a circadian rhythm[4] and therefore do not experience fatigue the way humans do. While robots require maintenance (e.g., repair and refueling) at some point, the interval between maintenance is flexible and can potentially stretch from days to weeks or even months, depending on how robots are designed. Compared to humans, who would find it difficult to operate continuously for a day without sleep, this strength of robots would provide significant tactical advantage. Using UAS as an example, this strength is translated to a long-dwell presence over the battlespace, giving military commanders a persistent source of intelligence (Gertler, 2012).

Another physical advantage that robots have over humans is their capacity to carry loads beyond what humans can. The physical construct of human bodies limits the amount of load that humans can carry. This limitation underlines the dilemma with which military commanders are constantly contending: overload soldiers with more gear and compromise a soldiers' performance, or reduce soldiers' load and compromise the capabilities that additional gear provides (Hoffman, 2012). Robots on the other hand, have been designed to carry heavier loads than human soldiers. Boston Dynamics' BigDog, for example, can carry a 340lb. load (Boston Dynamics, 2013), compared with less than a 100lb. load for a typical soldier (Gorman, 2009). The ability to carry heavier loads than human soldiers coupled with the fact that robots are not restricted in their physical forms and can be built with various materials makes robots more versatile in terms of what functions they can perform and how they can be deployed. This strength is validated by the diverse forms and application of robots currently in the military.

Cognitively, humans are superior to robots in many ways. According to renowned futurist and inventor, Ray Kurzweil (Kurzweil, 2005),

[4] A daily rhythmic activity cycle, based on 24-hour intervals, that is exhibited by many organisms (*The American Heritage Dictionary,* 2000). It includes the sleeping and waking in humans.

> The massively parallel and self-organizing nature of the human brain is an ideal architecture for recognizing patterns that are based on subtle, invariant properties. Humans are also capable of learning new knowledge by applying insights and inferring principles from experience, including information gathered through language. A key capability of human intelligence is the ability to create mental models of reality and to conduct mental "what-if" experiments by varying aspects of these models.

Robots, however, still possess some “cognitive” advantages over humans. These include the ability to store large amounts of information precisely and recall them instantly, as well as the ability to transfer or share the information they hold at extremely high speed to other robots or systems using the existing communication networks (Kurzweil, 2005). While humans are able to recognize patterns better than any currently available robots, robots are able to process signals three million times faster than humans (Kurzweil, 2005), allowing logical calculations to be made much more quickly and accurately.

B. THE PUSH FACTORS – MACRO ENVIRONMENTAL TRENDS

Pull factors make robots attractive to military organizations. The attractiveness is bounded by the context that surrounds military organizations. The attractiveness of robots could change as context changes. An argument for the rapid and sustained rate of adoption of robots would therefore require an analysis of the macro environment of military organizations and identify the key trends that are fuelling the need for robots. In contrast to pull factors, these key trends can be thought of as the push factors, driven by key developments, for the adoption of robots. This section defines the general macro environment of military organizations and identifies these push factors.

1. The Macro Environment

To appreciate the macro environment of military organizations the PESTEL framework (Gillespie, 2007) defines the macro environment in terms of political, economic, social, technological, environmental and legal factors. Using this framework, Figure 10 highlights the key trends in the macro environment that would affect the use of robots in military organizations in the long term.

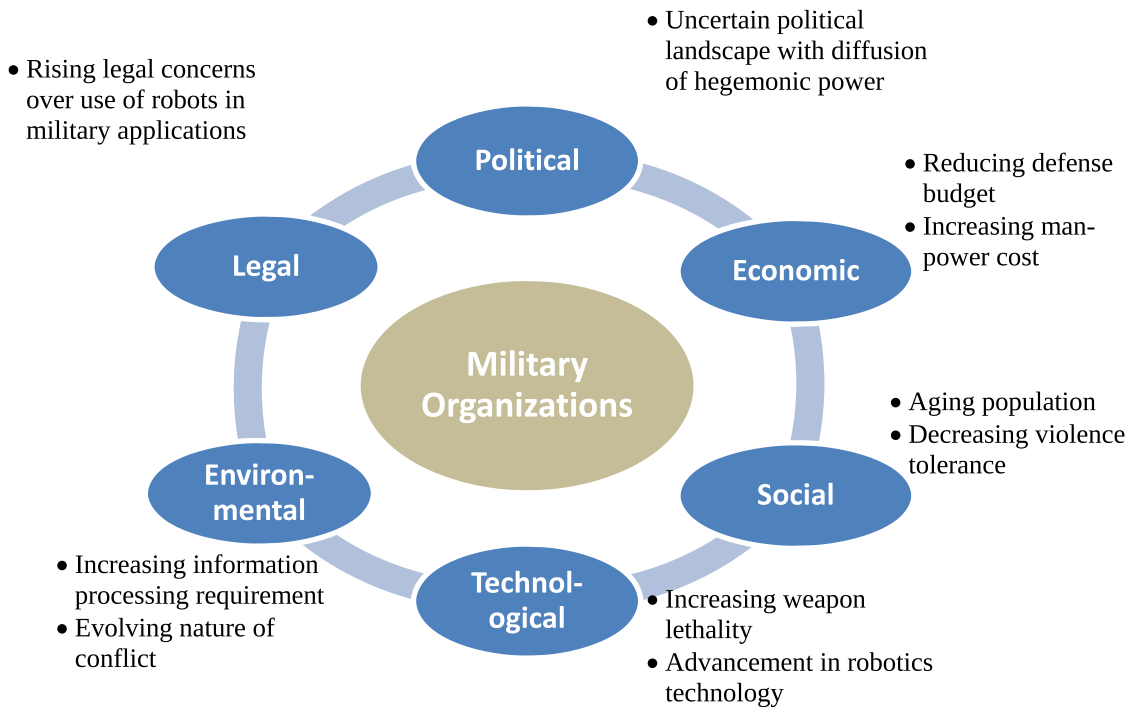

Figure 10. Macro environment and trends for military organizations.

2. Key Trends

a. Shifting Political Landscape

The adoption of robots in the military is premised on a military's need to improve itself constantly, so as to maintain its edge over an existing adversary or a perceived threat to its nation. Given the uncertain political landscape, there are reasons for military organizations to stay on their toes and continuously seek to improve.

One of the "Megatrends" identified in the *Global Trends 2030* report by the U.S National Intelligence Council, is the diffusion of power on the global stage, resulting in a shift from a world with a hegemonic power to one with multipolar networks and coalitions (National Intelligence Council, 2012). While it is clear which countries will be the major powers, how coalitions will form around them is less clear and the dynamics between coalitions will be uncertain. It is not in the interest of this thesis to speculate how power will be distributed and coalitions will be formed. What is to be highlighted is the uncertainty that will be brought about by the diffusion of power and the broad implication for militaries around the world.

As power shifts away from U.S., the confidence of countries that traditionally relied on the U.S. military for protection and deterrence may waiver. There is uncertainty about the ability of the U.S. to maintain order on the world stage, and there will be uncertainty about the intentions of emerging powers. These uncertainties will lead many countries to the logical conclusion of stepping up on investment in their own military, at least until the political landscape stabilizes. The increase in military spending across the globe will in turn fuel the adoption of disruptive technologies such as robots.

b. Aging Global Population

> Aging is widely seen as one of the most significant risks to global prosperity in the decades ahead because of its potentially profound economic, social and political implications.
>
> –Klaus Schwab, founder and executive chairman
> of World Economic Forum

The potential of robots to reduce manpower requirements in the military and the benefits of that cannot be understated, given the global aging demographic trend. Statistics from the United Nations Population Division shows that the percentage of population aged 60 years or older of developed and developing countries is 23 and 9 % respectively. These numbers are projected to rise to 32 and 19, respectively, by 2050 (United Nations Population Division, 2013).

The implication of an aging population is the increase in proportion of seniors, resulting in a decline in economic productivity and slower or stagnant GDP growth (National Intelligence Council, 2012). Greater pressure will be placed on the decreasing proportion of the working population to support the seniors, and the working age population will become an increasingly scarce economic resource. In this setting, militaries around the world will have significant pressure to downsize. This trend, coupled with the need to maintain or improve military capabilities, as a result of the uncertain political landscape, would drive militaries toward technologies that have the potential to reduce manpower requirements significantly without compromising effectiveness.

c. Decreasing Global Conflict and Casualty Tolerance

The importance of public support for a military's cause is well founded. There is no lack of examples of military campaigns that failed because of the inability to sustain public support. U.S. military war efforts in Vietnam and Korea are two prominent examples. Studies have shown that wartime approval is significantly dependent on recent casualty numbers and the longer term casualty trend (Gartner, 2008). Approval for participation in a war or conflict would decrease with casualty reports that suggest an increasing casualty trend. Interpreted from the perspective of the public, tolerance for casualties will be lowered in extended periods of peace.

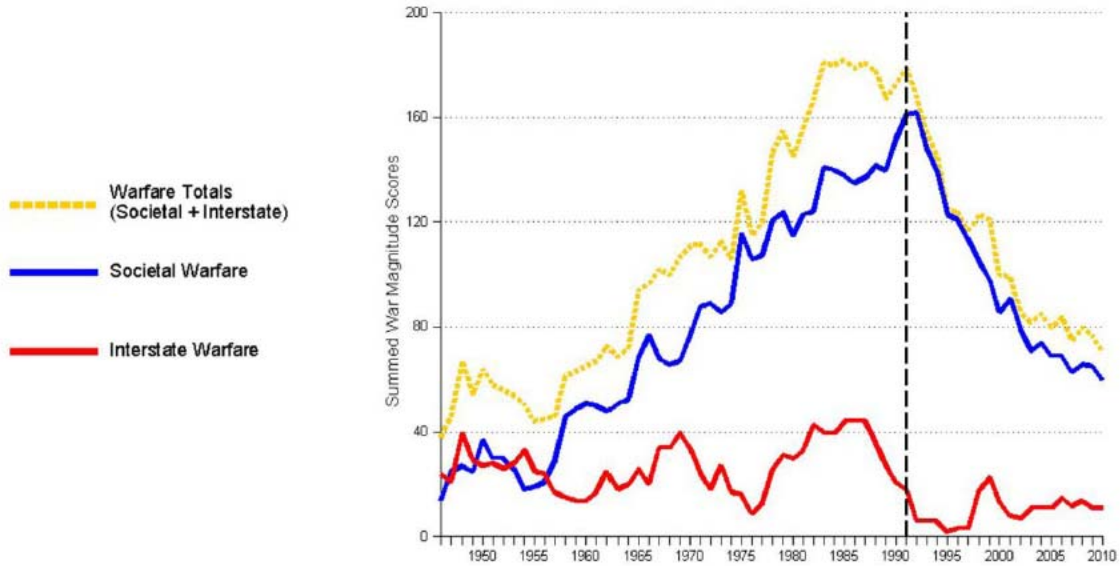

Figure 11. Global trends in armed conflict, 1946 - 2010[5]
(From Marshall & Cole, 2011).

As shown on Figure 11, the magnitude of armed conflicts on the global level has decreased since 1991 (Marshall & Cole, 2011). The turning point coincides with the end of the Cold War. Without any prospect for another "Cold War" this trend is likely to persist, and the public's tolerance for casualties in conflicts would likewise decrease. This trend would place pressure on militaries to reduce the number of casualties in future operations. This trend would pose an increasingly challenging task with continued advancements in weapon technologies that make them more lethal and precise.

d. Evolving Nature of War and Exposure of Human Limitations

An important strength of humans is the ability to adapt to changing environments and exploit tools to achieve our goals. This strength has secured

[5] Societal warfare includes civil, ethnic and communal conflicts, while interstate warfare includes armed conflicts between nations as well as wars for independence. The magnitude of each "major episode of political violence" (armed conflict) is evaluated according to its comprehensive effects on the state or states directly affected by the warfare, including numbers of combatants and casualties, affected area, dislocated population and extent of infrastructure damage (Marshall & Cole, 2011).

our survival and rise to dominance in the natural world. The ability to adapt and react to the dynamic conditions of war is also the reason for humankind's "5000-year-old monopoly on the fighting of wars" (Singer, 2009a). This strength, however, will not be sufficient to make up for human weaknesses that are increasingly exposed by the evolving nature of war and increasing demands on soldiers.

Conflicts will be increasing between states and non-state actors. Warfare will be increasingly asymmetric[6] in nature and will be characterized by the use of advanced weaponries with a significant multiplier effect (Kunstler, 2011). The asymmetric characteristics of a battlefield would include chemical and biological weapons that are targeted specifically at causing human casualties and dampening the will of opponents to fight. The ability of humans to operate in chemically or biologically contaminated areas, while possible, is limited and poses a significant risk.

e. Increasing Adoption of Robots in Industrial and Domestic Domain

The use of robots in different domains across the globe is on the rise. Statistics from International Federation of Robotics, IFR, shows the increasing sales of robots globally over the past few years and projects the trend to continue over the next few years. Figures 12 and 13 show the sales projections for industrial and domestic/personnel, respectively, in the next few years. For industrial robots, worldwide sales are projected to increase by an average of 5% per year from 2013 to 2015 (International Federation of Robotics, 2012). Sales of household robots and entertainment and leisure robots are projected to be 11 million and 4.7 million units, respectively, between 2012 and 2015 (International Federation of Robotics, 2012).

[6] Asymmetric warfare is defined as leveraging inferior tactical or operational strength against the vulnerabilities of a superior opponent to achieve disproportionate effect with the aim of undermining the opponent's will in order to achieve the asymmetric actor's strategic objectives. (Mckenzie, n.d.)

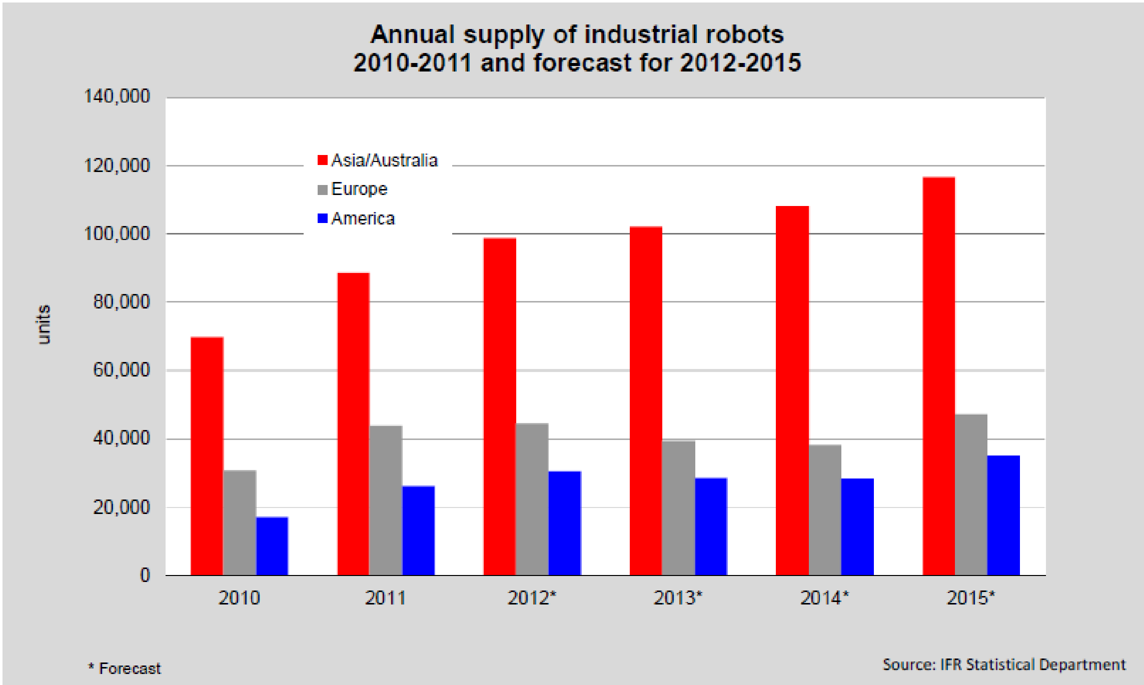

Figure 12. Annual supply of industrial robots to various regions (From International Federation of Robotics, 2012).

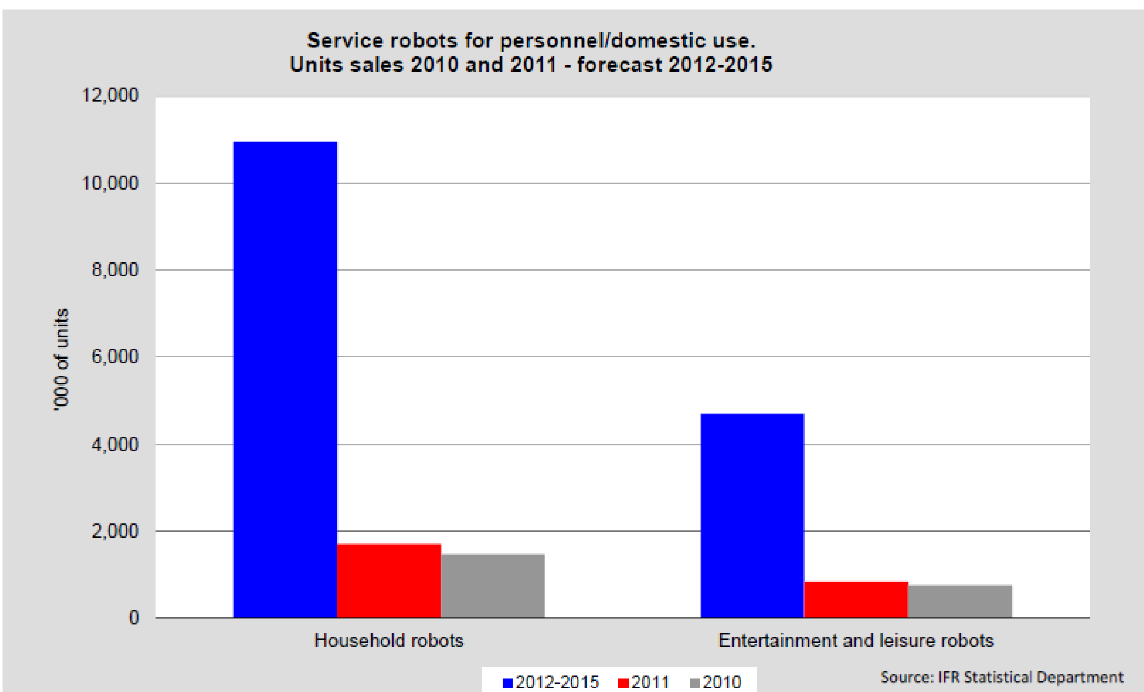

Figure 13. Unit sales figures and forecast for personnel/domestic service robots (From International Federation of Robotics, 2012).

The general increase in sales of robots across various domains is a reflection of the demand for robots and recognition of their value to the world as a whole. Should the increasing sales/demand trend be sustained, attracting competition into the market, military organizations may benefit from the lower cost and advancement in robotic technologies.

f. Legal Debates and Concerns

The macro environmental trends discussed so far are in favor of the adoption of robots in military organizations. Going forward, the rise of robots within military organizations will, however, not be unopposed. The ongoing debate over the legality of U.S. military's use of drone and legal concerns over the consequences of the actions of autonomous robots represents potential obstacles for the use of robots.

The legal debate pertaining to U.S. military's use of drones, as highlighted by the Stanford International Human Rights and Conflict Resolution Clinic, include: "Did U.S. violate the sovereignty of Pakistan by the use of force (in part by the use of drone) under the United Nation (UN) Charter?" "Did U.S. military's use of force against individuals contravene the International Humanitarian Law (IHL) or the International Human Rights Law (IHRL)?" "Did U.S. meet its legal obligation to operate transparently and ensure accountability of alleged rights abuses?" and "Is targeted killing legal under U.S domestic law?" (Stanford International Human Rights & Conflict Resolution Clinic). Given the specific context for the legal debate, it is unlikely that the outcome of the debate will impede the general adoption of robots in military organizations. The outcome of the debate will, however, have implications on how robots will be designed and developed for combat applications in the future. These implications will be discussed in Chapter III.

The current legal debate aside, results of a survey conducted by Camutari suggest that there are other legal concerns that will have greater impact on how robots will be used in the future (Camutari, 2011). Some of these legal concerns as highlighted by Camutari include: “Who will bear the responsibility for the unethical consequences resulting from the actions or malfunctioning of autonomous robots?” and “How can we regulate the use and actions of autonomous robots?” (Camutari, 2011). With regard to the ongoing legal debate, how these concerns are resolved will have implications on how robots are designed, developed and used in the future, and these implications will be discussed in Chapter III.

In summary, the macro environmental trends will push military organizations toward the adoption of robots. The need for military organizations to reduce the manpower requirement, reduce risks to human lives in military operations and adapt effectively to a changing operating environment in a cost effective manner will be a lasting justification advanced by proponents of robots.

III. PROJECTING THE RISE OF ROBOTS AND THEIR EVOLUTION

An important underlying assumption made in this thesis is that robots will be adopted extensively in military organizations. This assumption to some extent explains the significant impact that robots will have on military organizations and justifies the need for attention by military organizations. Building on this assumption this chapter projects the adoption curve for robots in military organizations as robots evolve over time. This chapter also identifies the possible forms and capabilities of robots as robotics technology advances and new applications are uncovered. The purpose of this chapter is to provide an estimate of the robot adoption timeframe, allowing appreciation of the urgency for military organizations to prepare for the rise of robots.

A. PROJECTING ADOPTION TIMEFRAME FOR ROBOTS

How readily will robots be adopted by military organizations? How long will it take before robots become commonplace throughout military organizations? The answers to these questions are important as they provide some reference to time, allowing military organizations to assess the urgency for action. There are, however, no readily available answers to these questions in the existing literature. To provide military organizations with some form of time reference, this thesis projected an adoption timeframe for robots by exploring the historical adoption trend for some of the significant electronic technologies, including radio, television, personal computer (including desktop, laptop and tablet), and the Internet. This section discusses the adoption timeframe for robots in military organizations.

1. Technology Adoption S-Curve

Rogers proposed that the cumulative number of individuals in a market adopting a new technology follows an ‘S’ shaped curve (Rogers, 1983). The adoption of technology is led by innovators, followed by the early adopters, early majority, late majority and finally the laggards (Rogers, 1983). Figure 14 shows a typical technology adoption over time.

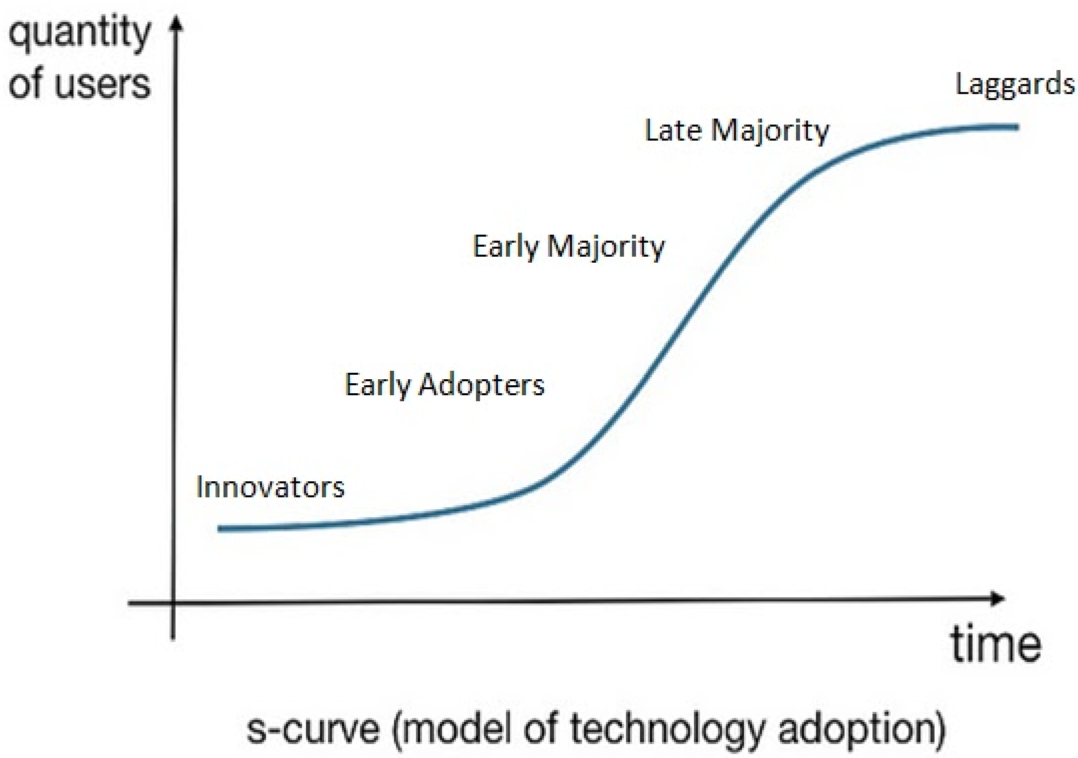

Figure 14. Technology adoption S-curve (From Peyeti, 2011).

Adoption of a technology may be thought of as being triggered by the first market introduction of the technology. From Figure 14, it can be seen that a technology will experience a phase of slow adoption rate after market introduction. The slow adoption phase is followed by a rapid increase phase, which will eventually enter a saturation phase where adoption remains relatively constant. While the adoption of technology generally follows the S-curve, the rate of adoption (i.e., gradient of the S-Curve and the time taken to reach saturation) depends on several factors, including: 1) the perceived attributes of the technology, 2) type of innovation-decision, 3) communication channels, 4) nature of social system and 5) extent of change agents' promotion efforts (Rogers, 1983). It is beyond the scope of this thesis to project the adoption timeframe for robots by performing a thorough analysis on the adoption rate of robots. The thesis, however, estimated the adoption timeframe for robots by reference to the adoption timeframes of existing technologies.

2. Adoption Timeframe for Robots

To estimate the adoption timeframe for robots, the historical adoption trends for radio, television, computer (includes desktop, laptops and tablets) and the Internet was explored. These technologies were chosen as they are deemed by the author to have been significant technological breakthroughs at the point of introduction, just as robots are now. The adoption of these technologies followed the S-curve model as suggested by Rogers. Figure 15 shows the adoption for these technologies by U.S. households.

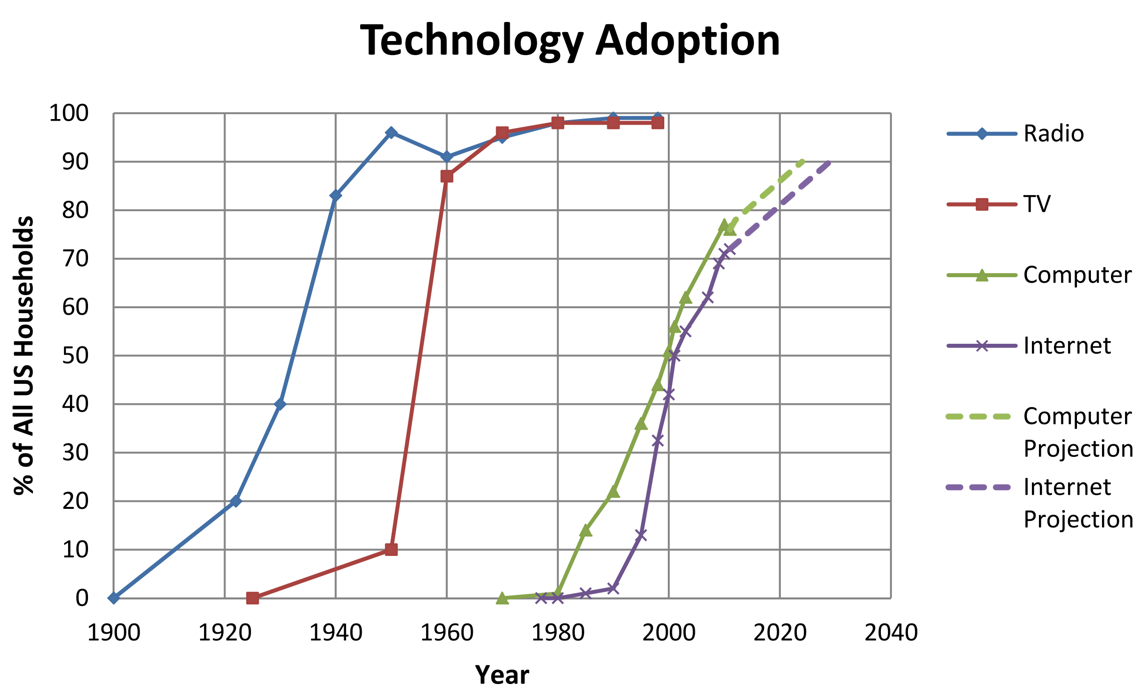

Figure 15. Analysis of historical data (Data from Moore & Simon, 1999; and File, 2013).

The point of introduction for the technologies was taken to be the year in which the technology demonstrates its value to the potential market. With this definition, the point of introduction for radio, television, computer and Internet was determined as 1900,[7] 1925,[8] 1970[9] and 1977,[10] respectively. Radio reached saturation around 1950, 50 years after introduction. Television reached saturation around 1970, 45 years after its introduction. The data in Figure 15 suggests that the personal computer and Internet have yet to reach saturation as of 2011. Taking a conservative stance and assuming that the adoption of the personal computer and Internet will continue to increase by 1% a year, and assuming that saturation is reached when adoption is 90%, the computer will reach saturation in 2024 54 years after its introduction, and the Internet will reach saturation in 2029, 52 years after its introduction.

The analysis on the adoption timeframe for radio, television, computer and Internet suggests that electronic technologies generally take 50 years from their point of introduction to reach saturation. The accuracy of this estimate is questionable given the subjectivity in determining the point of introduction. The applicability of this estimate to the adoption of robots in military organizations is likewise debatable given the different context of application. Despite the shortcomings of the method, it is safe to postulate that robots will become pervasive in U.S. households in a matter of a few decades and likewise in military organizations.

[7] Year in which Nikola Tesla was granted a U.S. patent for a "system of transmitting electrical energy" and another patent for "an electrical transmitter" (National Academy of Engineering, 2013).

[8] Scottish inventor John Logie Baird successfully transmits the first recognizable image (National Academy of Engineering, 2013).

[9] First personal computer emerges from Palo Alto Research Center (National Academy of Engineering, 2013).

[10] Demonstration of the ability of three independent networks to communicate with each other using the Internet protocol (National Academy of Engineering, 2013)

B. EVOLVING ROBOTS

When assessing the impact of robots on military organizations, it is important to note that robots are not limited to their current forms and applications. Robots will evolve as technology advances and as the potential of robots is uncovered. The impact of robots on military organization will change as robots evolve in form and application. This section identifies two distinct classes of robots and discusses their evolution and adoption in military organizations.

1. Free Robots (F-bots)

Chapter II explored the trends in the macro environment of military organizations that will affect the adoption of robots. The trends generally supported the adoption of robots to improve performance, reduce risks on human lives and make up for manpower shortages, suggesting the need for robots to replace humans. This need will drive the development of what is referred to as free robots (or F-bots) in this thesis, which can perform dynamic operations with minimal or no human supervision. From a technical perspective, F-bots would be characterized by the semantic technologies (Lund University, 2012) that would enable them to learn and adapt to their operating environment. The development and evolution goal for F-bots would be a fully autonomous robot that does not require any human support and is capable of replacing any human functions in military organizations. The robots in *Transformers* would represent the evolutionary goal for F-bots.

Examples of existing F-bots include the Boston Dynamics' BigDog (Boston Dynamics, 2013), Google's driverless car (Markoff, 2010) and robotic vacuum cleaners. These existing F-bots, while having limited applications, are capable of operating in a dynamic environment with minimal human control and supervision.

2. Tethered Robots (T-bots)

The drive towards a fully autonomous robot may, however, be impeded by the outcome of the ongoing ethical debate highlighted in Chapter II. Opposition to the idea of a robot capable of making kill decisions could drive the development of tethered robots (T-bots) in favor of F-bots, allowing humans to maintain control over robots and the kill decisions. Examples of T-bots include the various unmanned systems that are currently employed by military organizations and cars with robotic functions like cruise control and autonomous parking. These robots, while capable of autonomous actions, will require human control to accomplish their operations. As highlighted by the car example, human control over T-bots need not be remotely implemented (i.e., unmanned). Robots that are physically co-located (i.e., manned) with their human operators are also considered T-bots.

Ironman's exoskeleton suit could represent the evolutionary goal for manned T-bots. Given the need for interaction with humans, the development of T-bots will be characterized by a focus on technologies that would enhance human-robot integration, and a relatively lesser emphasis on semantic technologies when compared to F-bots.

3. Evolution and Adoption of Robots

Advancements in robotic technologies will drive the evolution of robots and increase the adoption of robots across military organizations. Using the projected adoption timeframe of 50 years as discussed in the earlier section, and assuming a separate evolution and adoption trajectory for F-bots and T-bots, a possible adoption and evolution path for military robots is projected in Figure 16.

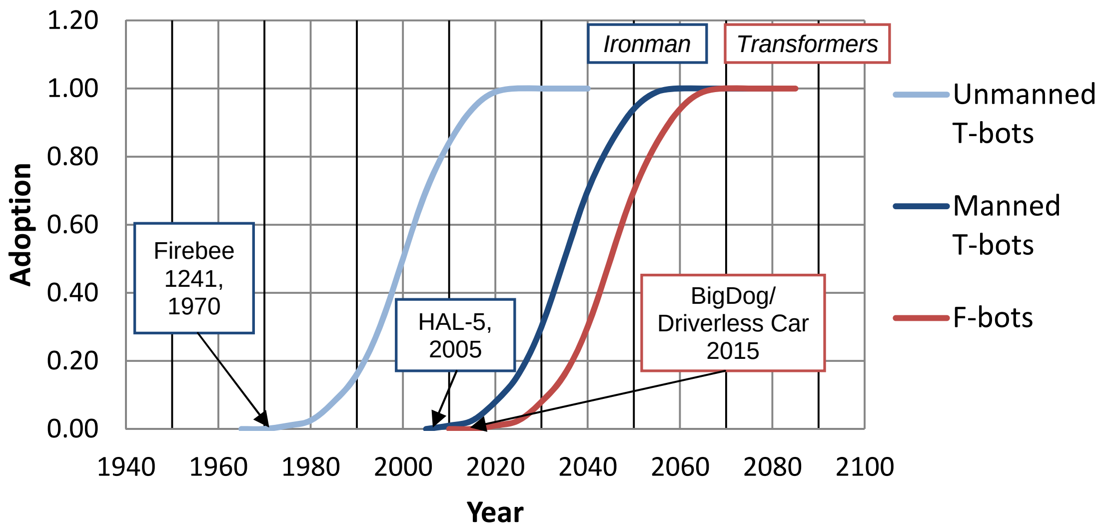

Figure 16. Projection for adoption and evolution of military robots.

The adoption ratio in Figure 12 is arbitrary and does not reflect the relative magnitude of adoption between the various types of robots. The adoption ratio for a particular type of robot may be taken to be the ratio of the actual numbers deployed to the potential numbers that can be deployed. Achieving an adoption ratio of 1 would therefore suggest that the potential of that type of robot, in terms of application, has been fully realized. Taking the development of Firebee 1241[11] in the early 1970s (Ambrosia, Wegener, & Schoenug, 2013) to be the point of introduction of unmanned T-bots, the projection based on a typical S-curve with an adoption time frame of 50 years suggests that the application of unmanned robots will reach saturation in the early 2020s.

For the case of manned T-bots, taking the point of introduction for manned T-bots to be the year 2005 when the HAL (Hybrid Assistive Limb) 5[12] was first made commercially available (Guizzo & Goldstein, 2005), it is projected that the

[11] Israel successfully deployed Firebee 1241 during the Yom Kippur War with Egypt and Syria, demonstrating the value of UAV to military organizations in modern warfare (Ambrosia, Wegener, & Schoenug, 2013).

[12] HAL-5 is the first commercially available full body powered exoskeleton with potential military application. It is built by Cyberdyne Inc. for the medical industry, to help disabled people walk and move (Guizzo & Goldstein, 2005).

adoption of manned T-bots will increase from 2020. Currently, there are no F-bots that have demonstrated value to military organizations. Boston Dynamics' BigDog and Google's Driverless Car, however, show potential. Should these developments demonstrate their value to military organizations by mid-2015, the adoption of F-bots will pick up in 2030 and reach saturation in 2065.

While the adoption timeframe for the various types of robots is projected to be 50 years, the actual timeframe will vary from organization to organization, depending on the rate of adoption within individual organizations. The rate at which robots are adopted within an organization is dependent on how much the organization needs robots (push) and how much money the organization is willing to or is able to invest (pull) in the development and acquisition of robots. These rates will necessarily vary from organization to organization according to the specific macro environment of the individual organization. The variation in adoption rate of F-bots and the corresponding adoption timeframe resulting from varying degrees of need for robots is highlighted in Figure 17.

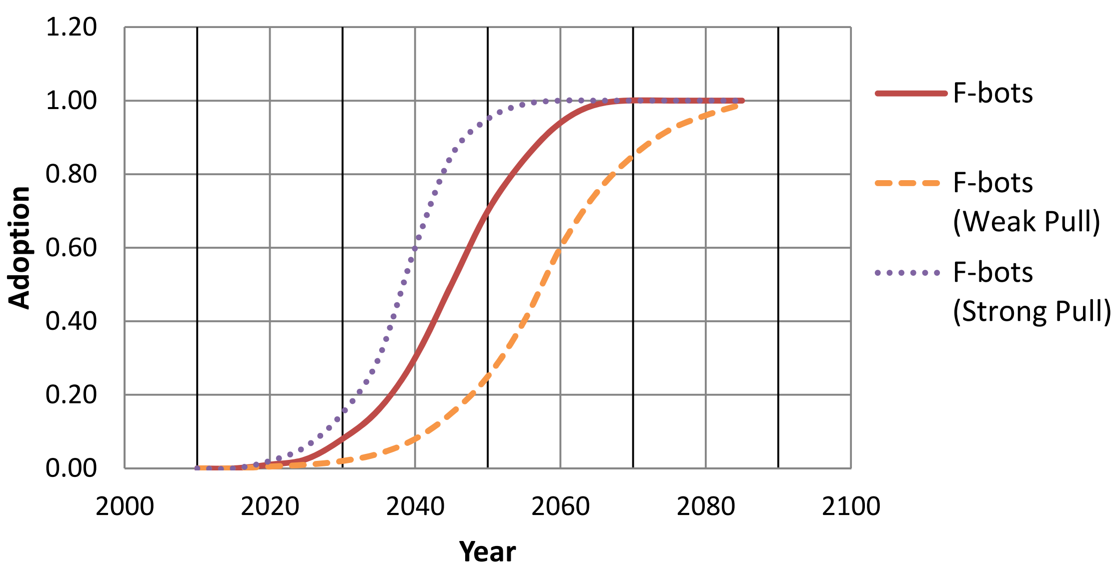

Figure 17. Variation in adoption of F-bots in various military organizations resulting from different emphasis on robots development and investment.

IV. IMPACT OF ROBOTS

The increasing adoption of robots over the long term has serious implications for military organizations. These long-term implications are a result of the dynamic near-term interactions that robots make as they are introduced into military organizations. This chapter discusses the near-term impact of robots and establishes the long-term implications arising from the rising number of robots. The chapter essentially serves to address the question of how robots will affect military organizations.

A. NEAR-TERM IMPACT

The near-term impact of robots on military organizations is essentially the changes that are brought about by the use of robots. Such changes will similarly be experienced with the fielding of any new equipment, and hence can be anticipated. The near-term impact will be felt as robots are introduced into the military organizations and may take effect at any point within the adoption timeframe of robots. This section establishes the near-term impact of robots from a systems integration perspective and highlights some of the specific impacts of currently deployed robots.

From a systems integration perspective, robots will fundamentally affect military organizations through interactions with objects (e.g., people, machines, and structures) within the organizations (Langford, 2012). The impact of robots can be seen from the physical, functional and behavioral dimensions (Langford, 2012) in terms of changes in these dimensions as robots are introduced. The specific changes will vary with the design of the robot and context of use. Generally, physical changes arising from the introduction of robots can be the addition or removal of physical objects from the military organization. Functional changes will include introduction of new function(s) to the organization, removal of obsolete function(s) or reallocation of functions between objects within an organization. Behavioral changes will include the establishment of new behavior(s) or altering of existing behavior(s) of objects within the organization. To provide examples of specific changes, the changes resulting from the introduction of an existing robot, the RQ-11 Raven,[13] are presented in the following sections.

1. Operational Impact of RQ-11 Raven

The RQ-11 Raven is a portable unmanned T-bot used by the U.S. military to provide ground troops with reconnaissance and surveillance capability (Headquarters, Department of Army, 2006). Figure 18 shows a picture of the RQ-11 Raven.

Figure 18. Picture of RQ-11 Raven (From AeroVironment, n.d.)

Some of the physical, functional and behavioral changes resulting from the introduction of RQ-11 Raven are identified and listed in Table 3.

[13] "Raven is a man-portable, hand-launched small unmanned aerial vehicle (SUAS) system designed for Reconnaissance & Surveillance and remote monitoring" (Headquarters, Department of Army, 2006) for the U.S. military.

Table 3. Examples of emergence.

S/No	Emergence
Physical	
1	Emergence of carrying case (Headquarters, Department of Army, 2006)
2	Emergence of maintenance kit (Headquarters, Department of Army, 2006)
Function	
3	Emergence of the function to pilot the RAVEN unmanned aircraft (Headquarters, Department of Army, 2006)
4	Emergence of the function to program mission into the RAVEN ground control unit (Headquarters, Department of Army, 2006)
5	Emergence of the function to provide live image streaming (Headquarters, Department of Army, 2006)
Behavioral	
6	Soldiers will use the RAVEN to assess the situation beyond an obstacle rather than physically repositioning themselves to assess the situation beyond the hill.
7	The soldier who carries the RAVEN is likely to distribute his combat load to other soldiers, so that the total load that he carries is manageable.

Beside the physical addition of the robot itself, other physical items were introduced to the operation as a result of the use of RQ-11 Raven. The carrying case and maintenance kit are two examples of additional physical items that were introduced and have to be carried by soldiers, along with the RQ-11 Raven (Headquarters, Department of Army, 2006). The implication of the additional items is a change in the total load that the soldier has to bear. The introduction of robots in general would result in the requirement for additional physical interfaces to allow interaction with the robots.

Functional changes that are introduced with the RQ11-Raven include the functions of the robot, like live image stream, and additional functions that soldiers have to perform. Examples of some of these additional functions include piloting the robot and programming the mission into the ground control unit for the robot (Headquarters, Department of Army, 2006).

Behavioral impacts may be assessed from changes in the actions of soldiers as a result of introducing the robots. In the case of RQ11-Raven, behavioral changes may include the tendency for soldiers to use Raven to assess the situation beyond an obstacle, rather than physically repositioning themselves to assess the situation. Another behavior that may emerge includes the redistribution of load by the soldier carrying the Raven to other soldiers.

While the introduction of robots may result in the removal of obsolete objects and functions, in the near term the introduction of robots is more likely to create more functions and objects for the military organizations. The implication of this tendency is the need for additional resources (i.e., manpower, infrastructure and budget) when introducing robots to military organizations in the near term.

2. Maintenance and Support for RQ-11 Raven

Provisions for the maintenance and support of robots have to be made with the use of robots. These provisions represent changes that arise from the introduction of robots. Some of the changes that may result from the maintenance and support requirements for robots are identified in Table 4.

Table 4. Possible changes due to maintenance and support requirements of robots.

S/No	Emergence
Physical	
1	Emergence of training facilities
2	Emergence of production facilities
3	Emergence of maintenance facilities
Function	
4	Emergence of the function to account for Raven
5	Emergence of the function to train Raven operators
Behavioral	
6	Targets will be more likely to move under cover to avoid detection
7	With Raven, higher level commands may grow to expect and demand for "live video" intelligence to make decisions.

Physical changes resulting from the maintenance and support requirements of robots would include the establishment or acquisition of infrastructures to support the use of the robots. These support infrastructures could include training facilities, production facilities, maintenance facilities and storage facilities. The magnitude of these physical changes would grow as the number and types of robots employed in military organizations increases and as the robots are deployed over a larger geographical area.

Functional changes resulting from maintenance and support requirements of robots could include the emergence of functions to support the use of robots. For the case of RQ-11 Raven, the emergent functions include training of operators, and the accounting of the robot. The functions that are introduced with the robots could also result in obsolescence of the functions of other systems downstream. In the case of the RQ-11 Raven, the ability of the RQ-11 Raven to provide surveillance images from the sky would render the use of manned aircraft for the same purpose obsolete.

Behavioral changes resulting from maintenance and support requirements of robots are diverse and difficult to anticipate. This situation is due to the dynamic nature of human and system behaviors that would vary from individual to individual. For the case of Raven, possible downstream behavioral impacts include changing opponents' choice of path for movement to avoid detection by the Raven and causing higher level commands to expect and demand live video intelligence when making decisions.

B. LONG-TERM IMPACT

The long-term impact of robots arises from the extensive and pervasive use of robots as adoption increases over time. The long-term impact is the result of the cumulative near-term impacts of robots. This section discusses the long-term implications of using robots.

1. A Model for Assessing the Long-Term Impact

To explain the long-term implications of robots, this thesis adopted a Systems of Systems[14] (SoS) view of military organizations. System of Systems (SoS), as defined by the U.S Department of Defense (DoD), is "a set or arrangement of systems that results when independent and useful systems are integrated into a larger system that delivers unique capabilities" (Office of the Deputy Under Secretary of Defense for Acquisition and Technology, Systems and Software Engineering, 2008). Taking an SoS view, military organizations can be modeled as shown in Figure 19.

[14] An SoS is defined as a set or arrangement of systems that results when independent and useful systems are integrated into a larger system that delivers unique capabilities (Office of the Deputy Under Secretary of Defense for Acquisition and Technology, Systems and Software Engineering, 2008). Each individual system and the SoS conform to the accepted definition of a system in that each consists of parts, relationships, and a whole that is greater than the sum of the parts; however, although an SoS is a system, not all systems are SoS (Office of the Deputy Under Secretary of Defense for Acquisition and Technology, Systems and Software Engineering, 2008).

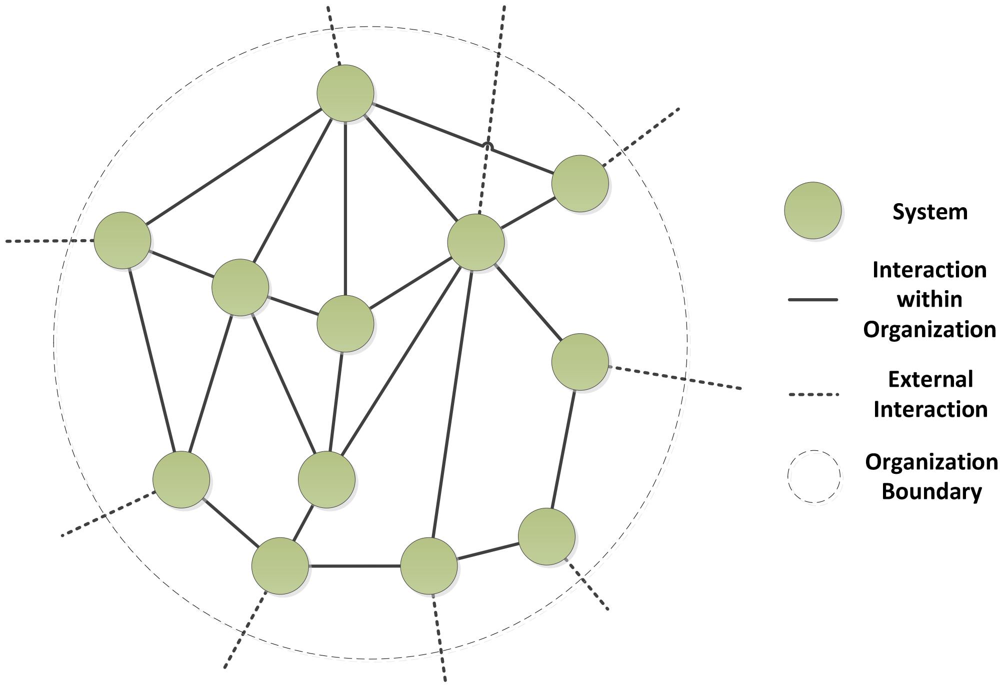

Figure 19. System of Systems (SoS) representation of a military organization.

The SoS view of military organizations focuses on system-level interactions between systems within the organization and interactions with the external environment. While represented by the same symbol on the model, the various systems within military organizations are different and the composition of systems would vary from organization to organization. The capabilities of a military organization from an SoS perspective can be thought of as being derived from the interactions between various combination of systems within the organization. The interactions that are established (i.e., the number of interactions and the subjects of interaction) within an organization, reflects the processes that are in place within the organization. From an SoS view of military organizations, the impact resulting from the introduction of a new system are changes to existing processes and how systems are organized within the organizations.

A problem with the system of systems model of military organizations is the lack of human representation; the SoS model in Figure 20 recognizes humans and human functions as being part of systems. A more human-centric model is required to allow for appreciation of the impact of robots on humans within military organizations. Figure 16 offers a human-centric system of systems (HcSoS) model of military organizations that is adapted from the SoS model.

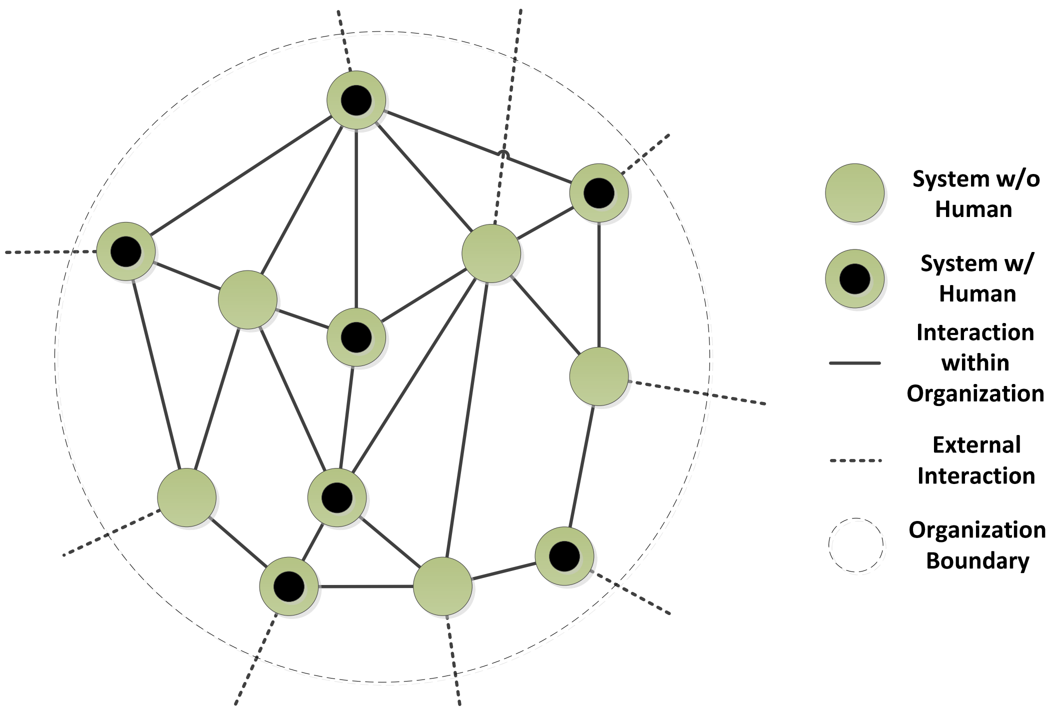

Figure 20. Human-centric SoS model of a military organization.

The problem is resolved by making a differentiation between systems with human functions and systems without human functions in the HcSoS view of military organizations. Systems with human functions are systems in which human(s) make the system complete in terms of allowing the system to achieve its purpose. Examples of systems with human functions include manned aircraft, aircraft carriers, tanks and command centers in general. Systems without human functions are systems that are capable of operating normally for a sustained period of time without the need for human intervention. Examples of systems without humans include satellites and communication networks in general. The HcSoS model of military organizations shown in Figure 20 depicts the current extensive reliance on human functions throughout military organizations. This reality is attributable to the dynamic nature of the operating environment of military organizations, which existing machines are largely inadequate to handle.

2. Organization-wide Impact

As highlighted in section A of this chapter, a consequence of the near-term impact of robots is the need for additional resources to support the use of newly introduced robots. At the organizational level, the introduction of robots to a system will affect how resources, in terms of manpower and material, are allocated among other systems within the organization. Assuming there is a limit to the amount of resources that are available to military organizations, the addition of robots will put a strain on the resources of military organizations, as the number of robots increase. The strain on the resources will place pressure on the military organizations to consolidate and reorganize. The new capabilities brought about by the introduction of robots will provide the scope for consolidation. Consolidation and reorganization will result in changes to how systems interact and alter the organizational level processes.

Aligning with the macro trends identified in Chapter II, the consolidation and reorganization of military organizations will be driven toward reducing the human role and manpower requirement and minimizing the risk to human life by reducing the interaction of humans with a dangerous external environment. The HcSoS model of a future military organization is shown in Figure 21.

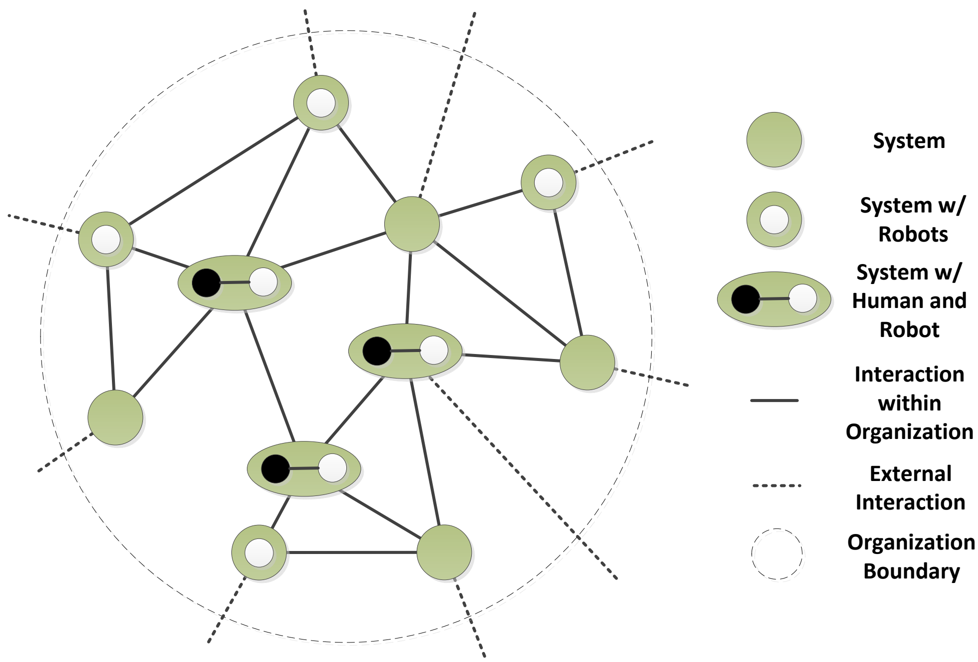

Figure 21. Evolving role of humans within military organizations.

Comparing the future model to the present model, reorganization of future military organizations is represented by the change in system types and the arrangement of the systems. Reduction in human functions is reflected by the reduced number of systems with human functions. Reduction in manpower requirements would follow the reduction in human functions provided military organizations do not expand the scale and scope of their operations significantly to offset the reduction human functions. Lowered exposure of humans to a dangerous environment is represented by the lesser number of external interactions by any system with human functions. Interactions with the external environment are made predominantly through robot systems.

3. Evolutionary Journey of Military Organizations

According to Ray Kurzweil, the guiding principal for evolution is to increase order, where "the measure of order is a measure of how well information fits the purpose" and "information is a sequence of data that is meaningful in a process" (Kurzweil, 2005). For life forms whose purpose is to survive, evolution increases the order of the information that is encapsulated within the DNA to increase the chance of survival (Kurzweil, 2005). For military organizations, the purpose is to win wars. In an information age where information superiority is critical to winning wars (Alberts, Garstka, Hayes, & Signori, 2001), evolution would favor an organization that allows for more efficient flow of information. Given this understanding of evolution, the adoption of robots would be a natural evolutionary progression, given the potential of robots to process information more efficiently than humans.

Looking at a longer-time horizon, the evolution of military organizations triggered by the introduction of robots would represent a second phase of the evolutionary journey for military organizations driven by technological developments. The technologically-driven evolutionary journey for military organizations is represented using the HcSoS model as shown in Figure 22.

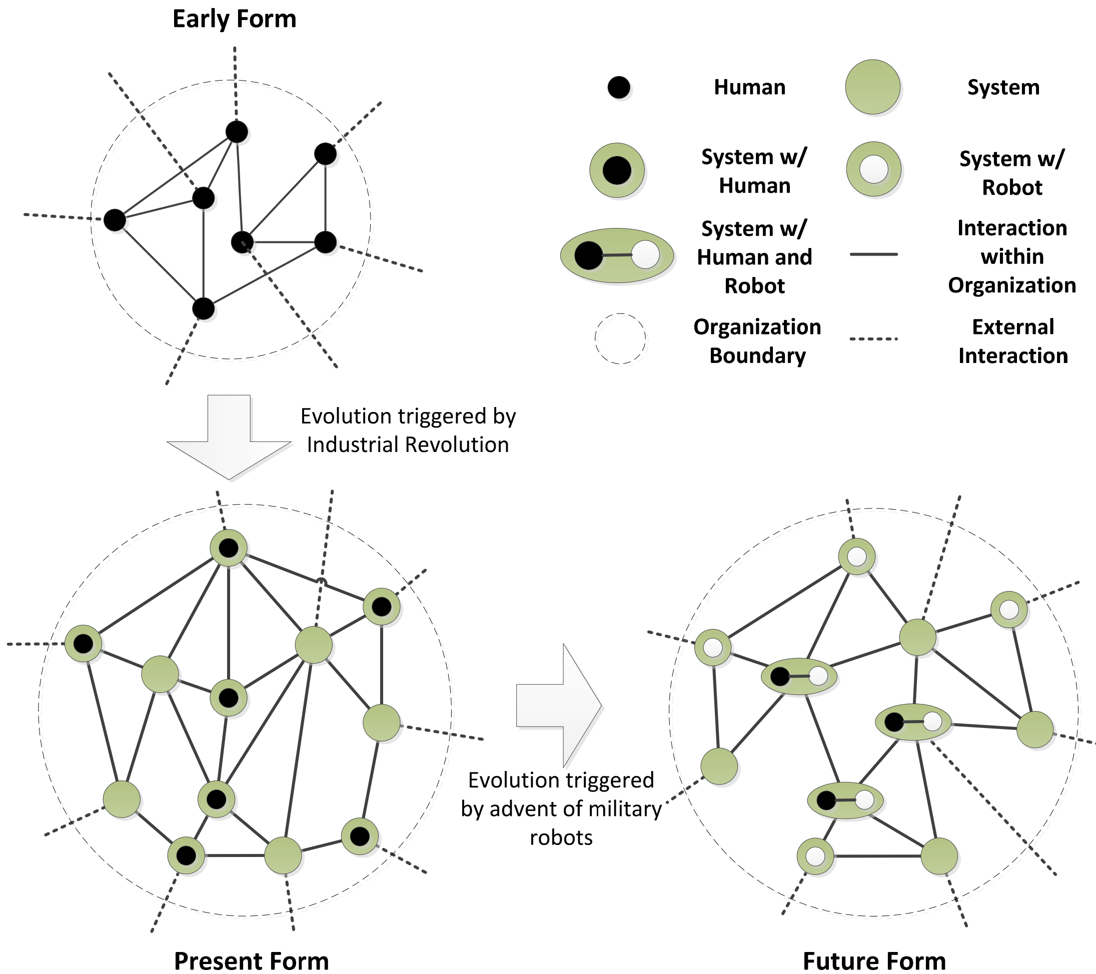

Figure 22. Technology-driven evolution of military organizations represented using HcSoS model.

The industrial revolution, which resulted in the embrace of science and technology and the development of military systems (Zapotoczny, 2006) contributed to driving the evolution of military organizations from its early form to the present form. The embrace of robots will drive the evolution of military organizations from their current form to their future form.

V. THE WAY AHEAD

The advent of robots is a significant milestone in the evolution of military organizations. Chapter II highlighted the inevitability of robots. However, knowing that robotics technology is still evolving and understanding the potential long term impacts of robots, we must acknowledge several challenges to the adoption of robots in military organizations. This chapter serves to propose the way ahead for military organizations, in terms of facilitating the introduction and integration of robots. The proposals represent broad strategies targeted at addressing the challenges that are identified from the assessment of the impacts of robots and aims to position military organizations for a smooth evolutionary journey.

A. NEAR-TERM ACTIONS

1. Differentiating Humans from Robots

Whether robots will ever become as intelligent as humans in the future is debatable. It is, however, beyond a doubt that robots will become increasingly intelligent and capable of filling an increasing number of roles that are currently taken up by humans. As the “capability lines” differentiating humans from robots become increasingly grey, the value of humans to military organizations will be questioned and the livelihood of humans threatened. There is, therefore, a need to establish a new differentiating line to protect the interests of humans and allow the peaceful coexistence of robots and humans within military organizations. This differentiating line should be identified early to guide the development of robots.

2. Establishing Research Focus

As highlighted in Chapter III, robotics technology is still in its infancy and has significant room for improvement. Research should focus on developing semantic technologies that would make robots more “intelligent” and on technologies that would enhance interactions between robots and humans, allowing efficient and effective transfer of information. Investment in these technologies will spur the development of F-bots and T-bots, potentially increasing their adoption rate and reducing their adoption timeframe.

3. Budgeting for Change

While the impact of robots in the long run is a reduction in the manpower requirement of military organizations, assessment of the impact of current military robots suggests that the manpower requirement is likely to increase in the short term. As military organizations explore the combat applications and roles of robots, additional manpower will be required to support the use of robots in the areas of operation and maintenance. The additional manpower requirement will have to be supported by military organizations together with the budget requirements for research and development of the robotics technology.

4. Expansion of Application

The current application of robots in military organizations is predominantly in the domain of combat. Diversifying the application of robots beyond the combat domain has at least two benefits. First, it would mitigate the risk of delay in the introduction of robots as a result of research deadlock in a specific application domain or roadblocks to specific application. Potential roadblocks could include objections by the public over privacy concerns and legal issues over the use of robots. Diversifying applications to other domains such as logistics and training would provide alternate avenues for development and deployment, thereby better sustaining the overall development of military robots.

Second, diversifying the application of robots early would allow for the potential of robots in other application domains to be uncovered sooner rather than later, and would likely allow the benefits of robots to be reaped earlier. The use of robots in the logistics domain is an area that might be worthwhile exploring early.

B. LONG-TERM FOCUS

1. Legitimizing the Robots

There is ongoing debate over the legality of U.S. drone strikes from the purview of both international law and U.S. domestic law (Stanford International Human Rights & Conflict Resolution Clinic, n.d.). While only the legality of a specific application of robots is put into question, it hints at more legal issues as the application of robots expands. There is therefore a need in the long term to legitimize the use of military robots.

Legitimacy of robots can be established through regulations on how robots are used and for what robots are used. The regulations would differ from application to application and should be considered prior to development of robots for a specific application.

2. Laying the Foundations

It should be noted that the inevitability of robots is enabled by some of their existing capabilities, and these enablers should not be neglected as robots proliferate. The enablers for the rise of robots include the communication and logistic support infrastructures.

The existing communication network provides an important channel for interacting with robots. The increased use of robots would likely put a strain on the communication network in terms of managing bandwidth availability. The reach of the communication network will also likely be pushed as robots are deployed over larger geographical area. It is therefore important to continue to invest in communication technologies and lay a strong foundation for the use of robots.

Human interaction with robots would be different from the interaction with systems, just as operating and maintaining a robot is different from operating and maintaining a human. The difference lies in the skills and competencies required for interaction. While some of the skills and competencies required for operating or maintaining robots can be trained within military organizations, others may have to be acquired through an external education system. The dependence on an external education system calls for external coordination to ensure there are sufficient qualified personnel to operate and maintain robots in the long run.

3. Reaping the Benefits of Robots

The assessment of the impact of robots in Chapter IV suggested that consolidation and reorganization of military organizations will occur as more systems are introduced to support robots, and manpower resources are strained. The consolidation and reorganization is necessary for the benefits of robots to be realized, in terms of reducing manpower requirement and cost within the context of aging demographics. While consolidation and reorganization are likely to be met with strong objections as jobs will be lost, military organizations need to recognize the longer term benefits and effect the change when the time comes.

4. Pacing the Change

As highlighted in Chapter III, robots are still evolving, and their integration into military organizations will take some time. It is important that military organizations manage the pace of change. On one hand, accelerating the development and introduction of robots would risk rejection by people. On the other hand, not investing in robots would risk falling behind adversaries in terms of capabilities. As a conservative strategy, the rate of introduction of robots into military organizations should mirror that in the civilian world. Social acceptance is likely to play an important part in ensuring the rise of robots.

C. CONCLUSION

This thesis explained why the extensive use of robots is inevitable for military organizations, projected the adoption timeframe for robots in military organizations, proposed how robots would evolve, assessed the impact of robots on military organizations and suggested the way forward for military organizations to facilitate the adoption of robots.

The inevitability of robots is fundamentally a result of the need to reduce manpower requirements in military organizations, while sustaining the capability needs of the organizations. The need to reduce manpower is driven by the trends of the macro environment for military organizations, which include the aging demographics and reducing public tolerance to human casualties. The evolving operational environment that places increasing demands on soldiers and exposes the limitations of the human body also supports the adoption of robots.

The adoption timeframe for robots in military organizations is projected to be 50 years. The projection is made by assessing the average adoption timeframe for earlier electronic technologies (i.e., radio, television, the personal computer and Internet). While the precision of the projection is debatable, the projection suffices to provide military organizations with an appreciation of the urgency for attention. As a follow on for the thesis, further research may be performed to provide a better estimate of the adoption timeframe of robots, tailored to various military organizations.

Robots are not limited to their current forms and will evolve as robotic technologies advance and the potential of robots is uncovered. Looking at the macro environmental trends, this thesis proposed the evolutionary goal for the two general types of robots, T-bots and F-bots. While F-bots would be more effective at replacing humans, development of T-bots is likely to predominate while semantic technologies, necessary for F-bots, are being developed and in the event that the macro environment favors human control over the actions of robots.

As robots evolve and their scale and scope of application increase, the impact on military organizations will change. The long-term impact of robots at the organizational level is a streamlining of the human resource within the organization, resulting in reduction in manpower requirements and change in organizational systems and their associated capabilities. The long-term impact is driven fundamentally by the changing interactions between systems within military organizations as a result of the introduction of robots. The changing interactions would manifest as physical, functional and/or behavioral changes, and these changes are observable from the assessment of the impact of currently deployed robots.

Understanding the impact and inevitability of robots, it is in the interest of military organizations to take necessary steps to facilitate the rise of robots and gain from the adoption of robots. In the near term, the priority for military organizations is to establish a clear distinction between humans and robots. This entails a clear segregation of roles that will be used to guide the development of robots. Investment in the research of semantic technologies and technologies that enhance robot human interactions should be made early to spur the development of robots and shorten their adoption timeframe.

Material and manpower resources should be provided for in the near term to support an expected rise in manpower and material resources for the operation and maintenance of robots. In the near term, the application of robots should also be diversified to provide multiple development channels and sustain the overall development of robots. Benefits of robots may also be realized earlier though the diversification of their application.

A longer term focus for military organizations is to legitimize the use of robots both internationally and domestically. The foundations supporting the rise of robots should be reinforced to sustain the increasing use of robots. These foundations include the communication network and the pool of specialists.

Consolidation and reorganization at the organizational level is the eventual means of harvesting the benefits of robots. This has to be recognized down the road and realized in spite of potential resistance.

Social acceptance is important for the successful integration of robots into military organizations. Military organizations should therefore pace the introduction of robots according to that in the public domain.

To conclude, macro environmental trends suggest that the use of robots is the way forward for military organizations. It is projected that the adoption rate of robots will pick up from this point forward and will reach saturation in a matter of decades. The use of robots has physical, functional, and behavioral implications for military organizations, and the increasing number of robots will affect how militaries are organized and alter the existing organizational processes in the long term. Military organizations will benefit from a better understanding of the impact of robots and the resulting challenges. Taking the necessary steps to mitigate the challenges, and facilitate the evolutionary transition for the military organizations will allow these organizations to reap the benefits of robots early and to operate effectively in the changing macro environment.

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