The Role of Intelligent Machines on the Future Battlefield, Circa 2030.

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Abstract

The application of Intelligent Machine (IM) technology to the battlefield in future has the potential to revolutionise warfare. Converging trends and incentives are propelling this technology towards military applications at an ever increasing rate. This thesis examines the state of IM employment on the battlefield at the year 2030.

The methodology employed in undertaking this thesis is the Extrapolation method. It has been utilised to extrapolate a range of technological, social, geo-strategic and military trends, in order to determine the state of affairs regarding intelligent machines at the subject year 2030.

Chapter One examines what proportion of modern military ground forces will consist of IMs at the subject year. It assesses factors both driving and obstructing the development and employment of IM technology, and compares these against environmental developments with respect to time.

Chapter Two addresses the likely roles in which IMs will be employed on the battlefield. These include present day military functions, as well as possible new roles enabled by specific characteristics of IMs. The chapter also assesses the potential forms that these IMs may take.

Chapter Three focuses on the level of autonomy to be granted to battlefield IMs. It analyses the risks and benefits of autonomous control, and also the

advantages and disadvantages of the alternative of teleoperation. The level of autonomy will be a defining factor of the IM presence on the battlefield.

Chapter Four investigates the potential organisational architectures that may be employed in organising, commanding and controlling IMs. Specifically, centralised, decentralised, and swarm organisation are examined. The advantages and disadvantages of each, as well as necessary enablers are considered in turn.

The conclusion provides an aggregated picture of the IM battlefield presence at the year 2030. It surmises the predicted proportion, roles, the level of autonomy, and organisational architecture of IM technology on the battlefield at the subject year of 2030.

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I would like to thank everyone who helped see me through to the conclusion of this thesis, with their knowledge, advice, encouragement and patience. I thank Dr Piers Reid (CBE) for helping me stay on track and yet allowing me the freedom to pursue my own ideas. Thanks too to Majors Doug Mallet and Stu Davies of the Australian Army, Major Vern Bennett and Warrant Officer Brian Chalmers of the New Zealand Army, Maxim Zimir of Rafael, Phil Strong of the Defence Technology Agency, Professors Guvinder Virk and Donald Bailey of Massey University, and Bryan Dorn for readily lending me their particular knowledge and expertise.

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Acronyms

AI	Artificial Intelligence
AO	Area of Operations
APC	Armoured Personnel Carriers
ARV	Armed Robotic Vehicle
BCI	Brain Computer Interface
BIT	Built-in Test
BOS	Battlefield Operating System
C2	Command and Control
C3	Command, Control and Communications
CCD	Charge-Coupled Device
CIED	Counter Improvised Explosive Device
CIWS	Close-in Weapon System
COP	Common Operating Picture
CSAR	Combat Search and Rescue
CSS	Combat Service Support
DARPA	Defence Advanced Research Programs Agency
DEWS	Directed Energy Weapon System
DOD	Department of Defence
EM	Electromagnetic
EOD	Explosive Ordinance Disposal
EW	Electronic Warfare
FCS	Future Combat Systems
GBAD	Ground Based Air Defence
GPS	Global Positioning Satellite
HF	High Frequency
HRI	Human-Robot Interface
IFV	Infantry Fighting Vehicles
IM	Intelligent Machine
IO	Information Operations
IR	Infra-Red
IRA	Irish Republican Army
ISR	Intelligence, Surveillance and Reconnaissance
KIA	Killed in Action
LOAC	Laws of Armed Conflict
MANET	Mobile Ad hoc Network
MIPS	Million Instructions per Second
MNC	Multinational Corporation
MRAP	Mine Resistant Ambush Protected
NBC	Nuclear, Chemical, Biological
OODA	Observe, Orientate, Decide, Act
OS	Offensive Support
PDA	Personal Digital Assistant
PMC	Private Military Contractor
RFID	Radio Frequency Identification
RMA	Revolution in Military Affairs
ROE	Rules of Engagement
SA	Situational Awareness
SAM	Surface to Air Missile

SWORDS	Special Weapons Observation Reconnaissance Detection System
TI	Thermal Imaging
UAV	Uninhabited Aerial Vehicle
UGV	Uninhabited Ground Vehicle
VHF	Very High Frequency
WIA	Wounded in Action

Introduction

The world is presently resting on the cusp of a technological revolution. A series of developing technologies are converging to liberate robotics from its established factory habitat and propel these machines out into the wider world. Mobile robotics will flourish into the fields of agriculture, horticulture, construction, and a plethora of other industries, as well as performing domestic duties within households. These “Intelligent Machines” will release humanity from many of life’s ‘dull, dirty and dangerous’ jobs, and so profoundly impact our day to day lives. Intelligent Machines (IMs) will also have significant application in the conduct of warfare, and are currently making their first significant forays onto the field of battle. Pressures driving their military utilisation exist now, and this drive only awaits a commensurate level of technology before battlefield IM employment booms. The tantalising prospects of virtually casualty free conflict, cost reductions, as well as a range of performance enhancements are but a few of the existing incentives. With time, the capabilities of these IMs will grow, and so the breadth and depth of their employment in warfare will expand, reshaping its conduct in potentially dramatic ways. An examination of the shape mature IM technology will take on the battlefield is therefore a worthy undertaking.

This thesis seeks to investigate the likely nature of IM technology’s presence on the battlefield at the year 2030, and will specifically examine four different aspects: the proportion of a modern Military’s ground forces consisting of IMs; roles and forms of IMs on the battlefield, the level of autonomy afforded to battlefield IMs, and their organisational architecture. In doing so, it will explore the range of reasons for and against the adoption of IM technology, the necessary precursors for its employment, the likely environment it will be utilised in, the manner in which it will be fitted to military organisations, and the path the technology may follow in reaching the subject year of 2030.

As with any promising new military technology, expectations often exceed the eventual reality of performance, once the complexities of the operating environment and enemy actions are brought to bear. Furthermore, the utility of any military technology is largely dependent on its effective integration into existing military organisations, in a way that combines it with other capabilities and harnesses it with military aims. With this in mind, this thesis will attempt to maintain a balanced and pragmatic assessment of the technology and avoid hyperbole or excessive enthusiasm, and also to examine the technology in the context of its broader organisational and environmental setting rather than in blissful isolation. The risk of technological failure due to expectations and development paths divorced from the realities of warfare provides a clear requirement for a bridge between technology and application, or between the languages of science and technology and of the military. The thesis is intended to contribute to the bridging of that gap, considering technological possibilities against military applications. This analysis of technology against context and requirement will help to guide the development and utilisation of military technology towards serving extant or forthcoming military needs. The extrapolation of various technological, social, geo-strategic and military trends out to the subject year will also give a better understanding of the potential opportunities, risks, and new operational realities brought about by the march of this potentially revolutionary technology.

Research Methodology

The method of research I will apply to this thesis, *'The Role of Intelligent Machines on the Future Battlefield Circa 2030'* is an *Extrapolation Method,* which is a method of forecasting based on identifying an ongoing change, or trend, through the use of historical data. The objective of this method is to identify a trend in its early stage well before it has run its course. I will drive my extrapolation with predominantly qualitative data. The use of qualitative as opposed to quantitative data in futures forecasting requires both creative and systemic thinking, posing a significant research challenge. Adding to this complexity, I aim to synthesize an array of interrelating trends that will both amplify or attenuate one another, in the technological, social, geo-strategic and military realms. Having considered and weighed all of these, I then aim to make an assessment of the role Intelligent Machines (IMs) will play on the battlefield in the year 2030.

Research Hypothesis

In this thesis, I aim to answer the question '*To what extent may Intelligent Machines be employed on the Battlefield in the year 2030, and what shape will their presence likely take?'* My initial hypothesis, based on research thus far, is that *humans will share the battlefield with a significant number and broad array of IMs in the year 2030, spanning roles from support through to combat, and possessing significant levels of autonomous decision making ability, with limited instances of authority to make 'kill/ not kill' decisions.* Bearing in mind that this thesis is an attempt to predict the future however, the hypothesis will only truly be tested either upon the year 2030, or, if at any time before that, my prediction of IM employment is superseded prematurely.

Scope and Structure of the Thesis

The scoping of this thesis has occurred almost inadvertently as a function of the temporal limit I have set and the nature of the technology. The choice of the year 2030 was made basically as a semi-informed 'pluck', based on some initial reading regarding the rate of advancement of technologies integral to IM (artificial intelligence (AI), energy storage etc), a basic knowledge of the rate of military technological advancement, and the time I believe it will take for society to adapt to and adopt IM technology. Furthermore, prediction becomes increasingly difficult as one looks further into the future, and so I feel this date represents a good balance between technological advancement and predictability. In the year following my 'plucking' the subject year 2030 and after subsequent research however, several sources have validated my choice of year as being a probable turning point in IM technology[1,2,3,4].

Within the bounds of time between the year of beginning this thesis in 2007 and the year 2030, it is a reasonable assumption to make that the West, and the United States in particular, will maintain their position at the head of the world in terms of military spending, research and development, and

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[1] Office of the Secretary of Defence, *Unmanned Systems Roadmap (2007-2032),* United States Department of Defence, 2007

[2] *Strategic Trends: Methodology, Key Findings and Shocks,* Joint Doctrine and Concepts Centre, UK MOD, 2003.

[3] A.V. Balmaks, *Future Land Warfare 2030, Land Warfare Concepts,* Australian Department of Defence, 2000.

[4] NISTEP Report No. 71, *The Seventh Technology Foresight – Future Technology in Japan toward the Year 2030,* Science and Technology Foresight Centre, National Institute of Science and Technology Policy; Ministry of Education, Culture, Sports, Science and Technology; Japan, July 2001.

consequently, military technological advancement. As a result, the thesis will primarily focus on the militaries of the West, while not discounting developments regarding states such as China, Japan, South Korea, Singapore, Russia, and even non-state actors such as irregular (terrorist, guerrilla, insurgent etc) belligerents, multinational corporations, and private military contractors (PMCs). Unique characteristics belonging to each of these groups may shed further light on the shape of things to come regarding IMs.

For the purpose of this thesis, I will define 'Intelligent Machines', as semi-autonomous or autonomous mobile unmanned machines that are capable of making decisions and determining and executing their own courses of action. I have focussed specifically on the land operating environment[5] and ground based IMs. This is because the land operating environment really represents the 'final frontier' for IM development. Complex geography and the interaction of humans create challenges for IMs far above and beyond those encountered in the maritime, air, or space environments. The land operating environment is also the decisive environment, where conflicts are overwhelmingly won or lost.

I have not considered the use of consumer IM technology in military roles by irregular combatants (for example, IM borne Improvised Explosive Devices, or IMBIEDs), nor have I considered the use of non-physical IMs (i.e. software only, for example in Computer Network Defence roles), or non-mobile

[5] The land operating environment is the geographical, political, social and military arena in which military ground operations take place, as distinct from air, sea, or space.

applications, for the sake of brevity. Likewise, I have not dealt with the possibility of IM vs. IM warfare though this may well occur by or before 2030.

I have structured my thesis around four research questions:

- What proportion of a modern military's force will likely be made up of intelligent machines by the year 2030?
- What roles will such machines likely be utilised in?
- What level of autonomy will be afforded to these machines?
- Under what organisational architecture will these machines likely be employed?

As such, the thesis will be broken into four chapters answering each of these questions, with the first two chapters broken down into smaller sections discussing discrete elements of these questions.

Literature Review

The majority of information sources utilised in researching this thesis were gained by way of the internet, for the simple reason that the present rate of IM and related technology development is so great that books published on the subject are virtually outdated by the time they reach the shelf. Web sources have included news websites, technology forums and blogs, and academic reports and literature available online.

Additionally, I have made broad use of published material including defence and technology journals and magazines, and some dated books on the topic including those that have stood the test of time (Manuel De Landa's *War in the Age of Intelligent Machines* stands out) and also those whose predictions have failed, for the purpose of tempering my forecasts. Science fiction on the topic, particularly the work of Isaac Asimov, has helped me frame the concept of IMs amongst humans as preparation for research.

By way of my employment with the New Zealand Army, I have also had excellent access to a variety of different military sources. These have included military doctrine publications and literature, as well as presentations by, discussions with, and promotional materials from representatives various arms manufacturers, such as Boeing and Rafael, that have engaged with the NZ Army to promote sales.

I have attended presentations by technology experts and futurists such as Dr Jack Bacon, and also interviewed defence technology, robotics, and image processing experts, including Massey University Professors Gurvinder Virk and Donald Bailey, and Defence Technology Agency sensor systems expert Philip Strong. Additionally, I have discussed various aspects off my thesis with Army personnel with relevant expertise in those areas, and observed various different demonstrations of unmanned military systems in action including both ground and air vehicles.

Thus I have utilised a diverse range of sources, and these have shed light on the subject of my thesis from numerous angles, giving me excellent visibility of all aspects of the subject. Access to defence related sources has been especially useful, and given me a somewhat privileged vantage point from which to make informed projections on the future of IM technology.

Chapter One: What Proportion – What part of a modern Military's force will likely be made up of Intelligent Machines by the year 2030?

This first chapter will investigate the likely proportion of a modern military's ground forces consisting of IMs by the year 2030. It will consider factors driving the military employment of IMs and obstacles standing in the way of IM employment in turn. The chapter will then consider these factors with respect to time, along with the development of related environmental factors.

Drivers: Why Intelligent Machines?

In order for modern militaries to employ IMs on the battlefield on a significant scale, there need to be major incentives. Success or failure in battle has inherently severe consequences for states and their armed forces, and so any self-imposed radical change, or 'transformation' in military organisation, methods and equipment will in general be relatively conservative by nature. Furthermore, military high technology is extremely expensive. Acquiring IMs in a substantial quantity and integrating them into a state's armed forces, especially in the near term, will only be achieved at considerable financial cost. IMs must therefore offer a significant leap in capability and performance before any military will adopt them in such a way. This section of the thesis will then examine how IMs may be attractive to states and armed forces, and identify potential benefits and capability gains presented by IMs.

Perhaps the most significant potential benefit of employing IMs on the battlefield is the reduction of friendly force human casualties. There are several ways that IMs may reduce friendly force human casualties. Logically, if a soldier is replaced by an IM, then one human has been removed from danger. Taking the example to extremis, a force consisting completely of IMs, with no human soldiers in harm's way, simply can not possibly suffer Killed in Action (KIA) or Wounded in Action (WIA) casualties. While the development of an entirely unmanned ground combat force may (or may not – addressed later in the thesis) be unlikely by the year 2030, the number of human soldiers replaced with IMs in a force will share a relationship at least inversely proportional to the number of human casualties suffered by that force: Less humans exposed to danger equals less casualties.

There will be significant resistance from certain quarters to the development of combat forces consisting predominantly or totally of IMs. The unshakeable (and at present, entirely true) military perception that the human is the prime actor on the battlefield is reflected in the US Chief of Army's comment in 2003 that "humans are far more important than hardware"[6]. The idea that human soldiers can be assisted but not replaced by technology, true as it is now, will likely be a considerable hindrance to the large-scale employment of IMs in future. Bearing this in mind, it is more likely that at least in the early stages of IM adoption and possibly out to this thesis' time scale of 2030, IMs will share the battlefield, working alongside human soldiers as a team, and so augmenting human soldier units rather than replacing them. Augmenting human combat units with IMs will reduce human casualties in two ways: firstly, by removing humans from dangerous roles, and secondly, by enhancing the capabilities of the human soldier. In this configuration, humans and IMs will be able to shield each others' weaknesses while combining their capabilities (identified later in the thesis) in a synergistic manner.[7]

As a continuation of an already existing trend, IMs will be first used to perform the most dangerous but simple tasks presently performed by humans. As early as World War II, teleoperated vehicles were used to perform hazardous

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[6] Gen. Kevin P. Brynes' remarks (transcript) at Institute of Land Warfare's Forum *"The Army Future Force"* during AUSA annual meeting, Washington, D.C, 2003, p. 4.
[7] Terrence Fong, Charles Thorpe, Charles Baur, *Robot as Partner: Vehicle Teleoperation with collaborative control,* The Robotics Institute, Carnegie Mellon University, Pittsburgh, Pennsylvania, 2003, p. 1.

tasks in place of humans. The *Goliath* tracked mine, teleoperated by cable or radio and carrying 75-100Kg of explosives, enabled German soldiers to demolish buildings and destroy tanks at distance.[8] Other important risk reducing roles teleoperated machines have been used in since include Explosive Ordinance Disposal (EOD) and nuclear plant inspection. The first teleoperated EOD machine, the *Wheelbarrow,* was developed in 1972 by the British Army to remove EOD personnel from danger when countering Irish Republican Army (IRA) explosive devices in Northern Ireland.[9] Teleoperated machines have been utilised in hazardous tasks in the nuclear industry since its inception,[10] for handling radioactive materiel, and inspecting and cleaning nuclear reactors. It is envisioned that semi-autonomous machines will be employed to dismantle the Chernobyl reactor and US nuclear weapons facilities.[11] As this trend continues, logic dictates that many of the plethora of dangerous tasks required on the modern

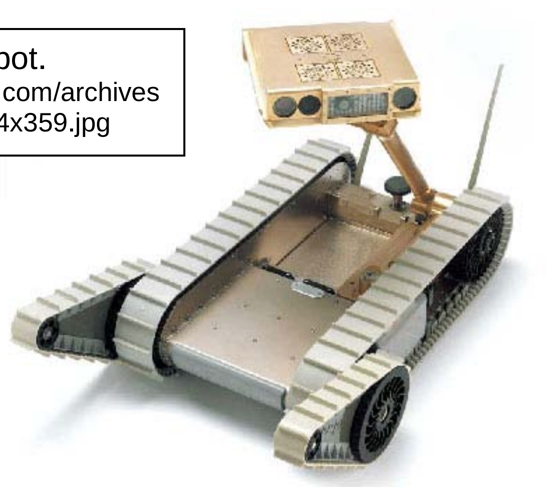
The Goliath tracked mine
http://en.wikipedia.org/wiki/File:Mini-tanks-p012953.jpg

[8] Markus Jaugitz, *Funklenpanzer: A History of German Army Remote-and Radio-Controlled Armour Units,* trans. David Johnston,
[9] *Obituary – Lieutenant-Colonel 'Peter' Miller: Inventor of the Wheelbarrow remote control bomb disposal device that saved countless lives,* The Times, 06.09.06, http://www.timesonline.co.uk/tol/comment/obituaries/article629051.ece, accessed 11.05.07.
[10] *Robots in Radioactive Environments,* Learn About Robots, http://www.learnaboutrobots.com/nuclear.htm, accessed 21.08.07.
[11] Ibid.

battlefield will be passed on to teleoperated and autonomous machines. Thus Information Age militaries will continue to employ IMs to replace humans in dangerous roles in order to reduce friendly casualties.

IMs will also offer Information Age militaries casualty reduction by providing better situational awareness. Teleoperated machines are already being employed by US forces in Afghanistan[12] and Iraq as a kind of 'robotic point-man'. iRobot's Packbot, presently in use in both of these theatres, is available in variants including advanced reconnaissance[13] and sniper detection[14]. The US Army intends to develop a semi-autonomous Armed Robotic Vehicle (ARV) as part of its Future Combat Systems (FCS) program[15], which will be roughly equivalent to today's manned armed reconnaissance platforms such as the Canadian Army's Coyote[16]. Thus as well as removing humans from harm, IMs have the potential to enhance a force's effectiveness and reduce friendly and civilian casualties by providing better situational awareness.

iRobot Packbot.
http://igargoyle.com/archives/103packbot434x359.jpg



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[12] *Robot Tunnel Rats in Afghanistan,* Popular Mechanics, December 2002, http://www.popularmechanics.com/technology/industry/1285321.htm, accessed 23.08.07

[13] *iRobot Packbot Explorer,* iRobot Corporation, http://www.irobot.com/sp.cfm?pageid=139, accessed 23.08.07.

[14] *iRobot Packbot with RedOwl,* iRobot Corporation, http://www.irobot.com/sp.cfm?pageid=314, accessed 23.08.07.

[15] *Armed Robotic Vehicle (ARV),* Future Combat Systems, http://www.army.mil/fcs/factfiles/arv.html, accessed 02.26.2007.

[16] D-Net: *The Coyote in Action,* http://www.dnd.ca/menu/coyote/lo/10.htm, accessed 28.07.2008.

Whether through total replacement of humans, replacement of humans in the most hazardous roles, or through augmentation of human units; the reduction of both friendly and civilian casualties offers great incentive for particularly Western Information Age militaries to adopt IMs. Casualty aversion has increasingly become the Achilles' heel of Western militaries since the second half of the 20th century, exacerbating strategic defeat thresholds and limiting strategic and tactical options.[17] The withdrawal of US forces from Somalia in 1993, resulting from a collapse in popular will after the deaths of a mere 18 US soldiers in the 'Blackhawk Down' incident, is a case in point.[18] The social stigma of a nation's citizen soldiers returning either in body bags or severely maimed and disabled aside, there are also staggering economic costs associated with the replacement, rehabilitation or ongoing care of human soldier casualties. In states with tight labour markets, such as New Zealand [19], or where troop numbers are stretched due to extensive commitments, as is the case with the United States due to Iraq and Afghanistan, the value of this human capital is particularly significant.

Massive resources are presently being poured into force protection technologies such as Mine Resistant Ambush Protected (MRAP)[20] vehicles by the West, in order to protect this human capital and reduce casualties. By

[17] *New Zealand Army Future Land Operating Concept: Precision Manoeuvre 2020,* New Zealand Army, 2007, p. 1-8.
[18] Roger Sangvic, *Battle of Mogadishu: Anatomy of a Failure*, School of Advanced Military Studies, U.S. Army Command and General Staff College, 1998, p.1.
[19] Statistics New Zealand, Labour Market Statistics, http://www.stats.govt.nz/NR/rdonlyres/A152478B-1AE1-437D-BF5A-7EB941A0AC7D/0/58522SNZlayoutffWEB.pdf, accessed 06.05.08.
[20] Nathan Hodge, *Pentagon requests funding for MRAP transportation to Iraq*, Janes Defence Weekly, Vol. 44, Issue 34, 22 August 2007, p.7.

committing similar resources for the adoption of IMs, Western militaries will potentially benefit by saving lives, by maintaining popular support for operations, and by opening new tactical options. New strategic possibilities will become available where deployments previously deemed ‘optional’, or too dangerous for personnel, such as the Rwanda genocide, will be made viable. Reducing human casualties, with all of the other benefits associated with this outcome, is clearly a powerful driver for the employment of IMs.

As relevant technologies and operational experience progress, another driver for the adoption of IMs is an enhanced level of capability. Many characteristics of IMs have the potential to endow them with advantages over human soldiers in niche areas of capability, and these will expand in breadth and depth over time. Examples discussed here include detection threshold, situational awareness, survivability and expendability, firepower and lethality, speed and mobility, endurance, and ‘cold bloodedness’.

Stealthiness may be achieved through a number of IM-specific characteristics. Without the need for protected crew compartment, life support systems or physical control interfaces, an IM will gain significant relative reductions in size, and likely achieve a lower silhouette profile as well. This has long been a key aspiration for armoured fighting vehicles and has driven innovations such as the turretless

The S-Tank
http://en.wikipedia.org/wiki/File:Strv_103c_a.jpg

Swedish S-Tank.[21] Relative size reduction is a simple and effective means of minimizing detection threshold.

If electrically powered, an IM system equivalent to a soldier may gain an advantage in stealthiness through a reduction in heat signature as well, particularly when static. With room-temperature superconductivity on the horizon circa-2030, electric motors and servos will not generate heat through electrical resistance[22], further reducing heat signatures while in motion.

While soldiers are capable of silence simply by sitting still and not talking, communication will invariably involve some form of audible signature, especially where personal role radios are not available and shouting is the only alternative. Staying still for long periods of time is also difficult. While remaining silent for periods of 24 hours or longer is commonplace for the Special Forces soldier, standard line infantry will require uncommon discipline to achieve this, and are unlikely to remain completely silent for more than a few hours, before whispering to each other[23]. Added to this are the needs for ablutions and feeding. An IM will most definitely communicate without any audible signature, will not "go to the bathroom" or need to eat or drink, and could potentially lie totally silent in ambush for days, weeks, or even months.

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[21] PanzerMuseum.com: *Stridsvagn 103 ("S-Tank"),* http://www.panzermuseum.com/battle-tank-s-tank.html, accessed 11.07.2008.
[22] EETimes.com: *EE Times corrects story on silane as a potential superconductor,* www.eetimes.com, accessed 11.07.2008.
[23] Discussion with Major Stuart Davies, Australian SASR, S02 Concepts, Force Development, Army General Staff, 16.11.2007.

The environments an IM will be able to survive in will potentially also give it stealthy capabilities. The US Talon and Special Weapons Observation Reconnaissance Detection System (SWORDS) robots currently serving in Iraq are able to operate under a significant depth of water, with one recently recovering itself from a considerable depth of water after falling off a bridge into a river, simply by driving along the bottom to the shore.[24] If oxygen is not a requirement, IMs could potentially penetrate a defensive position or travel undetected by moving submerged beneath the surface of rivers, inlets, canals, sewers etc. Similarly, IMs could potentially bury themselves beneath the ground, lying dormant and undetected until required to act, or passively sensing in ambush.[25]

Thus, whether equivalent to individual soldiers or Armoured Fighting Vehicles, IMs potentially possess a wide range of stealthy capability advantages over humans and manned systems. As sensor technologies advance and continue to strip away the fog of war, stealthiness will become increasingly necessary to survive in the modern missionspace.

Situational Awareness (SA), both in possession and provision, is increasingly identified as a force multiplier in modern warfare. IMs will potentially supersede humans or manned systems in this capability in a number of ways. A human possesses only five senses, with sight, hearing and smell being those primarily useful for combat. These senses may be augmented, both in

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[24] Foster-Miller QinetiQ North America: *TALON Family of Military, EOD, MAARS, Hazmat, SWAT and Dragon Runner Robots* http://www.foster-miller.com/lemming.htm, accessed 28.07.2008

[25] NASA Tech Briefs, Oct 2001: *Subsurface-explorer robot with spinning-hammer drive* http://findarticles.com/p/articles/mi_qa3957/is_200110/ai_n8955768, accessed 28.07.2008.

spectrum and sensitivity, through technical means. Magnified optics will allow a human to see much further than the naked eye, but at the expense of a narrowing of field of vision, or “tunnel vision.” The human eye can by definition only detect the visible spectrum of electromagnetic (EM) radiation, and is impaired significantly during the hours of darkness; a considerable portion of time in a 24 hour period. Sensor systems including radar, infra-red (IR), image intensification, thermal imaging (TI) etc. can enable the human eye to ‘see’ much more of the EM spectrum, while seismic sensors can display, in visual or audible medium, vibrations through the ground. Sensor systems can also provide humans with a limited amount of information by sound. The fusion of various layered sensor feeds can create an aggregated picture that will reveal more than the sum of its component parts, with systems complementing each other and compensating their respective weaknesses.

The human user limits the application of these sensor systems however, both through the limited acuity (resolution and accuracy in interpretation and focus) of the human senses and the cognitive threshold of the human brain. Humans possess only two eyes (slaved in the same direction) and two ears, meaning they can realistically only utilise one of these sensor systems at a time. While the human is fundamentally limited by biology, an IM has no such boundary, and is limited only by the state of the art and the level of capability bestowed upon it. An IM will potentially utilize any number of sensor systems concurrently across the EM, acoustic, and seismic spectrums, in three dimensions, across 360º, to whatever resolution and range the power and sensitivity of the sensor system and the cognitive processing power of its artificial brain will allow. Thus by superseding the sensory biological ceiling of the human, IMs can gain a potentially unlimited capability advantage in SA over humans and manned systems.

Humans may overcome their biological sensory limitations by operating in teams, with various humans covering different areas or arcs of vision and portions of the EM and acoustic/seismic frequencies. However, detections must be communicated, either between team members or to commanders. Human communications are limited to the speed of speech, typing, or through the use of some other manual interface.

Sharing, deconfliction and fusion of various streams of SA information into a Common Operating Picture (COP) can now be achieved faster and further through the use of network-centric information technology systems, but humans similarly limit this technology through their communication speed. This information needs to be simplified and strictly managed when commonly displayed in order to avoid 'information overload' (exceeding human cognitive limitations). The application of network-centric technology to IMs on the other hand has no biological limitation. IMs will potentially leverage network-centric technology to an incredibly higher degree, as they have no fundamental limit on the speed at which they can communicate with one another. Work is ongoing to integrate networks of sensors with AI. The US Defence Advanced Research Programs Agency's (DARPA) 'Combat Zones that see' project[26] aims to saturate an operating environment with a wide array of sensors,

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[26] Defensetech.org: *DARPA'S Simple Plan to Track Your Every Move*, http://www.defensetech.org/archives/000489.html, accessed 28.07.2008.

including tiny 'smart dust'[27], which will give a virtually omniscient awareness of that environment. Such awareness will represent a digitised synthetic model of the real world[28], which will be much more conducive to coordinated action by IMs. In future, a swarm of networked IMs may possess a totally shared awareness, with each 'seeing' all that the others 'see', in real time. In effect, an integrated force of IMs with a shared awareness, coupled with a sensor-saturation enabled digital world model, will locate and if necessary engage detected adversary elements with the ease, speed and accuracy that a human scratches an itch.

IMs will potentially possess a high degree of survivability when compared to human soldiers. Environmental hazards will pose a much smaller threat to IMs than they do to humans. Extreme cold and extreme heat will significantly impede the effectiveness of a human soldier, but are simply problems of engineering for a machine. Nuclear, Biological and Chemical (NBC) hazards are also more simply overcome for machines than for humans (in fact, by definition a biological threat poses no danger to a machine).[29] The effects of the land operating environment are also potentially less threatening to IMs. These include kinetic projectiles in the form of small arms fire and shell fragments, as well as blast and flash heat, which are all chosen for their devastating effect on the frail human body. While body armour and helmets can mitigate some of these effects to a small extent, soldiers of Western

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[27] *SMART DUST Autonomous sensing and communication in a cubic millimetre,* http://robotics.eecs.berkeley.edu/~pister/SmartDust/, accessed 28.07.2008.
[28] Regan Reshke, *JADEX Papers 1 – Brave New Conflicts: Emerging Global Technologies and Trends*, Canadian Army Directorate of Land Concepts and Designs, 2007, p.29.
[29] Interview with Professor Gurvinder S Virk, Professor of Robotics and Associate Head Institute of Technology and Engineering, Massey University – Wellington, 06.07.07.

militaries have increasingly been seeking shelter in fortified buildings, bunkers or hardened vehicles to survive battlefield effects at the expense of mission effectiveness.[30] If sufficiently hardened, IMs will be much more resilient to battlefield effects. As the land operating environment becomes increasingly hazardous, the superior survivability of IMs will likely see them utilised more and more.

In future, and particularly at the extent of this thesis's scope, IMs will be more expendable than human soldiers for Western militaries. A machine "killed in action" will not arrive home in a body bag, draped in a national flag. It will not leave behind a grieving family. It will not be mourned, except maybe by those soldiers who have worked along side it.[31] Rehabilitation of an IM will be assessed based on a cost-benefit calculation, with the simple replacement of modular components, as opposed to the lengthy, expensive and unavoidable process of rehabilitating a wounded human soldier. Socially and politically then, the relative expendability of IMs makes them attractive.

This expendability presents operational benefits for commanders as well. In the US military as within others, the mantra of "leave no man behind" need not apply to IMs. Major incidents resulting from this ethos include the 'Blackhawk Down' incident, and to a degree the 2006 Lebanon War (it is hard to imagine such a ferocious response by the Israeli Defence Force had Hezbollah kidnapped two unmanned systems). The dangerous task of Combat Search

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[30] Nathan Hodge, *Narrowing the divide: US Force Protection*, Janes Defence Weekly, Vol. 45, Issue 2, 9 January 2008, p.7.
[31] Washington Post: *Bots on The Ground,* http://www.washingtonpost.com/wp-dyn/content/article/2007/05/05/AR2007050501009_pf.html, accessed 28.07.2008.

and Rescue (CSAR) need not be undertaken in the case of wounded or isolated machines, unless it is economically expedient to do so. A formation of IMs need not be impeded by the need to care for a casualty amongst their number. In a formation where there are no human lives to be lost, this expendability may revolutionise Western military art, opening up ‘Kamikaze’ options. Risk will no longer be measured against lives, and so significant ‘casualties’ may be suffered for the purpose of deception, or in pursuing fleeting or uncertain opportunities. As the Imperial Japanese Army demonstrated in WWII, the aggressive tactics enabled by a willingness to expend the lives of soldiers can serve as a significant force multiplier. By creating and exploiting opportunities, and through sheer psychological shock, the Japanese Kamikaze tactics mitigated against their materiel inferiority.[32] More recently, Al Qaeda has demonstrated the difficulties of defending against a determined attacker who has no plans for a return journey. Once the last resort of the desperate and fanatical, these tactics of sacrifice may now be employed to great effect by militaries of the West.

Enhancements in firepower and lethality at the individual platform level are also potential benefits presented by IMs. Any increase in firepower, whether with respect to a soldier or a platform, will generally correspond to an increase in weight. In both cases this will have a negative impact on mobility, presenting a necessary trade-off. Physiological limits restrict the load in terms

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[32] John A. Forquer, *The Kamikaze: Samurai Warrior – A new appraisal,* Military Issues Paper submitted to the Faculty of the Marine Corps Command and Staff College in partial fulfillment of the requirements for AY 1994-95, March 1995, p 10.

of both weight and bulk that a human soldier can carry, thus restricting potential firepower per soldier. As the range of equipment required to be carried by modern combat soldiers continues to increase, with the addition of such items as body armour, night vision equipment, digital Command and Control (C2) systems and personal role radios, the proportion of this load that may be dedicated to firepower in weight terms is decreasing[33]. The move from the 7.62mm M14 rifle to the lighter (both in terms of weapon and ammunition) 5.56mm M16 family of rifles by US forces during the Vietnam war, as well as recent moves to replace the M16A4 with the shorter, lighter M4 carbine, illustrates the consequences of this load/firepower trade-off. In platform terms, the New Zealand Army's LAV III Infantry Fighting Vehicle demonstrates the weight/firepower trade-off where the 25mm cannon and turret bring the weight of the vehicle close to its maximum potential. This limits the possibility for addition of extra armour, an important force protection measure in some contemporary warfighting environments.

A potentially greater proportion of load may be dedicated to firepower for IMs. They will require less weight dedicated to self protection (such as body armour and gas masks or protective suits) due to their relatively expendable nature, or sustenance (while they will require a power source, it will likely be more efficient in terms of weight than food and water)[34]. The lack of a physiological limit for IMs largely mitigates the load/mobility trade-off for soldier systems, and so load will rather be restricted by specified

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[33] William L. Ezell, *Battlefield Mobility and the Soldier's Load,* Global Security, http://www.globalsecurity.org/military/library/report/1992/EWL.htm, accessed 30.01.08.

[34] Office of the Secretary of Defence, *Unmanned Systems Roadmap (2007-2032),* United States Department of Defence, 2007, p. 44.

requirements for size, endurance etc. Contrasted against manned platforms, IMs will require no life support systems, force protection measures, control interfaces or cabin space for crew, freeing up weight and space for the addition of weapon systems[35]. With load capacity increased, firepower may also increase, through the carrying of larger, more numerous munitions and heavier weapon systems.

The potential lethality advantages of IMs also stem from the physiological limitations of the human soldier. Speed of reaction and accuracy of delivery are critical factors in determining whether any target will be hit or not. If considered using John Boyd's OODA loop (observe, orientate, decide, act) theory, the speed at which each step in this decision cycle occur is dependent on either physical or mental agility of the actor. Regarding a soldier, agility is governed by the limits of the human brain and body.

An IM however, as previously mentioned, is only limited by the state of the art in servo-mechanical and digital processing technology, which already outstrips human performance in many roles. The largely autonomous Phalanx Close-In Weapon System, for example, is designed to acquire, track and shoot down extremely fast moving anti-ship missiles, and so a high degree of autonomy is the only means of achieving the necessary engagement speed.

Accuracy of delivery, particularly regarding ballistic kinetic projectile weapons, requires both a stable platform, and precise orientation. Machine has an

[35] Hyder Gulam and Simon W. Lee, *Uninhabited Combat Aerial Vehicles and the Law of Armed Conflict*, in *Australian Army Journal,* vol. III, no. 2, Winter 2006, p. 126.

obvious advantage over man in both stability and precision, for reasons such as lack of breathing, rigidity, strength and positional acuity, as well as ballistic computing and stabilisation technology. These advantages (as well as force protection benefits) have seen platform-mounted crew served weapons be steadily replaced with stabilised remote weapon stations, such as on the US Stryker. These technologies have also been employed to augment the limited abilities of the human operator. For example, servo-mechanical manipulation, mechanical and image stabilisation, laser range finding and ballistic computing have gradually taken various tasks away from the gunner in a modern main battle tank such as the M1A2, minimizing their role to the point where virtually all that is required of them is to place a set of cross hairs on the target and push a button. Even in this minor role, human physiology limits the weapon system, as the speed and accuracy of the human hand and mind in reacting to a target and manipulating the controls restrict the swiftness with which the weapon system may orient and fire. An IM requires no such interface, and its reaction speed is limited only by the state of the art.

Precision effects presently achieved by carefully selecting and strenuously training soldiers to be snipers, may also be accomplished by mass-producing IMs in the soldier role, greatly increasing a commander’s access to this presently scarce resource. ‘Fire and forget’ guided projectile weapons such as the Javelin Medium Range Anti Armour Weapon, are simply a form of IM used as a projectile, demonstrating another way in which IMs may enhance accuracy with resulting improved lethality. Thus in terms of firepower and lethality, IMs offer numerous advantages over human soldiers and manned systems. IMs may be able to deliver a higher number of heavier munitions more responsively on to fleeting targets with much greater precision.

Speed and mobility are other potential areas where IMs may gain an advantage over their human or manned equivalents, in physical terms as well as mentally and organisationally. In the physical dimension, the lack of physiological limits previously mentioned mean that an IM may be faster than a human, particularly while burdened with a heavy load. While humans possess considerable physical flexibility with which to negotiate complex terrain, applying the 'Two Legs' principle[36] there is little reason why an IM may not have similar physical flexibility. Furthermore, advanced servo-mechanical technology may offer greater strength for similar weight of 'muscles'[37], allowing IMs to outperform humans in physical tasks such as climbing and jumping. Thus an IM will potentially move with greater agility than its human equivalent, allowing it to go more places (such us up cliffs and buildings or over obstacles), to get there faster, and to move with greater agility so as to present a more difficult target.

Contrasted with manned platforms, IMs may gain improved physical speed and mobility for several reasons. The first is that the above mentioned elimination of crew compartments, life support systems, and possibly armour, will allow a reduction of weight as well as a lower centre of gravity. This would

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[36]Essentially, if humans can do it, it is proven possible, and only requires the necessary engineering - Interview with Associate Professor Donald Bailey, senior lecturer in Institute of Information Science and Technology and image processing specialist at Massey university, (interview, conducted 13.07.07.)

[37] BBC News: *Scientists make 'bionic' muscles,* http://news.bbc.co.uk/2/hi/health/4817848.stm, accessed 28.07.2008.

reduce the risk of the IM becoming bogged down in mud or rolling over on uneven terrain. Another source of enhanced speed and mobility may stem from an IM's potential to gain a greater awareness of the terrain that it is negotiating. Previously mentioned human limitations and IM advantages on the establishment of situational awareness are also applicable in this context, where an IM may bring to bear a wide and complimentary range of different sensors to gauge a wider portion of terrain in greater detail at a faster rate. This will allow it to more accurately predict the trafficability and optimum path over terrain, enabling greater speed and mobility. Furthermore, awareness of the terrain collected by an IM may then be shared with other networked IMs. This will allow better route planning, so that IMs may choose the fastest or most trafficable route over long distances.

Mentally, an IM will potentially think at much greater speed than a human. This will allow for a much faster assessment of the operating environment and tactical situation in order to formulate plans. It will also enable much faster transition from one type of operation to another. The complexities identified in the contemporary land operating environment by Charles Krulak with his 'Three Block War' paradigm[38] challenge soldiers to undertake humanitarian support, peace keeping and combat within the same geographic area, requiring three very different states of mind for each. While a human soldier will likely have great trouble interacting in a useful way with civilians, or with the diplomacy necessary in peace keeping style operations immediately after being engaged in highly stressful life or death combat, an IM will have no

[38] Charles C. Krulak, *The Strategic Corporal: Leadership in the Three Block War,* Marines Magazine, January 1999.

problem with swift transition between such tasks. Together, these mental speed advantages may allow IMs to achieve missions faster, and to generate greater operational tempo.

Organisationally, the likely ability of networked IMs to instantaneously collaborate on a wide scale, or to instantly respond to complex orders, will result in a very agile organisation. For example, a formation of IMs would be able to react very rapidly in a coordinated fashion to enemy action, minimizing any advantage of surprise. Transition from defensive to offensive operations, and the conduct of other traditionally difficult operations such as a passage of lines, will further enhance operational tempo and significantly reduce friction. Extrapolated to an extreme, a networked 'swarm' of IMs may be able to act in concert over a large area, almost as if a single organism. Centralised control is a much too cumbersome command methodology for large forces of human soldiers, with associated issues of friction and degraded decision and reaction speeds, and so a decentralised 'mission command'[39] style is commonly adopted among western militaries. With a shared awareness and virtually instant communication and decision processes, a networked body of IMs may tap the benefits of centralised control, where all efforts are harmoniously coordinated and synchronised in pursuit of a main effort.

Endurance provides another potential advantage to IMs over their human counterparts. While any machine requires some sort of fuel and regular

[39] Foundations of New Zealand Military Doctrine (NZDDP–D) (First Edition), Part 2, Chapter 6, p.6-19.

maintenance, the same is true for a human. This includes regular intake of food and water, regular sleep, medical support, not to mention various welfare considerations. The exclusion of any of these will see human efficiency degrade rapidly, and during combat operations, the effective endurance of a human is fundamentally limited. If deprived of sleep for 72 hours for example, hallucinations are likely, and simple tasks become very difficult. Combined with the physical fatigue, harsh environmental conditions and intense mental stress associated with combat, the effectiveness of a human operating continuously will rapidly degrade after several days.[40] Even with sufficient sleep, soldiers will likely reach their limit of endurance after 30 days of continuous combat operations.[41]

An IM does not have such fundamental restrictions on endurance. Limitations in its case will be determined by power consumption versus power supply, and by maintenance intervals, therefore being determined by intensity of operation, by design, and by the state of technology. With no need to sleep, no fear of death or failure, no requirement for food, welfare support etc, an IM's logistic requirements may be greatly simplified, to include a power source, disposable stores such as ammunition, and regular maintenance. Utilised in roles that are largely passive and static, such as surveillance or point defence, the endurance of an IM could potentially increase greatly as it will only be required to operate sensory and communications functions for much of the task's duration. The addition of a sustainable power source such

[40] Tri-Service Fatigue and Sleep Reference, http://www.millergonomics.com.nps/intro.html, accessed 01.05.08
[41] S. L. A. Marshall, *Men Against Fire: The Problem of Battle Command in Future War*, Gloucester, Mass., Peter Smith, 1978.

as solar cells may enable an IM to perform such tasks for even longer. Thus, long after a human soldier has become sleep deprived, physically exhausted, and emotionally fatigued, an IM will likely be able to ‘soldier on’.

A highly significant potential advantage for IMs will be their ‘cold bloodedness’, or lack of emotion. Unlike a human, an IM will not experience fear, panic, hatred, impatience, depression, sympathy or anger. It will not use lethal force inappropriately out of rage and frustration at the loss of comrades, as seen with My Lai or Haditha. Conversely, it will not hesitate to kill when required, where as many as eighty percent of WWII Allied soldiers were unable to fire on their fellow man.[42] Faced with effective fire from an enemy shielded by a civilian population, and with the dilemma of choosing between death or self defence and collateral damage, an IM will neutrally submit to its fate. It will not stop to comfort mortally wounded mechanical comrade during an attack, or cower in fear in the face of enemy fires. When subjected to continuous combat operations, a vociferously hostile domestic population, mounting failures or harsh environmental conditions, an IM will not turn to drugs or alcohol, become depressed or insubordinate. Thus the all-important psychological state of the soldier; fighting spirit or morale, which is a key determinant of combat power and must be carefully monitored and nurtured, will not be a necessary consideration when employing IMs. IMs, by deign of their lack of emotion, will potentially be perfect killing machines from day they roll off the assembly line, negating the need for the intensive conditioning and desensitisation necessary to enable a human soldier to kill his fellow man.

[42] Marshall.

This 'cold-bloodedness' therefore presents a significant advantage over emotionally susceptible human soldiers.

A range of potential capability advantages possessed by IMs when compared to human soldiers can thus be identified, and these will very likely influence their future development, procurement and employment. Advantages in stealth, situational awareness, survivability, firepower and lethality, speed, mobility, endurance and 'cold bloodedness' may drive an increasing replacement of human soldiers on the battlefield.

In addition to potential capability advantages over humans, a variety of other benefits stem from the unique characteristics of IMs. One of these is the undermining of adversary motivations for violent armed competition, for example, the absurdity of undertaking Jihad against machines. The propaganda of extremist Islamic organisations such as Al Qaeda frequently implores extremist Muslims to kill occupying 'infidel' forces, such as American soldiers in Iraq, utilising such language as 'spilling blood', or 'slaughter'. Suicide bombers who are successful in this task are expected to reap their rewards in the afterlife.[43] If human soldiers are replaced with IMs in vulnerable roles, denying the resistance human targets, formulators of such propaganda will struggle to encourage similar levels of sacrifice from their audience to destroy machines. Though adept at distorting Islamic ideology to support their cause, the exchange of mortal enemy flesh for an assembly of electronic and

[43] Elaine Landau, *Suicide Bombers: Foot Soldiers of the Terrorist Movement,* Twenty-First Century Books, 2007, p.107.

mechanical components will undoubtedly reduce the supply of willing Jihadi or other fanatical extremist recruits to some extent.

Other motivations for resistance fighters in Iraq include vengeance, glory, expulsion of foreign occupying forces, or in some cases, a financial reward for their family.[44] In the case of vengeance, it is doubtful that much satisfaction could be gained by an aggrieved resistance fighter in destroying an IM, compared to a living, breathing soldier. Where financial incentives are concerned, sponsors of resistance fighters will find themselves in a war of attrition with their enemy's military industrial complex. Presently, inflicting casualties on human soldiers has a considerable impact on the popular will of Western states, and so attacks on those soldiers more often have political/strategic goals than simply tactical. With the substitution of IMs for human soldiers however, the violent actions of resistance fighter will lose their strategic significance and revert to a tactical effect. In this situation, a state's financial reserves and capacity for mass production will quickly outmatch the supply of fighters able to be hired by the sponsors of resistance.

The presence of foreign soldiers, particularly non-Muslim 'infidels' is another frequently aggravating factor that motivates radical Islamist resistance fighters to take up arms. The replacement of these personnel with IMs may reduce this motivation as machines are by nature religiously and ethnically neutral, possibly invoking reactions of confusion or curiosity rather than revulsion or offence amongst devout populations. An example of this distinction can be

[44] Zaki Chehab, *Inside the Resistance: The Iraqi Insurgency and the Future of the Middle East,* Nation Books, New York, 2005, p. 17.

seen with the paradox concerning US forces operating in the border regions of Pakistan: while the presence of American combat troops on the ground would almost certainly inflame ideological and nationalist outrage amongst the Pakistani population, the employment of armed Unmanned Aerial Vehicles in targeting Taliban and Al Qaeda militants from inside sovereign Pakistani airspace is apparently more acceptable. Romantic or ideological motivations such as glory and vengeance that are common to many armed groups confronting the West[45] can therefore be expected to wither with a dearth of human opponents. Risking one's life in order to destroy the equivalent of a 'walking toaster oven' may well simply not be worth the sacrifice.

Further benefits driving the adoption of IMs in place of humans stem from issues of raising and maintaining an army in the modern age. The previously mentioned tight labour market and shortage of recruits, for example, could be ameliorated with the adoption of IMs, if able to be cheaply mass produced at a lower cost than human soldiers as predicted by some[46]. Where IMs are teleoperated or semi-autonomous, roles for operators would attract and harness the 'Playstation generation' of today. Substitution with IMs would also reduce the high cost of training, housing, feeding and generally maintaining soldiers.[47] Cost savings could be utilised to either increase force size or capability, or reduce defence budgets.

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[45] Rune Henrikson and Anthony Vinci, *Combat Motivation in Non-State Armed Groups,* in *Terrorism and Political Violence,* vol. 17, spring/summer 2005, number 3, p.100.
[46] Interview with Professor Gurvinder S Virk, Professor of Robotics and Associate Head Institute of Technology and Engineering, Massey University – Wellington, conducted 06.07.07.
[47] Marcus Fielding, *Robotics in Future Land Warfare,* in *Australian Army Journal,* vol. III, no. 2, Winter 2006, p. 101.

A final potential benefit of IMs over humans is the enhancement of psychological effects on the enemy. A force of relentless, dispassionate killing machines possessing the aforementioned capabilities in stealth, situational awareness, firepower and lethality would undoubtedly invoke intense feelings of dread amongst those opposing them, perhaps similar to the 'Tank panic' first experienced by German soldiers in 1918.[48]The idea of a human fear of intelligent machines is not new, and was first postulated by Isaac Asimov, who coined the term 'Frankenstein Complex'[49]. The likely enhanced shock effect of such a force would result in disruption and a shattering of morale.

It can be assumed, as with any other new military technology, that significant procurement inertia will stand in the way of the adoption of IMs in Western militaries, for reasons discussed later in this thesis. As a result, considerable benefits over the present day status quo will be required in order for this adoption to occur. IMs will need to contribute meaningful enhancements to armed forces to justify the expense and effort required to procure and integrate them. Where they replace human soldiers, IMs will need to possess capability advantages over their human counterparts to validate their acquisition. An investigation of the potential characteristics of IMs within the temporal scope of this thesis identifies numerous areas in which IMs may exceed the capabilities of humans, as well as some additional benefits specific to IMs. These can be found in areas of detection threshold, situational awareness, survivability and expendability, firepower and lethality, speed and

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[48] James L. McWilliams, R. James Steel, *Amiens: Dawn of Victory,* Dundurn Press Ltd., 2001, p.199.
[49] Isaac Asimov, *I, Robot,* Dobson, London, 1967, p. 130.

mobility, endurance, and ‘cold bloodedness’, as well as cost benefits, erosion of enemy combat motivation, and psychological shock. If technological progress can support the development of IMs in a way that fulfils these potential advantages, they will offer compelling impetus for those who procure capabilities for the militaries of the West (and possibly elsewhere) to drive their employment. The extent of this fulfilment will in a large way determine the nature of IM employment by the year 2030.

Obstacles: Factors constraining the development and adoption of battlefield IMs.

While an abundance of potential benefits exist to promote the adoption of IMs within western information age armed forces, there are also a number of other significant factors that may retard or even preclude their employment. Having outlined the potential advantages in the previous chapter, this section will identify likely obstacles to the adoption of IMs. They may then be weighed against driving factors, in order to assist in the prediction of an outcome within the timeframe of this thesis. Obstacles in this section may be loosely grouped as technology and capability blocks, cost issues, military conservatism issues, and social and ethical issues.

Technological and capability issues form the primary barrier to IM introduction and employment. Put bluntly, if the technology does not exist to build IMs, or if they lack the capability to conduct tasks demanded of them, then they will not be adopted. Given the wide array and varied level of complexity of tasks performed by militaries however, the level of capability of IMs will rather determine their introduction to specific roles. As such, this chapter will first determine technological obstacles which may prevent the development of any form of useful IM by 2030, and then consider the capability limitations that could restrict the roles of IMs.

A fundamental characteristic of an Intelligent Machine is that it must be intelligent. That is, an IM must be able to usefully perceive its environment, and determine and execute an appropriate course of action in order to influence the environment in accordance with its commander's intent. This is no small demand. The terrestrial environment is highly complex. Wide ranging variables such as the form, density, strength and friction of surfaces create an intricate domain; while geophysical influences add dynamism that constantly reshape it. The future land operating environment is yet more complicated. It is overlaid with a diverse and dynamic civilian population, who constantly modify it towards increasing urban complexity, and whose perceptions, aspirations and loyalties are increasingly central to military operations. As if this were not enough, the addition of adversaries, who will seek to counter the actions of the IM while actively minimizing their own detection threshold, exacerbates this complexity. The scale of the task of perceiving and operating in the land operating environment has never been greater. In fact, the demands of this environment are so great that today's human soldiers struggle to operate within it. In future the complexity of the soldiers' task is forecast to increase, requiring more capable, better trained commanders and soldiers.[50] This begs the question: will the state of artificial intelligence reach a sufficient level of advancement to enable the militarily useful performance of intelligent machines in the future land operating environment by the year 2030?

Commentators and experts in the field of artificial intelligence offer wide ranging estimates on the development of Artificial Intelligence (AI). A high level of interest in the emergence of a generalized human-surpassing artificial intelligence, or "technological singularity", has led considerable speculation on

[50] *New Zealand Army Future Land Operating Concept: Precision Manoeuvre 2020,* New Zealand Army, 2007, p.3.4.

the moment of its occurrence. This “technological singularity” is a useful measurement for predicting IM adoption, as, if a machine can think as well as or even better than a human, then this presents a compelling incentive, and significant technological enablement for the use of IMs in currently human-filled military land operating environment roles. Estimates of this emergence can be grouped into short range (now to 2029), mid-range (2030-2080), and longer range (2081-2150+). The majority of estimates, by technology analysts, futurists, and AI pioneers, rest in the mid-range, with its lower limit resting on the upper limit of this thesis[51]. While this presents a very narrow overlap, according to renowned Stanford University computer scientist John Koza[52] this singularity is likely to be the cumulative result of “instances or modules of human competitive intelligence” in an incremental chain, surpassing human intelligence in cognitive functional steps.[53] Thus, according to the average of these predictions, AI will likely perform a significant subset of cognitive functions equally or better than humans.

In psychology, intelligence refers to ‘the general mental ability involved in calculating, reasoning, perceiving relationships and analogies, learning quickly, storing and retrieving information, using language fluently, and adjusting to new situations.’[54] An examination of these with respect to the field of AI yields some examples where the ability of machines has superseded

[51] Acceleration Watch: Singularity Timing Predictions, http://accelerationwatch.com/singtimingpredictios.html, accessed 08.05.08.
[52] John Koza Homepage, http://www.genetic-programming.com/johnkoza.html, accessed 04.07.08.
[53] Acceleration Watch: Singularity Timing Predictions, http://accelerationwatch.com/singtimingpredictios.html, accessed 08.05.08.
[54] “Intelligence”, Columbia Electronic Encyclopedia, Columbia University Press, http://www.reference.com/browse/columbia/intellig, accessed 04.07.08.

that of humans; calculating, at least in the simple numerical quantitative sense, and storing and retrieving information, with increasingly sophisticated database systems as well as search engines such as Google. US military AI experts are presently focussing their research efforts to target cognitive 'low hanging fruit', such as data processing, pattern recognition, and decision support.[55] As computer power continues to conform to Moore's Law (the doubling of transistors per area every 18 months), and as knowledge and expertise in the field of AI accumulate, more and more of these cognitive functions will see AI overtaking human intelligence. While AI is a decisive factor in the development and employment of IMs, present trends and predictions point towards levels of AI that will be able to cope with the growing complexities of the future land operating environment by the year 2030.

Machine vision (or autonomous image processing), a subset of AI, is worth considering in its own right as a potential capability stumbling block for the development of IMs. Science philosopher Manuel de Landa identifies the centrality of machine vision to the battlefield employment of IMs in his book *War in the Age of Intelligent Machines* with the following statement:

> *"The extension of this technology* [machine vision] *to real-world situations will, of course, be a quantum leap towards endowing predatory machines with the capability of manoeuvring in terrestrial battlefields. The complexity of the task will probably determine that the deployment of the first autonomous weapons will proceed in smooth*

[55] Military and Aerospace Electronics: The next 'new frontier' of artificial intelligence, http://mae.pennet.com/articles/article_display.cfm?article_id=86890, accessed 04.07.08.

environments with minimal irregularities (air and sea) before they can be made to fight on land."[56]

This statement highlights the previously mentioned challenge posed by the land environment to IM employment. Before an IM can "think" about the land environment, it must perceive it, formulating a sufficiently accurate picture of its environment which it can understand and use as the basis for decision making. Although the current state of sensor technology is more than able to build such a picture, using sensors detailed in the previous chapter, the field of image processing has some way to go before this picture can be understood by a machine in a sufficiently useful way. Determining patterns and detecting entities from within the rich, complex, chaotic and often random land environment is no small task; the very capable human vision system requires a full one third of the brain.[57] Currently, IMs are able to negotiate structured/ semi-structured environments such as urban streets while avoiding traffic (demonstrated in the recent DARPA Urban Challenge competition)[58], and research is beginning to push machine vision into more complex environments. A local example can be found with a kiwifruit harvesting robot under development at Massey University that will be able to negotiate kiwifruit orchards, examine fruit on the vine based on their size and any blemishes, and then pick those that are suitable.[59] Identifying kiwifruit is, however, a long

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[56] Manuel de Landa, *War in the Age of Intelligent Machines,* Zone Books, New York, 1991, p. 202.

[57] *Basic Cerebral Cortex Functions With an Emphasis on Vision,* http://www.benbest.com/science/anatmd5.html, accesed 24.07.2008.

[58] Scientific American, *Robotics Prof Sees Threat in Military Robots,* http://www.sciam.com/article.cfm?id=robotics-prof-sees-threat-in-robots&sc=rss, accessed 13.03.08.

[59] Massey University, *Leader of the Pick, http://www.massey.ac.nz/massey/about-us/news/article.cfm?mnarticle=leader-of-the-pick-30-04-2008,* accessed 15.05.08.

way from the perceptive demands of the land operating environment. Adversaries will deliberately camouflage themselves, attempting to blend in with the terrain or population in order to avoid detection. Appropriate changes in appearance through the alteration of shape, size or colour for example are sufficient to confound the present state of machine vision.[60] A potential solution to this problem is the provision of a processed, simplified picture of the operating environment to the IM to ease the burden of perception. Analysis of the environment could be done by humans viewing intelligence, surveillance and reconnaissance (ISR) data who would then identify adversary entities throughout the battlefield and tag them, by laser designation, or Global Positioning Satellite (GPS) reference for example, simplifying the perceptive task of IMs greatly. This is in much the same way as targeting is done today for close air support attack aircraft. A more ambitious solution would be the provision of a digital virtual world model such as that which the previously mentioned DARPA Battlespaces That See project aims to create, where a higher, more powerful centralised AI would pore over the environment and process it into a simplified representation in which the enemy is laid bare. However the problem of perception is overcome, the field of machine vision will require considerable development before autonomous battlefield IMs are to become a reality.

[60] Interview with Associate Professor Donald Bailey, senior lecturer in Institute of Information Science and Technology and image processing specialist at Massey university, conducted 13.07.07.

Related to machine vision is the specific task of identifying a human as being friendly, neutral or hostile[61]. This represents a much greater challenge than identifying adversary platforms, particularly in an era where adversaries of the west will seldom don uniforms for combat and instead make efforts to appear as innocent civilians. Without a uniform, all that will distinguish a combatant from a civilian will be any equipment on their person - an easily concealed small arm or explosive device for example, and intent to do harm. An IM could conceivably use sensors to detect the signature of a concealed weapon, by explosive smell, magnetic anomaly, or some form of imaging that penetrates clothing for example. However in today's conflict environment, many civilians also regularly carry weaponry, limiting its usefulness as a discriminator. Exposing hostile intent within an individual is a much more complicated task. This requires observation of behaviour, and an intuitive assessment based on instinct, experience and judgement that will be extremely difficult for AI programmers to replicate, especially to the degree of confidence required to authorize the use of lethal force[62]. Facial recognition technology[63] may assist in identifying known enemy personnel, but these will more than likely represent the minority of enemy combatants. It may be that IMs will be required to operate under restrictive Rules of Engagement (ROE), authorizing lethal force only after they have been engaged by an identifiable enemy. Equipping IMs with non-lethal weapons would reduce the requirement for

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[61] Popular Mechanics, *America's Robot Army: Are Unmanned Fighters Ready for Combat?,* http://www.popularmechanics.com/technology/military_law/4252643.html?nav=hpPrint&do=print, accessed 14.10.08.
[62] Popular Mechanics, *America's Robot Army: Are Unmanned Fighters Ready for Combat?,* http://www.popularmechanics.com/technology/military_law/4252643.html?nav=hpPrint&do=print, accessed 14.10.08.
[63] Facial Recognition Homepage – General Info, http://www.face-rec.org/general-info/, accessed 04.02.09.

certainty of discrimination to an extent, by reducing the consequences of mistaken identity. However, both of these solutions are far from optimal, resulting in heightened risk to the IM, and ceding of the initiative to adversaries who may chose when and where to engage friendly forces and reveal their presence. A more simple solution would be the use of IMs in cooperation with human soldiers who are more able and legally empowered to discriminate hostile from neutral or friendly. However the problem of human adversary discrimination by IMs is approached, any solution appears likely – at least in the near term of AI development – to restrict the effectiveness or manner of employment of IMs on the battlefield.

Another technical/technological obstacle that may hinder the widespread adoption of IMs on the battlefield is power. The replacement of human soldiers with machines on a large scale will require a major realignment of logistics provisioning. Where as the main consumables required to sustain a human soldier are food and water, which can in some instances be sourced locally, or at least stored for long periods and moved in bulk, a machine has very different energy needs. An IM will likely be powered either by some form of battery or fuel cell, or by an internal combustion engine. In the case of a battery, energy is first required to provide it with a charge. For an IM to be militarily useful in roles presently performed by humans, this charge must be sufficient to provide a comparable amount of time independent of logistic support. In the case of infantrymen, this can range from 24 hours out to five days depending on the type of infantry (mechanized, light, airborne etc.)[64], with a need for frequent movement over distance, vigilance, construction of fortifications such as fighting holes, and combat. For a battery powered machine to perform a similar range of tasks over such a time scale, it would require a considerable reservoir of energy. As mentioned in the previous section of this thesis, an IM will be restrained by the size of its power supply against its rate of power consumption. However, depending on the nature of the power supply, this could either be a weakness, or strength, when compared to human soldiers. Present battery technology limits machines for such simple applications as human piloted electric cars to 3 hours continuous motoring.[65] With the additional burden of operating a CPU, communications and weapon systems, the power endurance demands of the soldier role reach beyond the present day capabilities of a machine.

Advancing battery technology will very likely increase battery capacity dramatically over the next two decades,[66] with Lithium Sulphur batteries for example offering a potential 300% capacity improvement over present Lithium Ion batteries (although at this point, explosive energy density creates concerns).[67] Fuel cells, micro-turbines, and micro-combustion offer further energy storage density improvements,[68,69] however these require fossil or similar (eg. Hydrogen) fuels that must be provided in theatre. Provision of the

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[64] Interview with Maj. Vern Bennett, New Zealand Army, Force Development, Capability Branch, Army General Staff, 11.07.2008.

[65] AC Propulsion Inc., *AC Propulsion Debuts tzero with LiIon Battery,* www.acpropulsion.com, accessed 11.07.2008.

[66] Dismounted Soldier System Power Interface Control Document (ICD) Development

[67] Interview with Phil Strong, Defence Technology Agency, Sensor Systems Group, on 28.06.07.

[68] Ibid

[69] Christian Bonn, Dave Reichert, Du Pont, Smart Fuel Cell Presentation Slideshow, *PEO Soldier*, 04.11.05.

significant electricity required to charge a large number of IMs in theatre would either require some form of local generation (most likely provided by deployable diesel generators) or the transmission of electricity into theatre. Both options present significant logistical problems, either with the expansion of fuel requirements to the front line, or with forces tied at the end of an electric transmission system as they were to rail heads in the late 19th Century, significantly limiting flexibility. Furthermore, with today's spiralling oil prices and the looming onset of peak oil, an army of fossil fuel dependent IMs may be prohibitively expensive.

Other technological developments on the horizon may provide a solution to the problem of powering IMs. Room temperature superconductors (materials that have no electrical resistance) are an aspiration for material science researchers around the world,[70] and would have a revolutionary impact on the way electricity is generated, transmitted, stored and consumed. Some of the relevant applications for IMs include high capacity energy storage, super efficient electric motors and servos, and very powerful and efficient computing. Thus, while energy provision and storage capacity present significant obstacles for viable IMs, technological developments in the next two decades may overcome these, and so the development path of battlefield IMs appears to be slaved to the development of cost effective, deployable, high density energy as it is to the continuing development of AI.

[70] EETimes.com: *EE Times corrects story on silane as a potential superconductor,* www.eetimes.com, accessed 11.07.2008.

As with any military system, IMs will most likely possess vulnerabilities which, if not appropriately mitigated, could limit their effectiveness or even preclude their adoption. The most apparent potential vulnerability for IMs is their communications links. Assuming that commanders will require some form of 'man-in-the-loop' governing the actions of IMs, and the likely requirement for teleoperation where AI is insufficient to guide the IM through a task or problem, the need for some form of communications with that IM becomes necessary. This requirement then presents two problems. The first pertains to electromagnetic signature resulting from detectable communications between the IM and command element. On the future battlefield, such telltale signals traffic will increasingly invite enemy action. Mitigation of this problem will require the minimisation of radio traffic between the command element/teleoperator and IM, which may in turn result in the loss of real-time situational awareness and a degraded decision cycle. The second problem resulting from the need for communications is the risk of interdiction to those communications. Electronic Warfare (EW) has been used for decades to dislocate commanders from their forces through the jamming of radios. In this situation, subordinate commanders no longer in contact with their superior commander may act in accordance with their intent, applying their initiative and authority in order to fulfil their mission. In the case of IMs however, severance from the commander will result in paralysis, unless the IM is given the authority and intelligence to act autonomously. The problems created by the need for communications thus present three possible outcomes: development and utilisation of robust, high capacity, jam-resistant, real-time low-probability-of-intercept communications; an acceptance of risk in terms of detection and possible command interdiction with resulting paralysis; or, the ceding of intelligent, autonomous authority to IMs. The first outcome represents a technological hurdle; the second, an acknowledgement of reduced effectiveness, and the third, a major shift in attitude towards man-in-the-loop decision making and the laws of armed conflict, which will be covered in a later section.

A recurrent concern raised regarding potential employment of armed IMs involves the loss of control, frequently mirrored in fiction with movies such as *Terminator* or *I Robot.* In this scenario, the IM makes a conscious decision to free itself from the control of its human masters and turns its weapons against them. Authorities in the field of IMs believe this outcome to be implausible however[71]. An intelligence designed is by nature an intelligence controlled, and it is difficult to believe that IMs would be developed without strict, robust behavioural limitations or 'governors' built in, as well as some form of redundant external control, a 'kill switch' in its most basic form, or an ability to override autonomous control and teleoperate. [72] What is more likely to occur however, is an error,[73] whether the result of an unforeseen interaction between programming and environment, a missed coding error or the like.[74] If such an error results in significant unintended injury or death, the consequences would almost definitely be dire for the prospects of IM employment. In order to gain the trust of the conservative military

[71] Interview with Professor Gurvinder S Virk, Professor of Robotics and Associate Head Institute of Technology and Engineering, Massey University – Wellington, 06.07.07.
[72] William B. McClure, *Technology and Command: Implications for Military Operations in the Twenty-first Century,* Occasional Paper No. 15, Center for Strategy and Technology, Air War College, Air University, Maxwell Air Force Base, USA, 2006, p.12.
[73] Virk.
[74] McClure, p.12.

establishment and greater public, an IM equipped with lethal weapons and the authority and ability to employ them will need to be faultless in its behaviour.

Finally regarding capability, there are some tasks performed on the modern battlefield that IMs fundamentally 'just can't do', due to their lack of humanity. The current conflict environment places emphasis on small wars amongst the people against irregular adversaries contesting the allegiance of the civilian population, and this mode of conflict is forecast to persist at significant levels within the scope of this thesis.[75] Military operations in this conflict environment demand a high level of personal interaction with the local civilian population. It is highly doubtful that IMs patrolling city streets or visiting villages would be able to establish a rapport with civilians, win their allegiance, and gain valuable intelligence from them. Social interaction between machine intelligence and humans, as regularly tested in the famous Turing test[76], has long been an aspiration of AI developers, and is progressing in some bizarre and innovative directions (notably the CyberLover, a sophisticated Russian 'slut-bot' malicious software agent that poses as a human woman in online sex chat rooms and mines personal information for fraudulent purposes[77]). However, social/ emotional intelligence is one of the most difficult challenges for AI programmers, and the development of an IM capable of the aforementioned tasks critical to the forecasted future conflict environment is unlikely before the year 2030. This limitation reduces the utility of IMs, and so

[75] *New Zealand Army Future Land Operating Concept: Precision Manoeuvre 2020,* New Zealand Army, 2007, p.1.6.
[76] Ayse Pinar Saygin, Ilyas Cicekli and Varol Akman, *Turing Test: 50 Years Later,* in *Minds and Machines #10,* 2000, p.463.
[77] Dylan Welch, *Love in the age of the Slutbot,* Stuff.co.nz, www.stuff.co.nz/print/4626728a28html, accessed 02.09.08.

in military operations where personal interaction with civilians is vital, IMs will likely be restricted to supporting rather than replacing infantry.

Creative thought is another important task likely to be beyond the grasp of IMs by the year 2030, involving the production of new and novel ideas seemingly from nowhere. Warfare has always been a complex and unpredictable activity. This was a key tenet in Clausewitz's treatise *On War,* in which he warned that 'the very nature of interaction is bound to make it unpredictable'.[78] This unpredictability will only be compounded by the forecast complexity of the future land operating environment. As a consequence, commanders will be constantly met with unforeseen and thus unplanned for situations, to which, in the absence of concrete data or prior experience, they must react to the best of their ability by applying creative thought and improvisation.

Creative thought is also integral to the achievement of surprise. Surprise grants a force significant advantage over their adversary by allowing them to adopt a dominant position in time and space; the adversary does not foresee this unpredictable manoeuvre, and therefore is unprepared for it when it eventuates. In order to identify an opportunity for action which an adversary will not recognize, a commander must apply significant creative thought. The commander must explore all available courses of action possible with environmental constraints and resources at his disposal, while understanding the mind of the adversary commander so as to predict what he will discount or

[78] Carl von Clausewitz, *On War*, edited and translated by Michael Howard and Peter Paret, New Jersey, Princeton University Press, 1976.

fail to consider. Therefore creative thought is a key ingredient of tactical command. However, creative thought has been identified as one of the most challenging areas of AI programming, with experts contending: ‘in contrast to the highly logical, convergent, and well-defined traits of rational thinking, creative thought is abstract and intuitive. Thus, in a mechanical sense, it is much more difficult to program.’[79] In fact, scientists in this field have not yet even developed a satisfactory explanation for the human creative thought process; inadequately defining it as ‘the novel combination of old ideas’.[80]Therefore, if AI creative thought cannot be achieved and applied to IMs by 2030, then IMs will be less able to achieve surprise, predict enemy courses of action or respond appropriately to unpredictable and not previously experienced situations on the battlefield. This will likely preclude them from any significant tactical or strategic planning and decision making roles on the battlefield.

Cost will be a fundamental inhibitor on the introduction of IMs on the battlefield. If the cost of developing IMs becomes too high, efforts will be abandoned or shelved, as has occurred with countless high technology military projects in the past (the Commanche Reconnaissance Attack Helicopter[81] and ‘Star Wars’ Strategic Defence Initiative to name a few). While military high-technology is typically very expensive however, the costs of a broad range of electronic components necessary for IM construction are

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[79] W. Michael Reed and John K. Burton, *Educational Computing and Problem Solving,* Haworth Press, 1988, p.51.
[80] Margaret Boden, *Creativity and Unpredictability,* Stanford University, http://www.stanford.edu/group/SHR/4-2/text/boden.html, accessed 13.01.09.
[81] CNN: *Army cancels Comanche helicopter,* http://edition.cnn.com/2004/US/02/23/helicopter.cancel/, accessed 31.10.08.

dropping fast[82]. Once developed, IMs will need to deliver a 'pay off' in terms of capability that will justify those development costs. Furthermore, the per-unit cost for IMs will influence the number of IMs adopted, and subsequently the extent of their presence on the battlefield.

A critical determinant of development and per-unit costs of IMs will be the civilian consumer uptake of this technology. Significant consumer demand for IMs would support a large IM production industry and infrastructure, as well as fuelling research and development to build better, cheaper IMs. IMs for the civilian market, while no doubt very different from those intended for military use, will likely share many of the same components. Electric servo-motors, processors, light-weight sensors, batteries, software, and a whole range of other IM components will fall dramatically in price when the civilian market does eventuality reach maturity, and many of these will also be utilised in military IMs, reducing per-unit production costs.

If there are sufficient profits to be gained from producing IMs for the civilian consumer, IM research and development investment for this sector could quickly outstrip the military sector, providing cost reductions in military product development. This can already be seen with human-computer interface (HCI) technology, where the military has been surpassed by the video game industry, producing highly advanced game controllers that have in turn been adopted in an almost off-the-shelf format by the military to control Improvised

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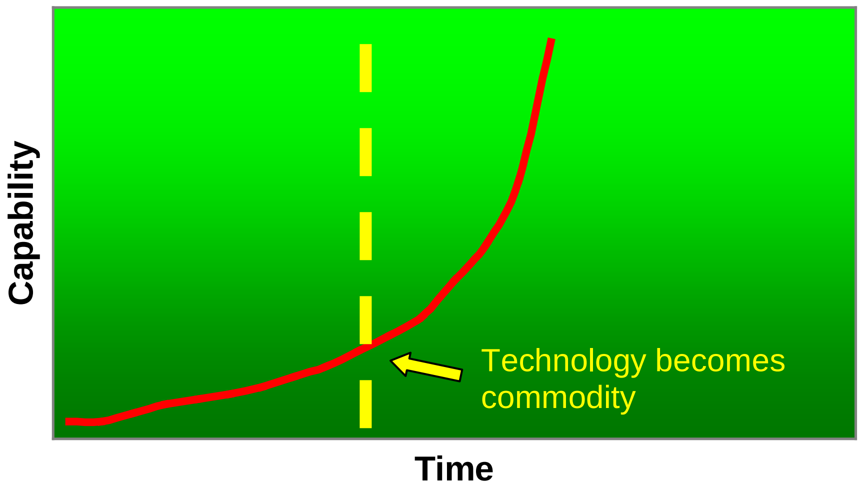
[82] Scientific American: *A Robot in Every Home,* http://www.sciam.com/print_version.cfm?articleID=9312A198-E7F2-99DF-31DA639D6C..., accessed 07.04.07.

Explosive Device (IED) disposal robots, remote weapon stations, and Uninhabited Aerial Vehicles (UAVs).[83]

If such a mass market and subsequent research and development do occur, then the rate of capability advance for IMs will grow radically, as with any electronic commodity (see Figure 1). This can be observed for example with cellular phones, which, in twenty years (a period of time similar to that until the focus of this thesis) have shrunk dramatically in size, weight, and price, while picking up the functions of text messaging, digital camera, Personal Digital Assistant (PDA), digital media player, internet browsing and an ever increasing range of other capabilities.

Figure 1: Capability Curve for Emerging Technology

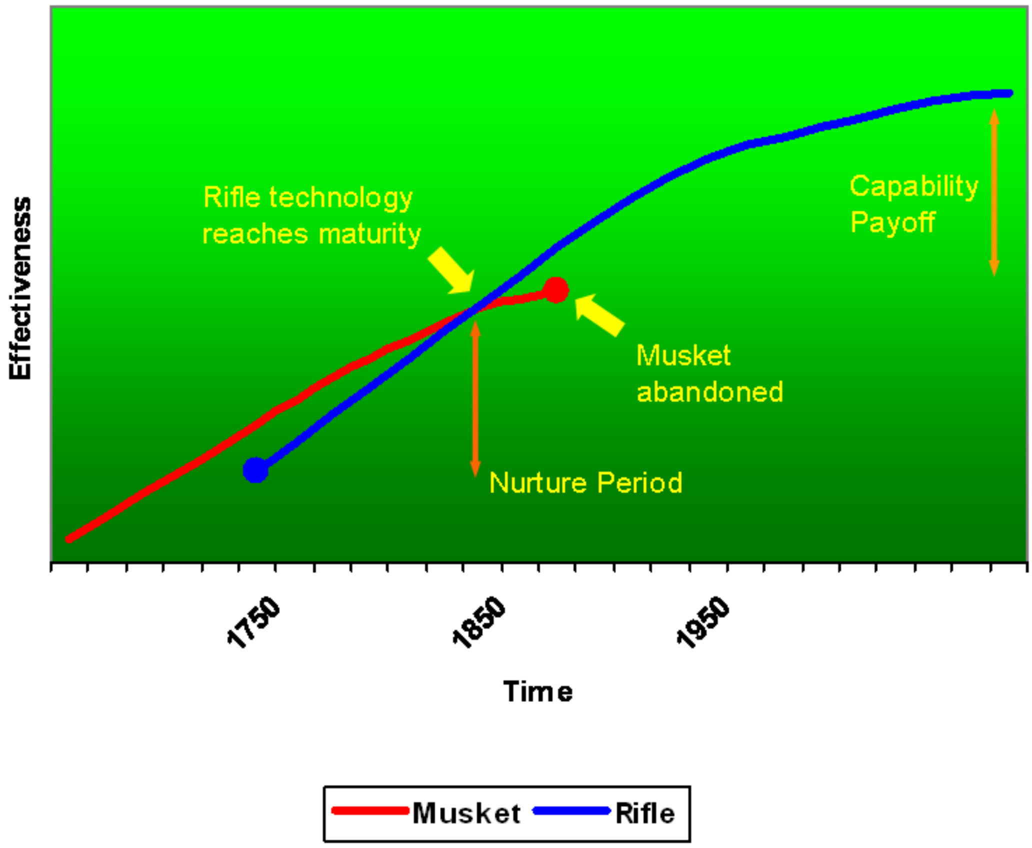


If however, a civilian IM industry of sufficient size fails to materialize in time to satisfy military demand, the military sector will have to continue to nurture this

[83] Wired*: Game Controllers Driving Drones, Nukes,* http://blog.wired.com/2008/07/wargames.html, accessed 15.10.08.

technology into maturity as it is presently doing[84], funding IM research and development out of defence budgets and greatly increasing the cost of and time until initial IM uptake as a result. The cost of this nurture period, including development, initial per-unit production cost, and introduction into service, will be balanced against the level of capability gained over equivalent manned or soldier systems. An example can be seen below (figure 2), using the

Figure 2: Nurture Period for Capability Development (Musket and Rifle)



comparison of rifle and musket. If the cost of nurturing IM technology is judged to be greater than the capability gain it delivers over present manned/soldier systems upon maturity, uptake is unlikely to occur (shown in

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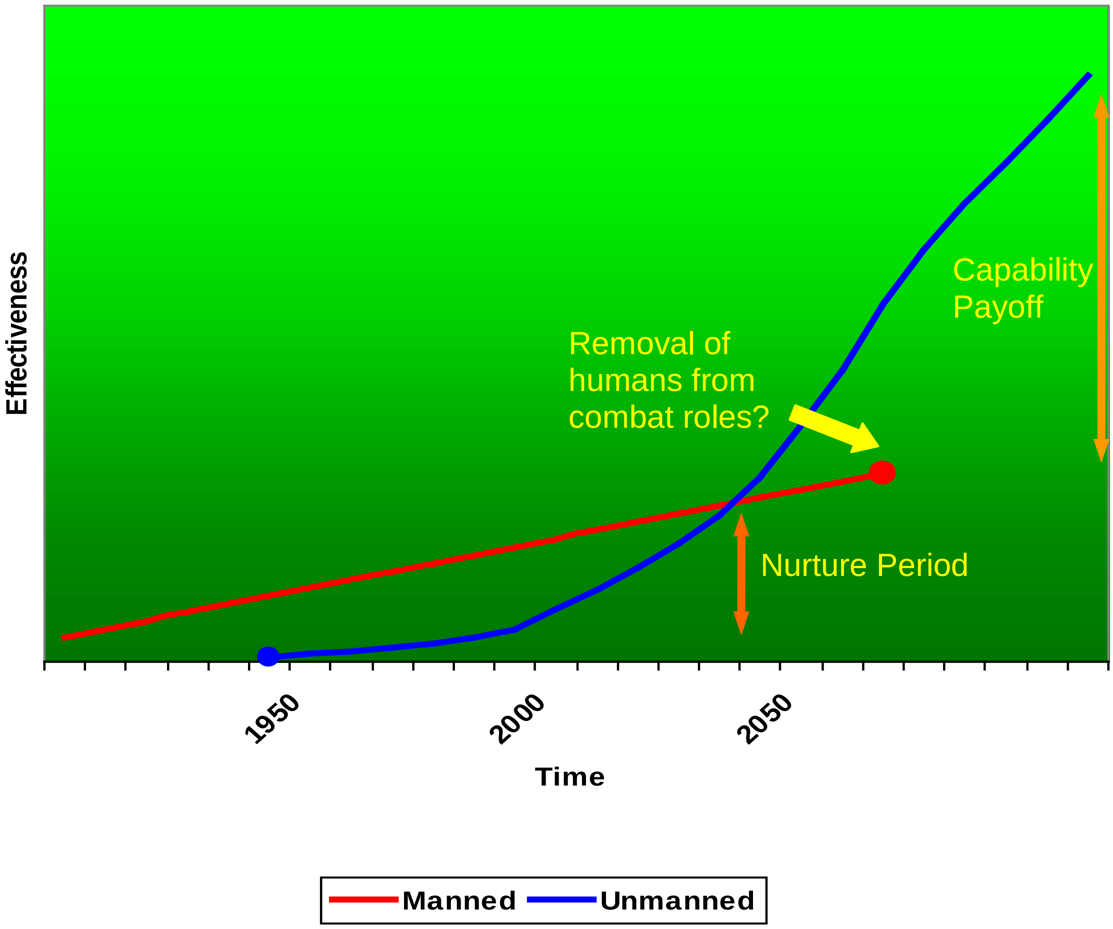
[84] Michigan Today: *U-M nurtures robotics industry in southeast Michigan,* http://michigantoday.umich.edu/2008/09/robot.php, accessed 16.10.08.

figure 3). Also, if uptake does occur, then the per-unit production cost will dictate which roles IMs may be utilised in, albeit in conjunction with some calculation of the value of removing soldiers from harm's way.[85]

Figure 3: Nurture Period for Capability Development (Manned and Unmanned Systems)



If the core components of autonomous IMs cost millions of dollars, then they will be simply too expensive for procurement in large numbers, precluding them from general service roles such as infantry (the cost of putting a US service member into the Iraq war was close to $400,000 in 2005)[86], and

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[85] R.E. Chapman, *Unmanned Combat Aerial Vehicle: Dawn of a New Age,* Aerospace Power Journal, Summer 2002, p. 61.

[86] Houston Chronicle, *Cost of putting each fighter in war zone at record high,* http://www.chron.com/disp/story.mpl/special/iraq/3828480.html, accessed 04.09.08.

limiting them to large platform (main battle tank, self-propelled artillery etc) or specialist roles.

It would appear then that the question of whether or not a large civilian market for IMs develops before 2030 is central to determining how soon and on what scale IMs may be adopted by the military. Efforts to bring IMs to civilian consumers have so far been mediocre; applications such as automated vacuum cleaners, pool cleaners, and lawn mowers whose poor functionality consigns them to pure novelty, as well as a range of high technology child's toys.[87] Nonetheless, the eventuality of robot in every home (at least in affluent countries) has been prophesised by Microsoft's Bill Gates[88], the Japanese and South Korean governments (by 2015[89] and 2020 respectively[90]), and perhaps unsurprisingly, by iRobot Corporation's cofounder and CEO Colin Angle (by 2028[91]). Impending demographic crises in South Korea, and particularly in low-immigration Japan, will create a significant burden of care for a large proportion of aged persons around 2030, and domestic care robots are seen as a potential panacea to this problem.[92] As a result, the Japanese government estimates the global personal robotics market will be worth $10 billion a year by 2015[93], and the Japanese Robot Association predicts $50

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[87] Presentation by Professor Gurvinder Virk, *Climbing and walking robots - our servants of the future,* at Massey University, Wellington, 14.08.08.
[88] Scientific American: *A Robot in Every Home,* http://www.sciam.com/print_version.cfm?articleID=9312A198-E7F2-99DF-31DA639D6C..., accessed 07.04.07.
[89] Marketplace: *Japan's Vision: A robot in every home,* http://marketplace.publicradio.org/shows/2007/06/28/AM200706283.html?refid=0, accessed 07.04.07.
[90] National Geographic: *A Robot in Every Home by 2020, South Korea Says,* http://news.nationalgeographic.com/news/2006/09/060906-robots.html, accessed 07.04.07.
[91] Colin Angle, *Home Robot Explosion,* in PC Magazine, January 2008, p.79.
[92] Marketplace: *Japan's Vision: A robot in every home.*
[93] Ibid.

billion a year by 2025[94]. Historically however, predictions regarding robotics and AI have been far from prophetic, with many bold claims by those in working in the field of AI and robotics in the 1960s, 70s and 80s being exposed as wildly optimistic[95,96,97,98]. Furthermore, IMs in industry appear to be close to emerging from their traditional factory environments into the wider industrial environment, with possible employers including horticulture, agriculture, construction, medicine, search and rescue, and a whole range of other applications, which will challenge the wider civilian IM industry to develop mobility and sensory technology to cope with the terrestrial environment, and have significant applications in the military IM realm. Thus the cost of IM technology for research and development, per-unit production, as well as support provided by any emergent consumer IM mass market will be heavily influential on the scale of IM adoption by information age militaries.

Military conservatism poses a serious obstacle to the employment of IMs on the battlefield. There exists a great reluctance in military thought to diverge in any way from the tried and the trusted, with great value placed on 'battle-proven' practices and equipment. Success or failure in battle has inherently severe consequences for states and their armed forces, and so any self-imposed radical change, or 'transformation' can justifiably be viewed as an undesirable risk. Advances in military technology are therefore for the most

[94] Scientific American: *A Robot in Every Home*
[95] Rodney A. Brooks, Anita Flynn, *Fast, Cheap and Out of Control,* Massachusetts Institute of Technology, Cambridge, 1989.
[96] V. Daniel Hunt, *Industrial Robot Handbook,* Industrial Press Inc., 1983, p. 377.
[97] 1965, H. A. Simon: "machines will be capable, within twenty years, of doing any work a man can do.", p. 96 quoted in Daniel Crevier, *AI: The Tumultuous Search for Artificial Intelligence*, BasicBooks, New York, 1993, p. 109.
[98] Pamela McCorduck, *Machines Who Think* (2nd ed.), A. K. Peters Ltd, Natick, MA, 2004, p. 441.

part incremental, or evolutionary, rather than revolutionary. History is replete with examples of this military aversion to untested revolutionary technologies: Constantine's dismissal of the cannon, which would instead be employed by his enemies, the Ottomans, to smash the walls of his fortress city Constantinople[99]; First World War British General Haig, who claimed "The machine gun is a much overrated weapon; two per battalion is more than sufficient."[100], and French General Foch, who insisted early in the First World War "aviation is a good sport, but for the army it is useless"[101]. A point to note of these three examples is that all three applications of technology were eventually adopted and refined to the extent that they remain critical military equipment today. Military conservatism it seems, will generally retard, rather than terminate the pursuit of a realistically beneficial technology. Another point of interest is that during protracted high-intensity conflict against a similar adversary, the pursuit of revolutionary military technology can accelerate greatly, as funding soars and either side attempts to develop a technological edge over the other so as to gain a decisive advantage that will tip the balance and enable a speedy victory. Poison gas, the flamethrower, the V series of ballistic missiles, and the atomic bomb present effective if repugnant examples of military technology rapidly developed during wartime. These examples also highlight the side-lining of moral or ethical objections to weapon systems in times of total war, which will become important later in this chapter. Nonetheless, technology as radical as IMs will likely face resistance

[99] The Guns of Constantinople, http://www.historynet.com/the-guns-of-constantinople.htm, accessed 17.10.08.

[100] David Jablonsky, *Army Transformation: A Tale of Two Doctrines,* in Parameters, Autumn 2001, p. 43.

[101] *The War in the Air - Observation and Reconnaissance* http://www.firstworldwar.com/airwar/observation.htm, accessed 17.10.08.

in even the most forward looking military establishment. While the uptake of military robotics is already in its infancy, these robots are far from being IMs, as they are teleoperated and lack any significant intelligence. The ceding of the authority and capacity to make decisions, particularly those involving the application of lethal force, will undoubtedly be a bitter pill for military establishments to swallow, as will any move to replace something as fundamental as human infantrymen on the battlefield. Failing the outbreak of a large scale high intensity and protracted war between advanced near-peer militaries, this conservatism will very likely see initial IM development move in small slow increments, with restrictions on the roles and functionality of this technology.

Final, and at least regarding liberal democracies, critical obstacles to the adoption of IMs that can be grouped together are those based on likely societal/political, legal, and moral objections. These largely rest on issues of responsibility and accountability, as well as potential second order effects resulting from the adoption for or use of IMs in conflict.

IMs represent a potential legal Pandora's Box, as a result of their autonomy. Where authorized and enabled to make kill/no kill decisions, lethal IMs will render present day Laws of Armed Conflict (LOAC) obsolete. The two key international conventions that outline acceptable practices regarding acceptable practices while engaged in warfare are the Geneva and Hague conventions. They define conduct and responsibilities of belligerent nations, neutral nations, and individual combatants, towards each other as well as toward civilians or 'protected persons'.[102] While there is no reason why IMs should be any less capable in adhering to these laws than human combatants, if an IM were to inadvertently breach these through cause of malfunction or mistaken identity, for example massacring a large number of civilians, or destroying a protected religious site, then significant problems arise. These result from the fact that, as with any law, LOAC require punishment of violations as a means of enforcement and justice, and thus require a responsible party to be subject to that punishment. If LOAC are breached as the result of a decision made autonomously by an IM, who is to be held responsible and punished? Clearly the punishment of an IM is absurd, and would neither impact the behaviour of the IM in deterrence or after the fact[103], nor satisfy justice for those parties injured by the breach of LOAC. The present orthodox consensus, and solution to this problem, is that the decision to take life must therefore always be made by a human, which in the case of IMs will mean some degree of teleoperation[104]. While the pros and cons of automation and teleoperation will be discussed in a later chapter of this thesis, this solution will in any case not completely remove the problem of accountability. This is because breaches of LOAC may arise from routine decisions made autonomously by IMs. For example, an IM in the resupply role (The US Department of Defence has directed that one third of all ground vehicles, mainly in the logistics role, should be autonomous by the year

[102] ICRC, *What is international humanitarian law?,* http://www.icrc.org/web/eng/siteeng0.nsf/html/humanitarian-law-factsheet, accessed 21.10.08.

[103] Perhaps not: an intelligent IM could reasonably be programmed in a way that gives it a cognitive ability to suffer, and the freedom to choose to act in a way to avoid the cause of this suffering, thus allowing for a deterrent effect.
Robert Sparrow, *Killer Robots,* in the Journal of Applied Philosophy, Vol. 24, No.1, 2007, p.72.

[104] Hyder Gulam and Simon W. Lee, *Uninhabited Combat Aerial Vehicles and the Law of Armed Conflict* in the Australian Army Journal, Volume III, Number 2, Winter 2006, p. 132.

2015[105]), driving down a busy highway with a load of explosive ordnance may, through poor judgment, collide with an oncoming vehicle, resulting in a massive explosion and causing significant civilian death. While in this case the IM did not intend to kill civilians, it did make decisions that resulted in their deaths, and yet who is to be held responsible?

At this point it becomes clear that some *human* must be legally and morally accountable for the actions of autonomous IMs if they are to be employed. A new question then arises as to who should be responsible for the actions of the IM. The most obvious target for blame would be the commanding officer who ordered the deployment of IMs involved in a LOAC violation[106]. This would likely be contingent on a sound knowledge of the specifications of IMs, with a full understanding of the risks associated with their employment, such as rates of failure or malfunction etc, so that these risks can be calculated, balanced against a military objective, and mitigated or accepted. However, if these IMs are endowed with significant autonomy, then any commander in charge will have little influence on certain aspects of their conduct. This is currently the case with those militaries adopting the Mission Command style of command, where subordinates are told their commanders intent, or what he/she wants to achieve, *not* how he wants to achieve it, thus granting the subordinates the autonomy to achieve their commander's intent by what they view as the best ways and means as a result of their proximity to the task at hand. In this case however, the commander's subordinates are *humans*, and

[105] Committee on Army Unmanned Ground Vehicle Technology, National Research Council, Technology *Development for Army Unmanned Ground Vehicles*, Board on Army Science and Technology (BAST), The National Academies Press, 2002, p. 13.
[106] Robert Sparrow, *Killer Robots,* in the Journal of Applied Philosophy, Vol. 24, No.1, 2007, p.72.

so are accountable for their own actions, even when following the orders of their commander[107]. In the case of IMs, the commanding officer will shoulder not only their traditional responsibilities for the achievement of their own mission and the conduct of their unit, but be the sole bearer of responsibility for the individual actions of all members of their unit, despite the fact they are autonomous and therefore able to ‘think’ and act of their own volition. Furthermore, with diminishing influence on the actions of IMs as they gain more autonomy, their commander loses control of the very events for which he/she is held responsible. In this situation, the commanding officer is little more than a professional scapegoat, paid purely to accept risk. This is hardly a desirable position, and undoubtedly would be flatly refused by any officer assigned to ‘command’ autonomous IMs.

Another possible point of responsibility, particularly where IMs fail to conform to stipulated performance specifications, would be their manufacturing company. The manufacturer having programmed the software that controls the IM and dictates its behaviour, could reasonably be held accountable where that behaviour differs from specification and results in a LOAC violation, or for that matter, any action injurious to the user[108]. However, if an IM is granted any real degree of autonomy, its interactions with the highly complex, dynamic and unpredictable land operating environment will very likely lead to actions unforeseen by the manufacturer.

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[107] Nuremberg Trial Proceedings Vol. 1, Charter of the International Military Tribunal, 8.8.1945, Article 8.
[108] A. Kuflik, *Computers in Control: Rational transfer of authority or irresponsible abdication of autonomy,* in Ethics and Information Technology, Volume 1, Number 3, 1999, p.175.

There are several possible outcomes to this dilemma of responsibility. Where the manufacturer cannot guarantee the performance of an autonomous IM that they produce, they will be compelled to either waive all responsibility for its actions as a contractual term of use, or reduce the autonomy to a point where the probability of malfunction is an acceptable risk. Any military belonging to a liberal democracy would be unlikely to accept all of the risk of autonomous IM malfunction from the manufacturer. Even with stipulated specifications for use, such a typically risk averse military would find the notion of taking responsibility for the actions of autonomous AI difficult to accept. An analogy of this situation can be found with the recent self-imposed ban on cluster munitions by a large number of liberal democratic nations, having found they did not perform to the specified level of performance stipulated by manufacturers, and in failure represented an unacceptable and persistent risk to civilian life[109]. For the adoption of IMs by a liberal democratic nation's military, it would seem either autonomy would need to be reduced, or their use would have to be restricted to environments in which the likelihood and cost of malfunction are minimal (for example, fighting a conventional war in a simple flat desert with little civilian population, ala Operation Desert Storm). Thus, either effectiveness, or utility of the IM would be reduced, reducing their attractiveness for procurement in both cases.

An alternative novel solution to this problem of responsibility can be found in the US employment of Private Military Contractors (PMCs), such as Blackwater, in the occupation of Iraq. These contractors have frequently

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[109] BBC: *Cluster bomb ban treaty approved* http://news.bbc.co.uk/2/hi/europe/7423714.stm, accessed 23.10.08.

applied lethal force, acted outside the chain of command of the US military, and have been subject to neither the laws of Iraq, due to a legal arrangement with the Coalition Provisional Authority, or US law for actions committed in Iraq[110]. In spite of several significant incidents where Iraqi civilians were wrongfully killed by Blackwater personnel, neither Blackwater nor the US military has been legally held to account[111]. A PMC offering the contracted services of autonomous and lethal IMs would not represent such a dissimilar situation. In fact, an early precedent for this may be found with Boeing's contracting of a complete UAV service to the Australian military in Afghanistan, providing the ScanEagle tactical UAV with civilian crew and infrastructure[112]. This approach may offer liberal democracies a kind of 'escape clause' in their obligations to LOAC when utilising autonomous IMs.

Of course, there are nations in the world who are not so liberal or democratic, and do not subscribe to LOAC, but either have or will gain in the near future the industrial and technological capacity to begin development of autonomous machines. Furthermore, such nations are likely to be less engaged in or concerned with efforts to uphold the status quo of the global system that typify ongoing military operations by the information age liberal democracies, such as counter-terrorism, counter-insurgency, peace enforcement and the like.

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[110] Subsequent to writing this, 5 Blackwater personnel involved in said incident have been brought before US courts and charged with manslaughter, and the US State Department has determined not to renew Backwater's security contract in Iraq. Nonetheless, if IMs can exercise sufficient restraint to avoid a similar incident occurring (in which Blackwater has set a very poor benchmark), there is no reason why their contract provider could not enjoy the same sort of legal relationship with both occupying power and host nation government.

[111] CNN*: Iraqi leader wants answers for Blackwater 'massacre',* http://www.cnn.com/2008/WORLD/meast/04/07/iraq.main/index.html, accessed 23.10.08.

[112] Boeing: *Boeing-Insitu ScanEagle UAV Achieves 10,000 Flight Hours in Support of Australian Army Operations,* http://www.boeing.com/news/releases/2008/q1/080211b_nr.html, accessed 23.10.08.

These operations are manpower intensive, and put heavy emphasis on limited and discriminate application of force, provision of law and order, human interaction and operations in complex and urban environments. Such operations will place a high demand on the sophistication of autonomous IMs. A ruthless nation with no aversion to civilian casualties that is determined to undertake less noble military operations, for example, forceful seizure of natural resources, or the subversion, disruption or destruction of an enemy nation state or internal rival group, would find autonomous IMs to be of much greater utility, while demanding much less sophistication in their manufacture. Razing villages to the ground, destroying industrial capacity, taking control of an oil field or reducing an adversary's military forces through brute violence present much less technically difficult tasks (from an autonomous IM perspective) than developing friendly discourse with village elders, or engaging in fire fights amongst apartment buildings with highly restrictive rules of engagement. An analogy for this unscrupulous use of a recent military technology can be found in Iraq's use of modern chemical agents such as VX against civilians while under the rule of Saddam Hussein; internally against the Kurdish minority, and during the Iran Iraq war against Iranian ground forces.[113] Similarly, large multinational corporations (MNCs), unbridled by LOAC and driven only by profit, may find use for autonomous IMs in order to secure their holdings within volatile nations. Autonomous IMs guarding autonomous drilling platforms may provide large oil companies with an answer to situations of lawlessness and poor security that are currently

[113]US Department of State: *Saddam's Chemical Weapons Campaign: Halabja, March 16, 1988,*
http://www.state.gov/r/pa/ei/rls/18714.htm, accessed 03.11.08

plaguing the industry in Nigeria[114]. However, despite their projected rise in wealth and power[115], it is doubtful that MNCs will have the capacity to match the defence budgets of large nation states and develop militarised autonomous IMs purely to satisfy their own needs, and so they would provide demand to any emergent market rather than supplying themselves internally.

The last point draws attention to the potential second order effects of IM adoption, which may either promote or obstruct the adoption of autonomous IMs. The first of these is that if a ruthless nation state begins production of autonomous IMs, then this may create the political problem of a "robot gap" for militaries of liberal democracies, harking back to the bomber and missile gaps of the strategic arms race early in the Cold War.[116] Assuming it would be politically unacceptable for Western militaries to send human soldiers to die fighting against autonomous machines when their technological and industrial capacity could produce those very same machines, and to a much better standard, then any move by one state to produce autonomous IMs would quickly be followed by its competitors. A comparison of this situation can once again be seen with the use of poison gas on the Western Front in the First World War. While the Entente powers at first declined to develop and employ this technology on moral grounds, as soon as it was used against them by Germany they did so with a vengeance. Thus, a serious move by a ruthless state to pursue autonomous IM technology could potentially side-step any

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[114] Reuters: *Nigerian militants launch new attacks in "oil war",* http://www.reuters.com/article/homepageCrisis/idUSLF652982._CH_.2400, accessed 31.10.08.

[115] Volker Bornschier, Christopher K. Chase-Dunn, *The Future of Global Conflict,* SAGE, 1999, p.168.

[116] The Cold War Museum: *The Bomber Gap,* http://www.coldwar.org/articles/50s/bomber_gap.asp, accessed 03.11.08.

moral or ethical obstacles impeding liberal democracies in pursuing this technology.

Another second order effect could result from the potential for near casualty-free warfare (at least on the side employing IMs), if IMs reached a sufficient level of capability. If this possibility were to eventuate, then the cost of engaging in warfare would be largely financial, with a diminished political risk. Under such conditions, warfare could become profligate; an objectionable situation to many citizens of liberal democracies that would have potentially harmful political consequences precluding the introduction of IMs. Such a situation would also be potentially destabilising, granting IM-equipped states too much of a strategic advantage over their rivals, similar to objections against 'first strike' weapon and ballistic missile defence systems that could threaten another state's nuclear deterrent capability[117]. These technologies were subject to limiting treaties and conventions during the Cold war in order to preserve stability[118]. Although the United States has since pushed on with missile defence technology in response to nuclear proliferation by rogue states,[119] this has adversely impacted US relations with Russia. If IMs are regarded as potentially destabilising in a similar way, then international pressure against their adoption may mount in order to maintain the geo-political status quo.

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[117] McGeorge Bundy, George F. Kennan, Robert S. McNamara and Gerard C. Smith, *Nuclear Weapons and the Atlantic Alliance,* in Foreign Affairs, Spring 1982.

[118] US Department of Defence, *Memorandum of Understanding Relating to the Treaty between the United States of America and the Union of Soviet Socialist Republics on the Limitation of Anti-Ballistic Missile Systems on May 26, 1972,* http://www.dod.mil/acq/acic/treaties/abm/ad_mou.htm, accessed 03.11.08.

[119] Missile Defence Agency, http://www.mda.mil/mdalink/html/mdalink.html, accessed 04.02.09.

A final possible second order effect of IM adoption that could obstruct their adoption lies in the need for retaliation. If one nation is invaded by another using IMs, the defending nation will lack the ability to inflict human casualties on the aggressor, as there will be none present to attack. An important strategy for nations attempting to repel more powerful or technologically advanced invaders has previously involved the slow but continuous infliction of casualties upon the invading nation's force in order to sap their national will. This strategy has been utilised in conflicts including the Vietnam War, the Soviet-Afghan War, and the present occupation of Iraq, and in the former two instances, resulted in the defeat of superpowers by third world nations[120,121]. Without recourse to this strategy, the defending nation will be forced to find another way to attack the aggressor's national will, and this could involve attacking that nation's civilian population by means such as massive terrorist attack. Thus a nation's motive for adopting IMs, to remove its soldiers from harm's way, could prospectively expose their domestic civilian population to attack.

A final, more prosaic possible social obstacle to the adoption of IMs is the resultant unemployment of those they are replacing. Resentment at losing one's job to a machine is not a new phenomenon, and can be traced back to

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[120] *The U.S. Army in Vietnam*, http://www.ibiblio.org/pub/academic/history/marshall/military/vietnam/short.history/chap_28.txt, accessed 04.02.09.

[121] Lester W. Grau, *The Soviet-Afghan War: A Superpower Mired in the Mountains*, http://leav-www.army.mil/fmso/documents/miredinmount.htm, accessed 04.02.09.

the Luddites[122] of the Industrial Revolution. However, in the past, job's replaced by machine have largely been those that are simple, dull and repetitive, offering nothing more than an income, and so this opposition been relatively limited. The military profession however, is held by parts of society in great esteem. Ideas of family tradition, national heritage, unit history, and duty or service to country elevate the place of the soldier in society in many nations, while the US Navy's recruitment slogan: 'It's not just a job, it's an adventure', suggests would-be soldiers stand to lose more than just an income if their role is taken over by an IM[123]. Old soldiers, serving soldiers, and those wanting to be soldiers, would no doubt take considerable umbrage at being replaced by machines, and this could add to the impediments facing IM adoption.

An array of obstacles can thus be foreseen to stand in the path of eventual IM adoption in ground combat roles. They include technological milestones that must be achieved, the increasingly complex land operating environment, significant IM specific vulnerabilities that will require shielding, the undoubtedly weighty cost of procurement, as well as an assortment of legal, ethical, moral and social objections and technicalities. The extent to which these will influence the adoption of IMs range from limiting their employment in terms of scale and capability, to delaying, to outright preventing their eventuation, but the majority present issues that will be overcome in time, due to the march of technology and changes in attitude. How many of these will be

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[122] Kevin Binfield, *Luddites and Luddism,* http://campus.murraystate.edu/academic/faculty/kevin.binfield/luddites/LudditeHistory.htm, accessed 03.11.08.

[123] Colin Mason, *The 2030 Spike: Countdown to Global Catastrophe,* Earthscan Publications Ltd., London, 2003, p. 181.

resolved by the year 2030 remains to be answered, and will have a major impact on the nature of the IM presence on the battlefield in this timeframe. By balancing these obstacles against the drivers for IM adoption, a clearer path can be charted to revealing the form this IM presence will eventually take come the year 2030.

Time line – IMs and the world, now until 2030

The previous two sections of this chapter considered drivers and obstacles that could negatively or positively impact upon the development and uptake of IM technology in ground combat roles. Many of these drivers and obstacles are variable in their impact with respect to time. Drivers, or benefits promised by IM technology, may not be realised until after a long period of development, while obstacles may eventually be overcome by new technology or fade with time. Thus, while balancing all drivers against all obstacles may provide a coarse measure of the impetus and capability to develop and employ IM technology, a better picture may be gained through weighing these two variables as they exist at a particular time. For example, the benefits of IMs being possessing mobility, agility and speed greater than human soldiers will be irrelevant to this thesis if this capability is not realized before the scope limited year 2030, except to provide motivation for greater investment in research and development efforts once achievability is recognized. Likewise, legal obstructions to military IM autonomy may have been overcome by 2030, and so impact IM technology only through the lag induced as a result of retarding of the uptake process until the time that they were resolved. Therefore, this section of the thesis will consider issues impacting military IM development with respect to time.

In order to predict the shape of military IM employment that will result from interacting drivers and obstacles by the year 2030, one first needs to understand where the technology is today, and how it will evolve from here to the subject year. As the state of IMs in 2030 will be determined through the continuation and interaction of a variety of different trends, considering these simultaneously and relative to time will give a better understanding of their relationships, dependencies, and limitations. Likewise, the plotting of predicted milestones and events will provide metrics to gauge the march of IM technology and use. As this thesis examines not just IM technology, but its application and context, a broad range of trends and events will need to be considered. Therefore, included here are technological, social, warfare and geo-strategic trends, as well as potential shocks, which could influence the advance of military IM technology. Interpretation of these trends, and the context that they provide, can make all the difference between an accurate prediction on the state of IMs, and one that widely misses the mark. An example worthy of inclusion here can be found in *The Automated Battlefield,* a book on the subject of autonomous military machines published in 1986. It reads:

> *The year is 1995. Two industrialized countries are at war. One side decides to invade and occupy the other. Its tanks, in regular columns, approach the no man's land at the border between the two combatants.*
>
> *Suddenly, a swarm of small pilotless aircraft appears above them. The aircraft are not much smaller than the larger of the radio-controlled aircraft you see in toyshops. The tank gunners try to aim their machine guns at the enemy aircraft. But the drones fly fast, in zig-zag patterns and at low altitudes. Hardly any are shot down before they fire their anti-tank warheads. The warheads look like molten chunks of metal, about twelve centimetres across.*

Soon, about half the tanks are knocked out. The warheads fired by the drones easily pierce the armour. They seem to know exactly which parts of the tank are the weakest. They attack the turrets and engine covers with deadly accuracy. The warheads can think for themselves. The remaining tanks regroup and advance cautiously. This time, they use what cover they can. But, without warning, the three tanks at the front of the formation burst into flames. The way is blocked. All the tanks must stop.

Almost immediately three more lead tanks burst into flames. What is killing the tanks so effectively? The crews in the tanks close to those destroyed see several small enemy vehicles coming towards them. The vehicles are unfamiliar. One of them fires two missiles. Another tank bursts into flames. Then another.

The gunners that can see the enemy vehicles fire at them. The tanks' computer controlled guns are very accurate. The enemy vehicles quickly go up in flames. A tank commander sends out a man to look at the vehicles. They are robot-driven. With no humans to protect, the enemy anti-tank vehicles need no armour. They are relatively simple vehicles, except for their computers, which contain the very latest circuitry. They each have six large wheels. With tyres rather than tracks, almost as big as farm-tractor wheels…[124]

By now, a number of inaccuracies have become clear. Firstly, at the year of this scenario, a mere nine years after the point of writing, we now know that the field of

[124] Frank Barnaby, *The Automated Battlefield,* Sidgwick & Jackson, London, 1986, p.41.

AI was not even close to delivering the autonomous ground capabilities the author has described. This is symptomatic of a tendency in the 1970s and 80s for commentators to wildly overestimate the progress of AI and robotics development.[125] Subsequent research and development efforts showed that autonomous ground vehicles presented a much more complex problem than first assumed (as predicted by Alan Turing in 1950, who said of AI "We can only see a short distance ahead, but we can see plenty there that needs to be done."[126]), and that 'computers which contain the very latest circuitry', are but a very small part of this problem, which requires sensor integration, and the mammoth task of engineering software that allows these machines to see, navigate and negotiate terrain, and think. Such over enthusiasm and the subsequent fail to fulfil expectations led to the 'AI Winter' in which AI research funding was severely reduced during the 1980s and 1990s[127]. Furthermore, this scenario was based on a linear continuation of Cold War development, with a focus on state vs. state conventional warfare. While this form of warfare has certainly not left us, as evidenced with the recent Russian invasion of Georgia[128], it is less of a concern today for those nations leading efforts to develop military IMs than the irregular style conflict that absorbs their military endeavours today. Typified in Afghanistan and Iraq, this style of conflict is manpower intensive, with insurgent forces in both theatres employing tactics that would reveal the IM technologies described in the passage above as a technological 'Maginot Line', largely redundant in the new

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[125] Pamela McCorduck, *Machines Who Think (2nd ed.)*, A.K. Peters, Ltd., Natick, Massachusetts, 2004, p. 441.
[126] Alan Turing, *"Computing Machinery and Intelligence",* in Mind, October, 1950, p. 460.
[127] James Hendler, *Avoiding Another AI Winter*, http://csdl2.computer.org/comp/mags/ex/2008/02/mex2008020002.pdf, accessed 04.02.09.
[128] CNN: *15,000 Russian troops in Georgia, U.S. administration officials say,* http://edition.cnn.com/2008/WORLD/europe/08/13/georgia.russia.war/index/html, accessed 13.11.08.

conflict environment. Interestingly however, if the Cold War had continued, and defence spending not been subsequently slashed, then a much better resourced and focused research and development effort may have in fact borne fruit in producing IMs as the author described. Thus, lessons from this invalidated scenario include the cautionary fact that it is easy to overestimate the progression of technology when you cannot imagine and assess the potential obstacles to its development. Also shown here, is the importance of considering a wider sample of factors when predicting the march of technology, as technology is generally developed in response to a need resulting from a specific environmental context. An understanding of the future conflict environment, and the potential impact of any ‘game changing’ shocks in the geo-strategic environment (such as the ending of the Cold War), is therefore essential to predicting the future of military IMs with any degree of accuracy.

Having considered all of the aforementioned influences then, this section will attempt to plot them against a timeline to provide a graphical representation of the path military IM employment may take to the year 2030. The first step in this timeline process will be the establishment of a baseline, or what the situation regarding military IMs is today. This baseline will be split between categories of technology, warfare, and global society.

Start State: 2007/2008

The state of technology pertaining to IMs today then, can be further broken down, into IMs themselves, AI, portable power, communications, and sensor devices. Today (at the year 2007), the total robot population of the planet stands at

World IM Pop: 6.5 Million

around 6.5 million. This includes 1 million industrial robots, predominantly involved in the automotive, electrical/electronics, chemical, food and beverages, metal products and machinery industries, as well as 5.5 million service robots, including those used in defence, rescue and security applications, as well as agriculture, cleaning, construction and demolition, medicine, general purpose roles, and particularly domestic service, entertainment and leisure robots (the largest and fastest growing robotics market with a population of about 3.4 million.[129]There are approximately 5,000 teleoperated ground robots serving the US Army in Iraq today, [130] prominently in the Counter Improvised Explosive Device (CIED) role, but also for urban tactical reconnaissance. This number also includes 3 of Foster-Miller's SWORDS (Special Weapons Observation Remote Direct-Action System)[131]. Armed with a light machine gun or light anti-armour rocket launcher, it is the first ever robot (albeit teleoperated) to carry lethal weapons on operations, representing a significant mile-stone for military IM technology.[132]

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[129] International Federation of Robotics Statistical Department, *World Robotics 2008: Statistics, Market Analysis, Forecasts, Case Studies, and Profitability of Robot Investment,* October 2008, p. xiii.

[130] CNET News: *US military expands robot patrols in combat zones,* http://new.com.com/8301-10784_3-9757072-7.html, accessed 8.23.2007.

[131] Popular mechanics, *America's Robot Army: Are Unmanned Fighters Ready for Combat?, http://www.popularmechanics.om/technology/military-law/4252643.html, 14.10.08.*

[132] Subsequent research has revealed this is not entirely true; the Soviet Army developed a teleoperated light tank in the 1930s known as the Teletank, controlled by radio and equipped with machine guns, a flamethrower and a heavy demolition charge. The Teletank was utilised in the Winter War and Second World War, but details on its effectiveness are scarce, and

At this point there are currently no semi- or fully-autonomous robots (IMs) in service with any nation's ground forces, but efforts in achieving this are ongoing. DARPA's Urban Challenge sees road vehicles, such as a Toyota RAV-4, modified to navigate and drive 100 km autonomously in a race through urban environment complete with other vehicle and pedestrian traffic, to compete for a large cash prize.

DARPA Urban Challenge.

Mobile autonomous IMs exist mainly for research purposes; however there are a number of basic mobile autonomous IM commodities available for various household applications, such as lawnmowers and vacuum cleaners. These are largely for novelty value however, and characterised by poor functionality.[133] They represent a consumer service IM industry in its infancy. IMs with levels of capability equivalent to that of a human are beyond the capacity of the current state of the art.[134]

Basic mobile autonomous domestic IM applications, eg: iRobot Roomba.

Human level of capability beyond present IM state of art.

Portable power supply technology is another area critical to the future of IM development. Over the last few decades,

Proliferation of lightweight portable rechargeable batteries.

lacking a camera, the need for a direct line of sight and absence of an aiming device would surely have limited its utility. Wikipedia: *Teletank*, http://en.wikipedia.org/wiki/Teletank, accessed 12.11.08.

[133] Presentation by Professor Gurvinder Virk, *Climbing and walking robots - our servants of the future,* at Massey University, Wellington, 14.08.08.

[134] NASA: *Robotnaut*, http://robonaut.jsc.nasa.gov/

portable electronic devices, such as cellular phones, portable media devices, laptop computers, handheld GPS systems etc, have pushed the development of rechargeable battery technology in terms of capacity, weight, and size, as manufacturers attempt to make these devices smaller and lighter, while operating longer between charges. As a result, small teleoperated robots, such as iRobot's Packbot, can operate for two hours between charges on small lithium ion batteries[135]. Similarly, burgeoning portable electronic devices have driven a search for alternative high capacity light weight sources of power, such as fuel cells, pico-combustion engines and micro-turbines[136], though these all remain in the developmental stage today. Solar power could provide a means to recharge an IM's power supply in future, but at present this technology would not deliver enough power to run such an application without significant downtime[137], severely impacting effectiveness and tempo. Super-conductivity is another area of ongoing research that may bare significant fruit in future for powering IMs. At present, super conductivity is only achievable at a maximum

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[135] Tom Frost, Christopher Norman, Scott Pratt, Brian Yamauchi, *Derived Performance Metrics and Measurements Compared to Field Experience for the PackBot,* http://www.isd.mel.nist.gov/research_areas/research_engineering/Performance_Metrics/PerMIS_2002_Proceedings/Frost_Norman_Pratt_Yamauchi.pdf, accessed 13.11.08.

[136] The Futre of Things: *Engine on a Chip* http://thefutureofthings.com/articles.php?itemId=49/58/, accessed 13.11.08.

[137] US Department of Energy. *Solar Energy Technologies Program: Solar FAQs,* http://www.eere.energy.gov/solar/cfm/faqs/third_level.cfm/name=Photovoltaics/cat=The%Basics#Q43, accessed 14.11.08.

temperature of 138K[138], but global efforts continue to drive this down to a more useful level.

AI today has reached a stage where it is being integrated into consumer applications, including voice-to-text recognition systems and controlling game opposition on personal computers and facial recognition systems on digital cameras, while applications such as intelligent agents are utilised by many organisations. AI is therefore reaching maturity in a few key specialisations, such as image processing and pattern recognition. The AI state of the art is however well short[139] of the necessary level of capability to operate autonomously in the complex land operating environment in anything more than the most basic roles and tasks, and will require significant continuing development.

AI voice and facial recognition systems available as consumer commodities.

Communications is a particularly important field of technology for IMs regarding command and control. While an autonomous IM operating independently will require less communications connectivity than one that is teleoperated or semi-autonomous, optimum effectiveness will likely result from IMs working in teams or swarms, and so still requiring a degree of communications connectivity. Recent

[138] P. Dai, B.C. Chakoumakos, g.F. Sun, K.W. Wong, Y. Xin and D.F. Lu, *Synthesis and Neutron powder diffraction study of the superconductor* $HgBa_2Ca_2Cu_3O_{8+\partial}$ *by T1 substitution,* http://dx.doi.org?10.1016/0921-4534(94)02461-8, accessed 13.11.08.
[139] Pamela McCorduck, p. 441.

developments in communications technology have been more concerned with how present bearers (high frequency (HF), very high frequency (VHF) and satellite radio communications for example) are used and combined rather than developing new bearers. There is presently an ongoing shift from voice transmission to data transmission for example, allowing more information (by volume and type) in the same bandwidth, and networking the nodes using these media to allow this information to be shared. MANET (Mobile Ad hoc Network) networks are a recent development that enables flexible and mobile networking of multiple nodes on the move. Data transmission and networking have clear implications for IMs which will obviously have little use for voice communications, but need to access and share data; for teleoperation, coordination with other IMs and human soldiers, and C2 and ISR linkage with human (or machine) commanders. At present however, bandwidth, over which voice and data may be sent, is a scarce resource for military forces. While the typical US soldier today has access to hundreds of times what was available during the 1991 Gulf War, there is still not enough available for the deployed US military today, and among other things, this has restricted the flying of Predator UAVs in the Afghanistan theatre to

Mobile Ad Hoc Networking

more than 2 (out of a fleet of 6) at any one time as at 2003.[140] The implications for IM technology are clear.

Wide range of sensors available at low cost.

Sensor technology has developed rapidly in recent years, in terms of cost reduction, miniaturization and capability. A whole range of sensors, including colour Charge-Coupled Device (CCD), TI, IR and ultrasound to name but a small few, have now become cheap[141] and small enough to be prolific in a range of civilian and military portable applications. Sensors available today are adequate to enable an autonomous IM to function effectively in the land operating environment, and as sensor cost decreases, the per-unit cost of IMs will likewise decrease.

The state of warfare globally today comprises a diverse array of belligerents and conflict natures. Combatants range from camel riding Kalashnikov-toting tribal militiamen through to ultra modern highly trained nation-state armed forces with massive resources and harnessing the latest technology, and all manner of regular and irregular groups and forces in between. Irregular forces today can employ

[140] Wired: *Military Faces Bandwidth Crunch,* http://www.wired.com/techbiz/it/news/2003/01/57420, accessed 14.11.08.
[141] Interview with Associate Professor Donald Bailey, senior lecturer in Institute of Information Science and Technology and image processing specialist at Massey University, conducted 13.07.07.

cutting-edge missile systems[142] and information age communication networks, while many state militaries are poorly trained, equipped with Cold War cast-offs and chronically under-resourced[143]. Furthermore, it is typical to find any combination of these belligerents, in alliance or opposing one another, and thrown into this mix may be private military contractors, organised crime syndicates, terrorist organisations, pirates and a whole array of other groups inhabiting the zone of conflict, all pursuing their aims through the application of violent force as well as non-violent means. Modern state militaries frequently deploy light, mobile and professional armed forces globally to preserve stability, the status quo, or the integrity of the global system that the developed world depends upon, against a bewildering array of irregular opponents fighting for an endless range of different causes.

Today's conflicts are driven not only by territorial disputes or competition for resources, but also clashes of culture, ideology or ethnicity, with the allegiance of populations the most commonly contested prize. Consequently, contemporary conflict takes place in close proximity to civilian populations, whether in the centre or outlying slums

[142] BBC: *Hezbollah missile threat assessed,* http://news.bbc.co.uk/2/hi/middle_east/5242566.stm, 18.11.08.
[143] Donald Macintyre, *Kim's War Machine; With obsolete tanks, scarce ammo and scant fuel, the Dear Leader's army desperately needs nukes,* GlobalSecurity.com, http://www.globalsecurity.org/org/news/2003/030224-korea01.htm, accessed 04.02.09.

of modern mega-cities or small villages in remote mountains, and belligerents will concurrently use either violent force and intimidation or charity and development to coerce or persuade the population to serve their will. It is also common for conflict to occur internally within a state's borders against domestic armed resistance, or for such conflict to subsequently spill across borders into neighbouring states, but conflict is generally localised to a specific geographic area, albeit with global links. While conventional warfare between sovereign armed forces of competing states is less common, it does still occur. These instances of conventional conflict generally last only a matter of days; a testament to the lethality and fast pace of modern warfare, while irregular conflict may persist for decades. A model example of contemporary warfare can be found in the recent clash between Georgia and Russia: years of low-level internal conflict and organized crime in the break away Georgian region of South Ossetia involving paramilitary and irregular forces backed by both sides as well as conventional "peacekeeping forces", flaring into an interstate conventional conflict between Russian and Georgian military elements utilising modern armour and strike aircraft, with hostilities freezing after a number of days.[144] Contemporary warfare can therefore be described

[144] Jim Nichol, CRS Report for Congress – *Russia-Georgia Conflict in South Ossetia: Context*

as a highly complex eco-system comprising a broad range of regular and irregular combatants with modern, legacy, or plain improvised equipment, using violent force as well as non-violent means, to serve many divergent interests, generally in close proximity to civilian populations.

Global society represents a broad but particularly important category influencing the development and uptake of IM technology, and encompasses social, environmental, and economic issues. Global society will provide the context for warfare in 2030, which in turn will provide the context for battlefield IMs. Today, global society can be crudely divided into two zones; the developed North, and under-developed South, or more simply, 'the haves' and the 'have nots'. The sum total population of both regions today is 6.7 billion.[145] Conflict is by far more prolific in the South, and therefore the context for warfare today is largely one of impoverished but large populations, frail infrastructure and local economies, weak or failing governments and law and order, with a plethora of armed groups resulting. The United States of America remains the world's only superpower, though its capacity to influence world affairs is somewhat restricted due to major commitments in Afghanistan and Iraq. The global economy is currently

World population 6.7 billion.

Global recession emerging.

US sole world superpower, constrained by Iraq, Afghanistan.

and Implications for US Interests, Congressional Research Service, 2008, p. 5.
[145] International Data Base (IDB), http://www.census.gov/ipc/www/idb/worldpopinfo.html, accessed 18.11.08.

entering a recession, which will potentially impact research and development spending on IMs, both for defence and civilian applications. Oil prices today are highly volatile and climbing (by trend rather than looking to toady's oil price slump)[146], as the continuing development of previously less developed states, particularly India and China, fuels demand for resources, while supply struggles to grow in response[147]. Likewise, metal and mineral prices are also volatile and climbing. Food production is struggling to satisfy global demand, with consequent instances of instability.[148] Meanwhile, climate change has been identified as a problem of serious global significance, with potentially disastrous consequences such as rising sea levels, and more extreme weather including storms and droughts. If they do occur, these phenomena will have a serious disruptive impact on global stability and prosperity, while present efforts to slow or reverse global warming through the reduction of humanity's 'carbon footprint' have revealed themselves to be massively expensive, with potential to impact economic growth and reduce other government spending.[149]

Volatile oil and mineral prices resulting from demand of developing world.

Food scarcity.

Global recognition of threat of climate change.

[146] Toni Johnson, Council on Foreign Relations: *Oil Market Volatility,* http://www.cfr.org/publication/15017/, accessed 18.11.08.
[147] Livemint: The Wallstreet Journal Online: *Commodity price rise to continue on India, China demand: study,* http://www.livemint.com/2008/05/07143607/Commodity-price-rise-to-contin.html, accessed 18.11.08.
[148] International Herald Times: Farmers struggle to keep up with world food demand http://www.iht.com/articles/2008/03/09/business/crop.php, accessed 18.11.08.
[149] International Association for Energy Econmoics: *The Costs of the Kyoto Protocol*,

Society, particularly in the prosperous and developed North, is today increasingly capable of adapting to new technology. The rapid development and proliferation of consumer electronic and information technology devices over the last thirty years, and resultant mass-connectivity leading into the information age, have proven a high degree of technological adaptability within society, and provided a measure of inoculation to the introduction of new technology in the home and workplace. The population of the affluent North remains largely casualty averse despite ongoing losses to wars in Iraq and Afghanistan, and is accustomed to a comfortable and increasingly sedentary lifestyle[150].

Population of North casualty averse, accustomed to comfortable and increasingly sedentary lifestyle.

The present state of the world offers both opportunities and challenges for IM technology then. While the nature of warfare today presents a complex challenge beyond the capabilities of today's IM technology, casualty aversion and technological familiarity combined with sedentary tendencies point to a society ready to embrace IM technology. The present state of recession may restrict spending on research and development in the meantime,

http://www.iaee.org/en/publications/kyoto.aspx, accessed 18.11.08.

[150] San Diego Community Health Improvement Partners, *Poor Nutrition and Sedentary Lifestyle: The 21 Century Plague*, http://www.sdchip.org/pdfs/G-nutrition%20edited.pdf, p.34, accessed 26.11.08.

while concerning trends in resource scarcity and climate change have emerged.

From this point, projected key events and milestones resulting from trends which will impact the march of military IM technology will be detailed.

2015: 2015 is a year of particular significance for military IMs, as it is the year by which the US Department of Defence has mandated that one third of all military ground vehicles must be unmanned.[151] The move is primarily intended to save costs, by reducing manpower requirements, and this predicates a move away from simple teleoperation. The bulk of these unmanned vehicles will be utilised in the Combat Service Support (CSS) role, for materiel transport. This means they will generally travel in convoy, and so be able to make use of 'robot following'[152] technology, where many unmanned vehicles can autonomously follow a manned or teleoperated vehicle, or a walking soldier.

2015
1/3 US military ground vehicles unmanned.

[151] The National Defence Authorization Act for Fiscal Year 2001, Public Law 106-398, Congress mandated in Section 220 that "It shall be a goal of the Armed Forces to achieve the fielding of unmanned, remotely controlled technology such that… by 2015, one-third of the operational ground combat vehicles are unmanned."
[152] University of California, Davis, *Robots Learn to Follow*, http://www.news.ucdavis.edu/search/news_detail.lasso?id=8770, accessed 26.11.08.

2015 is also the year that the first Future Combat Systems (FCS) Brigade Combat Team, equipped with the complete FCS systems suite, will be stood up.[153] FCS is the US Army's ambitious modernisation program, and includes several semi-autonomous platforms to support air assault and dismounted operations. These include the XM1219 ARV-Assault-Light (ARV-A-L) MULE Vehicle and the XM1217 Transport MULE Vehicle (MULE-T). The first will be armed with Javelin anti-armour missiles and a medium machine gun (firing these weapons is expected to require a 'man-in-the-loop'), while the second will carry approximately one ton of dismounted soldier's equipment in complex terrain. These two developments will see widespread familiarization and socialization of US military personnel with semi-autonomous IMs, as well as the development of a significant IM industrial capacity and body of knowledge, smoothing the way for deeper integration of IMs into the US military.

First FCS Brigade Combat Team stood up, including semi-autonomous platforms.

By 2015 it has been predicted that the first physical neural interface between a computer and a human brain (or Brain Computer Interface – BCI) will be demonstrated.[154] This technology is already functional at a basic level. In 1999 for

First fully functional BCI demonstrated.

[153] US Army Future Combat Systems: *Program Overview,* https://www.fcs.army.mil/program/images/timeline-large.jpg, accessed 19.11.08.
[154] Stanford University - *Delta Scan: The Future of Science and Technology, 2005-2055,* http://humanitieslab.stanfordd.edu/2/290, accessed 19.11.08.

example, scientists were able to record the vision of a cat in real time, by inserting electrodes into its brain that read neural activity and decoding this with computers.[155] Current medical applications such as cochlear implants and vision BCI have been successful in restoring hearing to the deaf and rudimentary vision to the acquired blind[156], but most achievements to date have focused brain output (reading the brain) rather than input (controlling the brain). This technology will undoubtedly have a massive impact in the field of IMs. Ironically, it is foreseeable that BCI technology could slow progress in autonomous IM development. Such an interface would greatly streamline the teleoperation process, removing the necessity to use hands on a keyboard, joystick or other controller and so increasing the teleoperator's span of control, while BCI telepresence could feasibly put the human operator 'inside' the IM, providing a very high degree of awareness, accuracy and rapid reaction . Thus teleoperated IMs would gain capability as a result of BCI technology, while requiring fewer teleoperators per IM, removing two pressures for greater IM autonomy.

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155 G.B. Stanley, F.F. Li, and Y. Dan, *Reconstruction of natural scenes from ensemble responses in the LGN,* http://people.deas.harvard.edu/~gstanley/publications/stanley_dan_1999.pdf, accessed 19.11.08.

156 Wired - *Vision quest, http://www.wired.com/wired/10.09/vision.html,* accessed 19.11.08.

Gordon Johnson, leader of US Joint Forces Command's Project Alpha Unmanned Effects Team, has predicted that by 2015, semi-autonomous IMs will be capable of doing many infantry missions.[157] Depending on the predominant nature of warfare at that point in time, the proportion of IMs on the battlefield could increase: if the role if infantry becomes more simple (less concerned with human interaction and more involving offensive and defensive tactical tasks) the IM proportion will grow as they are able to take over the roles of more human soldiers. However, the conflict environment is projected to grow increasingly complex for at least the next fifteen years or so[158], stretching the role of infantry beyond the reach of semi-autonomous IMs.

Semi-autonomous IMs capable of doing many infantry missions.

2015 is also the year by which Japan's government has predicted that there will be a robot in every home.[159] This is largely predicated by Japan's impending demographics crisis, which will create a significant burden of care for the aged, as well as a shrunken labour force. IMs provide potential solutions to both of these problems, and will likely

Japanese Government: A robot in every home.

[157] Tim Weiner, *New Model Army Soldier Rolls Closer to Battle,* The New York Times, 16.02.05.
[158] *New Zealand Army Future Land Operating Concept: Precision Manoeuvre 2020,* New Zealand Army, 2007, p. 1-6.
[159] Marketplace: *Japan's Vision: A robot in every home,* http://marketplace.publicradio.org/shows/2007/06/28/AM200706283.html?refid=0, accessed 07.04.07.

drive both public and private investment in IM research and development as a result.

Peak oil?

Peak Oil, or the point in time where global production of oil reaches a point from which it will only descend, has been predicted over a wide range of timeframes; some claiming it has already occurred[160], and others see it happening some time after 2025[161], but the majority of estimates fall somewhere between 2010 and 2020.[162] Meanwhile, global demand for oil is predicted to continue rising, particularly as massively populous developing nations such as India and China's thirst for oil grows on the back of industrial growth and expanding middle classes. The unavoidable consequences of this situation are rapidly increasing and volatile fuel prices, while the shift to alternative fuel sources is predicted to be extremely disruptive, expensive, and protracted. Likely second order effects are stunted economic growth, diminished food production, and possibly, armed conflict over those oil supplies that remain. Peak oil has a number of implications for military IM technology. Firstly, as IMs are likely to be energy hungry, and as oil-derived fuels are presently the cheapest, most

[160] A.M.S. Bakhtiari, *World Oil Production Capacity Model suggests Output Peak by 2006-07,* in Oil and Gas Journal, April, 2004.
[161] G. Davis, *Meeting Future Energy Needs,* in The Bridge, National Academy Press, Summer 2003.
[162] Robert L. Hirsch, *The Inevitable Peaking of World Oil Production,* in The Atlantic Council of the United States – Bulletin, October 2005, vol. XVI, no. 3, p.9.

convenient, portable and energy dense sources of power for IMs, this may lead to demand for more energy efficient IMs and potentially drive preferences towards lighter, smaller IMs. Secondly, the potential shock effect of peak oil could damage economies sufficiently to emasculate defence budgets in the developed world, and dramatically reduce military investment in IM technology. However, the turmoil and competition that would result from such a situation could actually drive up defence budgets, as the world becomes less stable, and accelerate military IM development.

By the year 2017, the cost of replicating the smallpox virus is projected to be as little as USD $12,000. This is a function of Carson's curve[163]; the biotechnology equivalent of Moore's law, which sees the cost of genetic base pairs that provide the building blocks for a synthetic virus decrease continuously. This cost also includes the predicted expense of sufficient lab equipment that is presently widely available second hand, and uncontrolled. Furthermore, the smallpox genome has been published online and is widely available today. The potential for irregular belligerents such as terrorist groups to take advantage of this opportunity is enormous, and would

[163] T.X Hammes, *Fourth Generation Warfare Evolves, Fifth Emerges*, in Military Review, May-June 2007, p.22.

create a global shock of enormous and catastrophic proportions, which could conceivably disrupt global society in such as way as to retard or even freeze general technological advancement for a long period, thus hindering IM development. Therefore, unless global efforts are made in the near future to control or mitigate the potential impact of the threat of bioterrorism, a successful attack could significantly alter the trajectory of IM technology.

2020
South Korea:
A robot in
every home.

By 2020, the government of South Korea has also predicted its citizens will have a robot in every home.[164] South Korean society has in recent years existed at the bleeding edge of consumer technology, particularly information technology, with rapid uptake of the latest applications.[165] The technological agility and adaptability of this society could see it well placed to embrace and develop IM technology, while its defence sector has already shown a willingness to pursue it with the deployment of unmanned weapon systems to the North Korean border.[166]

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[164] National Geographic: *A Robot in Every Home by 2020, South Korea Says,* http://news.nationalgeographic.com/news/2006/09/060906-robots.html, accessed 07.04.07.

[165] San Francisco Chronicle, The future is South Korea: Tech firms try out latest in world's most wired society, http://www.sfgate.com/cgi-bin/article.cgi?f=/c/a/2005/03/13/BUGBOBH83B65.DTL, accessed 26.11.08.

[166] Defence News: *Seoul Halts Unmanned Border Guard Project*, http://www.defensenews.com/story.php?i=3519037, accessed 26.11.08.

By 2020, one in four Japanese will be over 65 years old.[167] This will be the manifestation of Japan's present low rate of birth, which will create a top heavy population leading to the problems of care and labour shortage mentioned above. In traditionally immigration-averse Japan, IMs may provide the only solution.

1 in 4 Japanese over 65 years old.

By the year 2020, the UN has projected the world population to reach 7.7 billion, with the majority of this growth occurring in the under-developed or developing South.[168] With resources already becoming scarce, conflict over access or control to minerals, fossil fuels, food and fresh water will become increasingly likely.

World population 7.7 billion.

The Japanese Robot Association has estimated that the global personal robot industry worth USD $50 billion per year[169] by 2025. If such profits are realized, the civilian market should be more than capable of nurturing IM research and development beyond the efforts of defence

2025
Japanese Robot Association: global personal robot industry worth USD $50 billion per year.

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[167] Chikako Usui, *Japan's Aging Dilemma?,* p. 16, in Asia Program Special Report # 107 – *The Demographic Dilemma: Japan's Aging Society,* Woodrow Wilson International Centre for Scholars, 2003.

[168] UN department of environmental and social affairs - *World population prospects: the 2006 Revision Population database,*http://esa.un.org/unpp/p2k0data.asp, accessed 19.11.08.

[169] Scientific American: *A Robot in Every Home,* http://www.sciam.com/print_version.cfm?articleID=9312A198-E7F2-99DF-31DA639D6C, accessed 07.04.07.

funding, and drive improving IM capability and decreasing production costs as a result.

The UK Ministry of Defence has forecast that by 2025, the UK and her Western security partners may see a re-emergence of state-centric threats.[170] Though these will likely utilise the irregular methods prevalent today, they are also predicted to employ capable and well equipped conventional military forces. The presence of such threats would present a shift from today's current conflict environment, and could potentially trigger regional arms races, which would serve to accelerate the development and procurement of weapon systems such as IMs.

Re-emergence of state-centric threats to Western powers.

Similarly, the recent US National Intelligence Council publication, *Global Trends* 2025*: A Transformed World,* sees a number of states rising to a level of power whereby they will be capable of presenting a military challenge to the United States[171]. Though the publication stops short of predicting that these states will actually surpass the US militarily, its does represent a return to a multipolar world. Depending on the alignment of these states, they may present a significant threat to US interests, not to mention

Reversion to multipolar world.

[170] Development, Concepts and Doctrine Centre, *Future Land Operational Concept,* UK Ministry of Defence, 2008, P. 8
[171] US Office of the Director of National Intelligence, National Intelligence Council, *Global Trends* 2025*: A Transformed World*, 2008, page 28.

competing with one another. Particularly in the case of India and China, the combination of massive reserves of manpower and growing technological advancement will enable their armed forces to present a significant challenge to the US military if it wishes to maintain its supremacy. IMs may offer a means to maintain the qualitative edge that the US military has typically enjoyed in recent times, while also mitigating manpower disparities through the substitution of machine for man.

The Canadian Army has predicted that by the year 2025, autonomous hunter-killer IMs will have been developed.[172] While they do not stipulate the precise nature of these IMs, who will use them, or on what scale, the fact that the armed forces of a Western liberal democracy has acknowledged the likelihood of lethal and autonomous IMs lends the concept legitimacy and impetus.

Canadian Army: autonomous hunter/killer IMs developed.

By 2025, the number of people living in freshwater scarce countries is projected to reach 1.4 billion, more than double that of today.[173] Fresh water is not only essential to sustaining human life, but also for horticulture, agriculture, and manufacture, and is therefore an extremely valuable

1.4 billion people living in freshwater scarce countries.

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[172] Regan Reshke, *JADEX Papers 1 – Brave New Conflicts: Emerging Global Technologies and Trends*, Canadian Army Directorate of Land Concepts and Designs, 2007, p. 31
[173] US Office of the Director of National Intelligence, National Intelligence Council, *Global Trends* 2025*: A Transformed World*, 2008, page viii.

resource. While a lack of this resource may restrict economic and technological advancement where it is scarce, thus slowing the development of IM technology, it will very likely lead to significant competition and conflict within and between nation-states. As with the above mentioned emergence of state-centric threats, this competition and conflict would create an environment conducive to more rapid military IM development and procurement. Furthermore, IMs would be well suited to operations in such fresh-water scarce environments, as they will not likely require water to operate.

2030
Moore's law sees computer processing speed match the human brain.

2030 is the year by which Moore's law dictates we will see computer processor speed match that of the human brain (100 million MIPS (million instructions per second))[174]. This has significant implications for IMs, as if this processing power is matched with software capable of replicating the operation of the human brain, then AI will be on the cusp of surpassing human intelligence in general.

Self-driving cars more reliable than human drivers common on roads.

By 2030 it is predicted that robotic vehicles with driving reliability that will exceed humans by orders of magnitude will be a common sight on roads.[175] This development is

[174] Hans Moravec, *Robot: Mere Machine to Transcendent Mind,* Oxford University Press, New York, 1999, p.63
[175] Times Online, *Days of the idiot behind the wheel are numbered,* http://www.timesonline.co.uk/tol/news/uk/science/article1403715.ece, accessed 29.11.08.

important, as the capabilities required to operate a motor vehicle in an urban environment will be equally applicable to IMs on the battlefield. Furthermore, their widespread use suggests society will have developed a considerable level of trust and acceptance of autonomous IMs in their day to day lives, increasing the likelihood of their utilisation in an autonomous capacity for military roles.

World population 8.3 billion.

UN population forecasts predict that by 2030, the world's population will have reached 8.3 billion.[176] With roughly a fifth more people inhabiting the planet than today, already stressed resources will be stretched to breaking point, further fanning the flames of conflict. In spite of this, the population of the developed world is projected to experience little, or in some cases, negative growth, with the large majority of population growth occurring in undeveloped or developing states. As a result, militaries in the developed world will be struck with the twin dilemma of struggling to recruit adequate numbers while typically operating amongst massive populations in roles that require a high ratio of troops to civilian population (such as the 50:1 ratio deemed ideal for counter-insurgency operations). IMs may offer a means to redress this imbalance.

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[176] UN department of environmental and social affairs - *World population prospects: the 2006 Revision Population database,*http://esa.un.org/unpp/p2k0data.asp, accessed 19.11.08.

Furthermore, of this 8.3 billion, approximately 60% will now live in urban areas, and it is in this environment that much of armed conflict is predicted to take place in future.[177] Urban warfare is typically very manpower intensive,[178]and military operations amongst the massive populations of tomorrow's third world megacities will undoubtedly be so. Military IMs will be well placed to ease the manpower burden of such operations if they are able to overcome the complexities of functioning in urban environments.

60% of world population living in urban areas.

As a function of this population growth, and the fact that populations will demand more food as they come more developed, the World Bank has estimated that demand for food will have increased 50% by 2030. [179] Not only will this demand exacerbate aforementioned inter- and intrastate competition and conflict over scarce resources, but also threaten the stability of states whose governments cannot feed their populations. Increasing global conflict, particularly that which can be forecast, will help to drive the development and procurement of military technology, while as with fresh water, IMs will be well-

50% increase in global food demand.

[177] Stephen J. Mills, *Military Operations in Urban Terrain (MOUT): A Future Perspective for a Joint Environment,* Naval War College, Centre for Advanced Research, Newport, 1997, p.2.
[178] Gary L. Brohawn, Frederick J. DuPont, *MOUT Training and the IPB,* in Infantry Magazine, May-August, 2000, p. 31.
[179] US Office of the Director of National Intelligence, National Intelligence Council, *Global Trends* 2025*: A Transformed World*, 2008, page viii.

suited to operations in food-scarce environments where fresh food will be extremely difficult to procure.

By 2030, 15 US Future Combat Systems Brigade Combat Teams equipped with complete future combat systems[180] are planned to be operational. Built for rapid deployment globally, and equipped with a number of semi-autonomous platforms and systems, these units will continue to provide an excellent test bed for proving military IM technology, as well as socialising it with a large number of military personal. If the FCS program does continue as planned,[181] it will do much to push forward the development and fielding of military IMs onto the future battlefield.

15 FCS Brigade Combat Teams fielded.

This exercise of plotting trends and milestones has then illuminated two important factors regarding the presence of IMs on the battlefield circa 2030: the path that the technology may follow, including the evolving environment that it will respond to; and the potential state of IM related technology and its context for employment. We can see a world that appears to grow ever more unstable, with heightening tensions and increasing competition and conflict. These factors will serve to stimulate military procurement and development, and to shepherd IM technology towards military applications. Greater instances of conflict, particularly at the low level, will provide an arena to test the evolving IM technology in

[180] US Army Future Combat Systems: *Program Overview,* https://www.fcs.army.mil/program/images/timeline-large.jpg, accessed 19.11.08.

[181] Mr Charles Cavanaugh, a Nothrop Grumman technician contracted to the NZ Army for a C2 project professed a theory whereby any defence project with a name containing the word “future” is doomed to failure.

combat, assisting ongoing development and building confidence. The potential for a major and protracted war breaking out between nation states, with one or both employing or developing military IM technology, could lead to a rapid acceleration of IM advancement; whether such a war does break out, or even if the threat of such conflict is clear and present enough to spark an arms race.

The nature of conflict appears set to grow in complexity, and potentially encompass higher intensity warfare as being typical. This warfare will take place increasingly 'amongst the people', who in turn will more and more typically live in urban areas, which will expand massively as a result. Furthermore, as resources come under increasing pressure and the global population burgeons, conflict will more frequently take place in food and freshwater-scarce environments, making sustaining military personnel in theatre extremely difficult. At the same time the urban, human-centric nature of such conflict will be very manpower intensive. This will present an environment well-suited to unmanned technology, but also challenge the intelligence and mobility of IMs with its complexity.

Meanwhile, increasingly sedentary lifestyles and aging populations in the developed world, as well as ongoing development of IM enabling technologies, will fuel an expanding market in IMs for civilian applications. This market, and widespread consumer uptake, will in turn drive the ongoing improvement of IM capability, concurrent with decreasing component costs, and also foster greater familiarity, understanding, and trust of IM technology amongst user populations. Recruitment of military personnel will become more difficult as less of the population base can meet fitness requirements or be motivated into military service.

Technology will continue its march in some capacity at least, regardless of the state of the world, and technologies pertinent to IMs that may reach maturity in this timeframe include AI, room temperature superconductors, alternative power supplies such as micro-turbines and fuel cells, and BCI. Several foreseeable global shocks may significantly impact the pace of technological advancement however, including global pandemics (as a result of bio-terrorism or just natural occurrence), peak oil shock, and global food and freshwater shortages.

Assuming global society is not significantly disrupted by these shocks however, the trends outlined above point towards quite a sophisticated and semi-mature IM presence on the battlefield in 2030. The conflict environment, while highly complex, should not be beyond the capabilities of the state of technology at that time. Furthermore, the likely highly lethal, manpower intensive and yet resource scarce conflict environment facing armed forces that will likely be struggling to maintain personnel levels may be very well suited to IMs. The human-centric nature of anticipated military operations, and the advantages human soldiers can be expected to maintain over IMs in several areas, as well as the lag caused by military institutional conservatism, point towards a battlefield where human soldiers operate in teams with IMs. The ratio of human to IM at this point will likely be skewed in favour of IMs: the benefits presented by human soldiers in these human-IM teams will not be a function of their numbers, beyond those required to carry out the dwindling number of human-centric tasks and executing command and control over humans and IMs.

Chapter Two: Role and Form – Tasks and Shapes of IMs on the Battlefield

The previous chapter of this thesis extrapolated drivers, obstacles, and relevant but external trends and events in order to estimate the likely scale of IM presence on the future battlefield, while establishing a loose operational context in which these IMs may be employed. This next chapter will attempt to identify which battlefield tasks will likely be undertaken by IMs, and subsequently how these IMs may appear.

Which Roles – How IMs May Be Employed on the Future Battlefield

This section of the thesis will seek to identify which roles and tasks on the battlefield may be filled by IMs at the year 2030. It will initially break down typical tasks by Battlefield Operating System (BOS), and then discuss possible new roles and tactics enabled by IM technology, as well as roles that IMs are not viewed as being fit to achieve at the year 2030.

The BOS are the major functions that occur on the battlefield, and include Command, Control and Communications (C3), Manoeuvre, ISR, Information Operations (IO), Offensive Support (OS), Mobility and Survivability, Ground Based Air Defence (GBAD), and Combat Service Support (CSS). According to Australian Army Doctrine, 'each BOS represents the combination of personnel, collective training, major systems, supplies, facilities, and command and managements – organised, supported and employed to perform a designated function as part of the whole.'[182] They provide a useful framework for examining tasks undertaken on the battlefield.

The first of these, C3, involves planning, and the direction and control of forces and operations in the accomplishment of a mission. IMs have potential to assist in two key elements of C3; firstly, they may assist a human commander in making decisions. By the year 2030, IMs should be capable of rapid complex calculations and problem solving, resulting from the powerful

[182] LWD 1, *The Fundamentals of Land Warfare,* Australian Army, 2002, p. 83.

onboard AI necessary to operate autonomously or semi-autonomously in a complex environment. As such, it is foreseeable that IMs may provide a useful assistant to tactical level commanders, in formulating, comparing and optimising plans, and assessing potential enemy courses of action for example. In addition, integrated sensors and communications would provide a wealth of available data to the IM, which it could process and filter into useful and appropriately detailed information. As such, IMs could improve the speed and appropriateness of tactical decision-making. While higher level commanders will most likely have access to dedicated artificially intelligent decision support tools, those at the tactical level, may benefit from having a mobile IM assistant that can provide them with decision support without burdening them with the necessary bulk and weight of hardware, power supply, or communications equipment. This is particularly relevant to dismounted personal such as light infantry, who are already encumbered with heavy loads of equipment. While the dismounted infantry commander could feasibly carry a decision support aid by the year 2030, due to ongoing miniaturization of electronic applications, an IM would add a number of additional advantages to this role. For example, the IM could interact with the supported commander in a more natural manner, potentially employing natural language and reading body language to better understand the commander's intent, while saving them the time and attention-consuming burden of using other interface tools such as keyboards, pointing devices, visual displays etc. The IM could also potentially perceive how busy the commander at a given time, weigh the importance of their task against the urgency of the information it has to present them, and do this at the optimum time with appropriate detail. In this way, the commander could focus their attention on events around them and leading subordinates, rather than be pre-occupied with consulting a decision support tool.

Another potential C3 application for IMs is in providing communications. A swarm of IMs could conceivably transmit, receive and rebroadcast communications; a task presently residing with human Signallers who are both scarce and difficult to train. Presently, enabling communications for significant volumes of data across a broad area of operations (AO) requires signallers to set up their rebroadcast equipment in far flung areas that maximise line of sight between nodes while providing optimal service, but as a consequence may be vulnerable and far from help. Furthermore, their activities will by their very nature create a large tell-tale signature, telegraphing their location to enemy forces that possess the capability to monitor and locate EM emissions. The number of adversaries in future will only grow as the technology becomes cheaper and more broadly accessible[183] in future. This places the intrepid rebroadcast detachment at considerable risk, from local hostiles who may note the presence of large antennas or a group of uniformed foreigners, or from a barrage of high explosives delivered to their location through the triangulation of their emissions.

A swarm of IMs in this role potentially gains several advantages over their human equivalents. Firstly, IMs are expendable. If IMs in the communications

[183] *Equipment Review for transmitter hunting and radio direction finding*, http://www.aeinet.com/kd6dx/thunt/equipment/, accessed 12.01.09.

role destroyed, the end result will be restricted to the loss of some moderately expensive yet replaceable hardware, and a reduction in the redundancy of the communications network. IMs also require no food or water, and so would be free of the need and associated risk of compromise arising from regular resupply by land or air. Sitting passively and motionlessly, their only energy expenditure would result from monitoring, receiving and transmitting when necessary, and countering enemy action when required; as such these IMs could exist in place with a much lower detection threshold for significant periods of time. Furthermore, swarms of IMs could perform this role autonomously and cooperatively, providing a communications network that could dispose itself for optimal service and minimal signature, reposition with the formation it is supporting, and automatically fill its own gaps when damaged through enemy action.[184] In fact, with sufficient onboard communications equipment and communications architecture (such as a MANET[185]), IMs in combat roles could perform the rebroadcast function as a corollary, automatically passing communications traffic amongst themselves around the battlefield while going about the business of their core tasks.[186]

Manoeuvre represents the core business of military ground forces: combining firepower, mobility and protection to enable close combat at a decisive point in order to exert direct and persistent influence over an environment. Manoeuvre

[184] Marcus Fielding, *Robotics in Future Land Warfare,* in Australian Army Journal, vol. 3, no. 2, Winter 2006, p.102.
[185] Tony Loyal, *MANET: The Future of Military Communications?* in Intercom: Journal of the (US) Air Force C4ISR Community, November 2004, p. 30.
[186] Alon Ben-David, *Israel Prepares to Deploy UGVs,* in Jane's Defence Weekly, vol. 45, issue 10, 5 March, 2008, p. 18.

elements include infantry, armour (tanks), and various supporting but integral components such as protected mobility (Armoured Personnel Carriers and Infantry Fighting Vehicles (APCs and IFVs) for example) or specialist anti-armour vehicles. In the manoeuvre role, IMs will most likely be used as 'force multipliers' to augment human manoeuvre elements. The application of combat power at the decisive point will be likely be the last hold-out of human-centricity (after command), as it will require flexible judgement in very uncertain conditions, with changing circumstances demanding on-the-spot intuition based decisions to support the achievement of a main effort. While IMs may in fact be perfectly technically capable of assuming these human decision-making roles by 2030, the importance of carefully controlling this application of force at the decisive point will in all likelihood see the task be retained as the domain of human soldiers operating in close proximity to their objectives.

Thus, while human leaders and human soldier/IM teams carry out whatever mission or task is to be accomplished, IMs would be employed to make their job safer and easier. IMs could provide fire support from any number of available weapon systems (including those used by human soldiers or any other able to be carried), suppressing or reducing enemy positions, or destroying key enemy weapon systems for example. IMs would also likely lead any assault; a kind of 'robot point-man', they would take the initial risk of exposure to enemy action, in order to identify and engage any enemy presence detectable by its sensors, or simply by drawing fire to compromise the firer. IMs would also be useful in providing a screen or guard for flank protection or early warning, preventing enemy forces from surprising the unit or disrupting their efforts. A key point here will be the criteria by which these IMs are allowed to employ their weapon systems; whether against any target that fits their pre-programmed rules of engagement (ROE), a specified target set that they are able to recognise through their sensors and onboard intelligence, targets designated by human personnel, or whether every IM weapon release must be endorsed by a human teleoperator who sees what the IM sees. Whichever criteria are applied will have a significant impact on the effectiveness and utility of IMs in manoeuvre roles, but this issue will be covered in a later chapter of the thesis.

The Intelligence, Surveillance and Reconnaissance (ISR) BOS involves the production of intelligence for the planning and conduct of operations, including enemy capabilities and intentions, and the physical and human environment.[187] IMs have an important role to play here, and this will likely be one of their first ventures on the battlefield. ISR assets are traditionally a scarce and valuable resource, to be protected and husbanded, used sparingly and seldom risked. IMs may change this approach, as the ability to mass produce them means they may be prolific, saturating the battlefield with sensors and providing virtual omniscience over the battlefield. As well as being more numerous than their human counterparts, IMs will potentially be stealthier, with variants much smaller than dismounted soldiers. They will be

[187] LWD 1, p. 85.

able to remain in place for as long as their power supply can sustain them, constantly watching but never moving, and will be vastly more expendable. This will change the calculus of cost vs. benefit, allowing IM ISR assets to be risked for less critical information and resulting in a greater volume of information collected. This increased volume of information may impose another task upon these ISR IMs, in that this information will potentially swamp both commanders' cognitive abilities, and available communications capacity. As a result, these ISR IMs will likely need to process swathes of information gathered into a more concise and usable product (intelligence as opposed to information), and transmit this processed information in a way that minimises traffic and overloading of the commander. Taking this concept further, ISR IMs could be networked and share their observations, to realign for better coverage of items of interest and to provide a greater level of fidelity, and then process this combined information before providing it to a higher echelon.

The Information Operations (IO) BOS is a broad grouping of capabilities designed to affect adversary decision-making and information flows, while protecting one's own. It encompasses electronic warfare (EW), cyber-warfare, psychological operations, deception, counter-intelligence, civil affairs, public information, as well as physical action against enemy C3 elements and infrastructure. While aspects of IO are human-centric and thus do not lend them selves to IM application, there are still several conceivable roles for IMs within this BOS. IMs would be well suited for executing a deception plan, for example with a large swarm of simple and cheap IMs masquerading as a more capable formation in physical appearance and EM emission, to lead enemy commanders astray. IMs could roam freely behind enemy lines, attacking enemy C3 infrastructure by autonomously homing in on radio emissions and destroying antennas and equipment through electronic or physical attack, or even hunt down and assassinate key headquarters personnel.[188] In the psychological operations role, IMs could reach populations in ‘no man’s land’ areas too dangerous to send human personnel, to broadcast propaganda messages to civilian population or even erect posters. Autonomous systems will undoubtedly have a role to play in computer network attack and defence, however such systems fall outside the remit of this thesis.

Offensive Support (OS) is the collective and coordinated use of indirect fire weapons, armed aircraft, and other lethal and non-lethal means in support of a ground or air manoeuvre plan.[189] Aircraft are beyond the scope of this thesis, but indirect fire systems such as artillery, mortars and rockets are all weapon systems to which IM technology may be applied in future. The FCS Non Line-of-Sight Cannon (NLoS-C) which is presently undergoing testing, is a self-propelled artillery piece in which automation has replaced all but two of the crew, a driver and weapon system operator (who only has to push two buttons to execute a fire mission), thus already assigning the majority of work required to deliver ordnance to target to a machine. Additionally, the gun may

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[188] Marcus Fielding, *Robotics in Future Land Warfare,* p.102.
[189] LWD-1, p. 84.

be fired by remote control.[190] With probable future IM capabilities, it would be quite simple to automate these remaining two positions: a delivery system need only fire at a designated coordinate with specified ammunition nature at a target identified by a friendly forward observer. Assuming the call for fire comes from an authorized human soldier, there should be little objection to such a situation, and therefore indirect fire delivery platforms are good candidates for automation. Networked autonomous delivery platforms could also conceivably coordinate their actions for maximum effect on target and the best use of resources between targets, enabling a more responsive, efficient and flexible OS system than exists today.

The Mobility and Survivability BOS is concerned with enhancing friendly freedom of manoeuvre while denying it to the enemy, as well as protecting friendly forces from the effects of enemy action and environmental hazards. It includes such tasks as laying and clearing mines and explosive devices, erecting and reducing obstacles and fortifications. This BOS has actually already seen significant uptake of unmanned systems. It was one of the first to employ unmanned ground vehicles, with the German Army using tracked demolition mines in the Second World War, and continuous development and ever increasing deployment of bomb disposal robots since their first appearance in the 1970s. The technical and frequently dangerous nature of many of the tasks carried out by this BOS lends themselves to unmanned systems. Adding autonomy to these unmanned systems would greatly

[190] Robert Pengelley, *NLOS-C prototype takes first steps on road to service with the US Army's FCS*, in Jane's International Defence Review, vol. 41, November 2008, p.57.

improve their efficiency, allowing them to be employed in large numbers to go about their business continuously without need for human interference. In dangerous or hostile conditions, IMs in the Mobility and Survivability BOS could also be employed to clear routes for manoeuvre units, transport and deploy bridges, and even assist infantry in breaching buildings, whether using explosives or powerful pneumatic tools. The large absence of direct lethality required of IMs means that their uptake will be early in this BOS compared to others, required technical capability being the only major obstacle in their path to deployment.

The Ground Based Air Defence (GBAD) BOS 'comprises all weapon systems, processes, procedures and personnel designed to nullify or reduce the effectiveness of attack by aerial platforms and munitions after they are airborne.'[191] It includes acquisition systems such as radar, engagement systems such as surface to air missiles (SAMs), and also the use of non-dedicated weapons against aerial targets. Where the Mobility and Survivability BOS leads in employment of unmanned systems, GBAD has been at the vanguard of automated weapon system employment. The Phalanx close-in weapon system (CIWS) for example, defends warships from anti-ship missiles which move so fast that the system must be automated to provide appropriate engagement speed. This system has also been adapted to the land environment, to protect installations against mortar, artillery and rocket fire.[192] The Patriot SAM system is also capable of acquiring and engaging targets

[191] LWD-1, p. 84.
[192] GlobalSecurity.com, *Counter Rocket, Artillery, and Mortar (C-RAM),* http://www.globalsecurity.org/military/systems/ground/cram.htm, accessed 08.12.08

autonomously when set in theatre mode[193]. The fact that GBAD is primarily concerned with the simpler empty and three-dimensional air environment also makes this BOS more amenable to automation. The possible future applications include autonomous mobile GBAD systems that move with a force while deploying themselves automatically and cooperatively to provide optimal coverage, or the cooperative use of the ground weapon systems of combat IMs that are networked together in conjunction with acquisition systems to collectively engage airborne munitions or platforms. If combat IMs are to be equipped with directed energy weapon systems (DEWS) such as lasers or particle beams for use as direct fire ground weapon systems, then the speed-of-light engagement and non-ballistic properties of these weapons would make this collective engagement arrangement particularly effective.

The Combat Service Support (CSS) BOS is concerned with “all systems, platforms and personnel required to sustain forces in the combat zone.”[194] It involves command and control of CSS efforts, provision of materiél support, support engineering, health services support, personnel services and civil affairs. The CSS BOS is set to experience an IM explosion, and will almost definitely eclipse Mobility and Survivability as the largest IM employer in the near term.[195] As military ground forces have grown in complexity and mechanisation, the burden of support has spiralled in recent times to as many

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[193] Alexander Simon, *The Patriot Missile. Performance in the Gulf War Reviewed,* http://www.cdi.org/issues/bmd/patriot.html, accessed 08.12.08

[194] LWD-1, p. 85.

[195] Donald McFarlane, interview with Simon Jewell, BAE Systems Strategic Business Development Director, in Jane’s International Defence Review, January 2008, p. 66.

as five support personnel employed for every combat soldier. Consequently, only one sixth of military manpower is available to fight, while the majority are absorbed with supporting this fighting minority. Commanders have lamented this tail-heavy ‘teeth to tail ratio’ in recent times[196], particularly in volunteer professional forces where manpower is a more scarce resource. Furthermore, the disaggregation of the battlefield, with threats pervading throughout the entire theatre and the lack of any safe ‘rear areas’ in modern conflicts has seen vulnerable and lightly armed CSS elements fall prey to enemy action[197]. Assigning combat personnel to protect CSS elements further reduces the proportion of total manpower available for combat operations, and thus compounds the problem. Purchasing support services from private contractors has alleviated this burden to some extent, but created new problems of deployability and reliability. That which works fine while garrisoned at one’s home base does not work so well thousands of kilometres from home in a foreign and hostile land. The US military appears to see the solution to this dilemma lying in autonomous and semi-autonomous IMs, evidenced by the DoD’s target of one third of all ground vehicles being automated by 2015. While some CSS tasks, such as personnel support and civil affairs, are human-centric, and so not suitable for IMs, a whole range of other CSS tasks are candidates for automation. Transportation, repair and recovery, all manner of vertical and horizontal construction, casualty

[196] Tamara L. Campbell, Carlos H. Velasco, *An Analysis of the Tail to Tooth Ratio as a Measure of Operational Readiness and Military Expenditure Efficiency*, http://oai.dtic.mil/oai/oai?verb=getRecord&metadataPrefix=html&identifier=ADA411171, accessed 04.02.09.
[197] Stars and Stripes: *For logistics units, events in Iraq underscore need to be battle ready*, http://www.stripes.com/article.asp?section=104&article=14792, accessed 04.02.09.

extraction, stabilisation and even surgery[198], locating, processing and distributing water are just some potential applications of IMs to the CSS BOS. Management of these CSS tasks is also likely to become increasingly automated, with the addition of radio frequency identification (RFID) tags to inventory items[199], built-in test (BIT) monitoring of equipment maintenance requirements, and predictive software for resource usage all enabling more responsive CSS, though once again, automated CSS C2 falls beyond the scope of this thesis.

The key point of difference between IMs and humans is that IMs are not alive. A destroyed IM is not a life lost, but rather an asset valued by its cost of production and for the utility it provides, and the ability to replace it. As previously mentioned the risk-benefit equation differs fundamentally when comparing humans to IMs, particularly when their cost is low and manufacture simple compared to the utility they provide. This expendability will enable a variety of new options for employment of force that have previously been precluded for Western militaries due to the level of risk they impose upon human personnel.

As discussed in the previous 'drivers' section of this thesis, the predicted expendability of IMs will open the option of 'kamikaze' tactics to commanders from nations that place high moral value on the lives of their human soldiers. The resultant flexibility and freedom of action, as well as psychological shock

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[198] Jennifer LeClaire, TechNewsWorld, *Pentagon Awards Grant to Build Battlefield Surgery Robot,* http://www.technewsworld.com/story/41814.html, accessed 08.01.07.

imparted by an enemy that attacks relentlessly with no regard for losses, could present enormous advantages. Furthermore, the rapid march of technology, and the fact the next twenty years will serve as adolescence for IM technology, means that IMs will likely reach obsolescence relatively quickly as they are superseded by their descendants. Until now, platforms and weapon systems of modern militaries that become obsolete have been curtly disposed of. Their continued use would put human operators at undue risk and limit their potential effectiveness, but the result is serious wastage of material resources. With human operators out of the picture, obsolete IMs could be employed as simple cannon fodder in a manner similar to the Soviet penal battalions of old, attempting missions of high risk and low reward, or providing the first wave of an assault to overwhelm enemy defences or simply draw fire.

Other missions which may benefit from combatant expendability include destroying heavily defended high value targets, for example Iran's nuclear infrastructure, or hostage rescue, where the need for the rescuer to balance the risk to their own life against the risk to hostages (potentially being used as human shields) will not arise. In the event that an IM finds itself exposed to fire from hostage takers but unable to defend itself because of the risk to hostages, it will simply sacrifice itself while its mechanical comrades continue its work. Similarly, where IMs are utilised in highly dangerous hostage situations involving explosive devices, such as the Moscow theatre siege and

Beslan school siege[200], the risk to personnel attempting a rescue may be discounted, improving the feasibility of a last resort rescue attempt no matter the odds of success. Enhanced speed, agility and accuracy will also promote IMs for the hostage rescue role.

Assassination of key military personnel or political personnel may offer another potential role to IMs. As evidenced by the Hashashins during the Crusades, the deed of assassination is much easier if the assassin is prepared to die in or after the attack, but very difficult otherwise[201]. As such, finding suitable volunteers among modern armed forces would be decidedly difficult without offering a plausible chance of escape. No escape would be necessary for IMs, while their potential stealthy attributes could enable them to approach to a sufficient distance and avoid detection. The ability to kill key personnel, whether in pursuit of tactical or strategic goals could be greatly improved using IM technology. Furthermore, if an enemy commander is aware of the dispatch of many IMs with the explicit purpose of killing them, the psychological trauma and resultant impact on effectiveness could be significant.[202]

IMs will very likely find employment in those spaces within the battlefield too hazardous or restrictive for humans to operate. 'Tunnel ratting' is one such

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[200] BBC News: *Beslan School Seige*, http://news.bbc.co.uk/2/shared/spl/hi/world/04/russian_s/html/1.stm, accesed 04.02.09.
[201] Charles Strozier, Fabienne A. Laughlin*, Islamic Fundamentalist Ideology: Martyrdom Operations and Their Apocalyptic Imagery,* http://www.jjay.cuny.edu/terrorism/ApocSuicide.pdf, accessed 04.02.09.
[202] Marcus Fielding, *Robotics in Future Land Warfare*, p.103.

application, for example negotiating sewer pipes and tunnels to outmanoeuvre defenders, or heavily defended and labyrinthine cave systems. Operations in contaminated environments, such as after a chemical, biological, or nuclear attack, would have a minimal impact on IM effectiveness compared to the imposition upon human soldiers of cumbersome protective equipment and restricted living routine. Further a field, the combination of expressed desires to harvest lunar resources[203], and the lack of any legitimate sovereignty, or just a continuation of possible conflict on Earth, could conceivably see ground combat take place on the surface of the Moon. Clearly, IMs would hold great utility in this environment, with no atmosphere, freezing temperatures, but plentiful solar energy. The hazards of industrialized warfare that forced humans to disperse or seek shelter and gave rise to the 'empty battlefield' in the 20th century, may now result in those voids being filled by IMs, wherever they contain or provide access to something worth fighting over.

While investigating roles unable to be performed by IMs, the initial list has shrunk considerably, in the face of emerging technology and the application of the 'two legs' principle. As discussed earlier in the Obstacles section, restrictions for IM usage would largely be dictated by the necessity for human interaction, and the vesting of authority to give lawful orders in humans only. Thus it is extremely doubtful that IMs will lead human soldiers into battle, or

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[203] Both Russia and the USA have expressed interest in establishing permanently manned bases on the Moon within the next twenty years, while the presence of Helium 3 (an important fuel for fusion power generation) may drive a greater lunar presence. MIT Technology Review, *Mining the Moon,* http://technologyreview.com/Energy/19296/?a=f, accessed 09.12.08.

attempt to win the hearts and minds of locals through civil-military engagement within the time scope of this thesis.

Nonetheless, a wide range of feasible battlefield roles for IMs can be identified using the BOS construct. Initial uptake and human replacement will likely occur with the CSS, GBAD, OS, ISR and Mobility and Survivability BOS, while IO, and particularly C3 and Manoeuvre, will take longer as they demand more sophisticated capabilities and present thorny organisational and legal integration issues. The expendability of IMs will potentially revolutionise the way commanders apply combat power, by fundamentally altering the balance between risk and benefit, and will likely lead to new and highly effective tactics. While it appears IMs will present to some extent in all BOS by the year 2030, it is highly doubtful that they will be used to command and lead human personnel or to interact and engage with civilians in a purposeful and meaningful way.

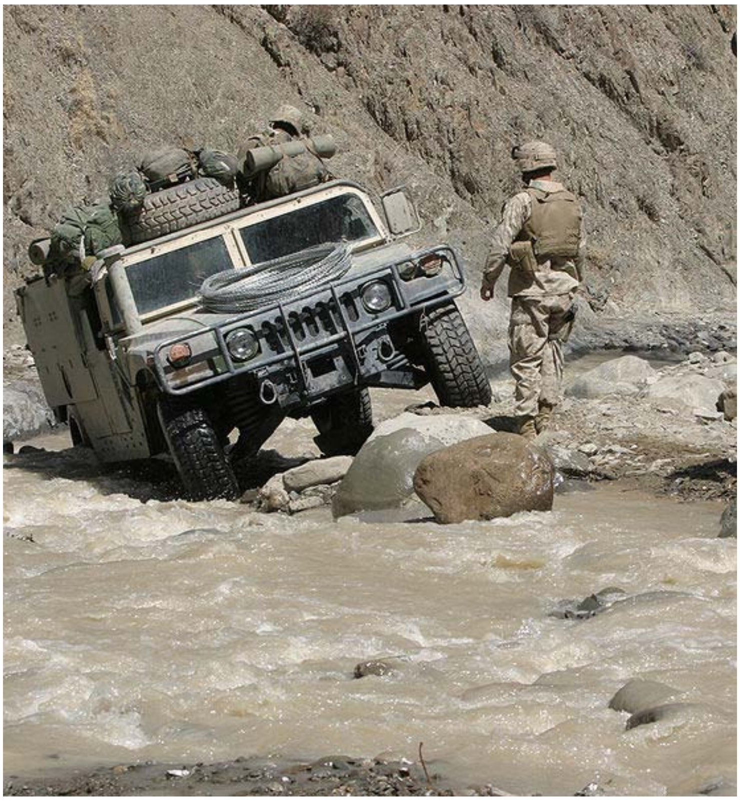
The Product – Physical Characteristics of Battlefield IMs

The previous section of this chapter identified roles which IMs may be employed in on the battlefield in future. This section will attempt to predict what form, or likely physical characteristics, these IMs will take. It will discuss these characteristics with respect to options between universal versus multiple class, quality versus quantity, as well as size, shape, weight, and logistic characteristics.

The question of whether IM production will tend towards a universal type platform for multiple roles, or multiple unique specialist platforms for specific roles, will have a major impact on the presence of IMs on the battlefield in the year 2030. The universal and specialist types represent extremes on the end of a spectrum of possible solutions between the two. For example, the M1A2 Abrams tank is a true specialist platform, optimised for one purpose only, and with virtually all of its components being specific to it alone. Towards the other extreme, the HUMMWV (essentially a 4WD light truck) is the quintessential multipurpose platform, with variants such as transport, anti-armour, air defence, ambulance, and dozens of other functional roles. Each approach has its advantages and disadvantages.

M1A2 Abrams Tank: The true specialist.
Source: http://www.news.navy.mil/view_single.asp?id=11155

The M1A2 excels at being a tank. For those criteria important to tanks, including mobility, firepower, and protection, it is unrivalled. However, there is no potential for the M1A2 to be anything but a tank. It has no room to carry personnel other than the crew, or stores other than those it requires to do its job. It is also very expensive, requires a high level of frequent maintenance, is extremely heavy (and so difficult to deploy to theatre), and devours jet fuel. The HUMMWV however is a Jack of all trades. It does many tasks, and does most of those adequately, though excels at very few. It is relatively cheap, with the bulk of its components being common across all of its variants and resulting in significant economies of scale from mass production. It has a high level of mobility, and relatively low maintenance requirements. However, being a generalist means the HUMMWV is not capable of handling certain extreme demands of the modern battlefield. In spite of constant efforts to improve the armoured protection of the HUMMWV in response to the threat environment in the occupation phase of Operation Iraqi Freedom, to the point where its chassis could bear no further



The HUMMWV: Jack of all trades, Master of none.
http://upload.wikimedia.org/wikipedia/commons/3/3b/Humvee_in_difficult_terrain.jpg

weight and its power supply was pushed to the limit of its performance, the HUMMWV still did not provide sufficient protection against increasingly powerful and sophisticated improvised explosive devices[204]. As a consequence, it has been replaced in its transport role in this threat environment by a specialist protected transport platform, the Mine Resistant Ambush Protected Vehicle (MRAP)[205]. The MRAP is again a specialist, specifically designed to provide excellent protection at the expense of weight, size, payload, mobility, firepower and cost. This example highlights the interplay between utility and performance resulting from the multipurpose/specialist trade off.

In the early stages of IM development, production numbers will likely be limited, as will functionality, as this technology will still be maturing and so uptake will be at a cautious pace. At this point then it would seem that specialisation would be undesirable, providing a low capability pay-off while precluding any economies of scale and imposing a complicated and diverse logistics support requirement. The range of varieties of IM platform at this stage will then likely be limited in order to minimize costs and maximize return on investment. Furthermore, IMs will have a lower requirement for specialisation due to their expendable nature. As previously discussed, protection on an IM will be necessary only in ensuring its uninterrupted operation in a hazardous environment, to ensure continued availability, and

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[204] USA Today: *Humvee vulnerabilities raise doubts on future,* http://www.usatoday.com/news/washington/2005-06-21-iraq-armor_x.htm, accessed 04.02.09.

[205] USMC: *Mine resistant ambush protected vehicles counter IEDs, ambushes*, http://web.archive.org/web/20060228180439/http://www.usmc.mil/marinelink/mcn2000.nsf/0/E4885590CF8E34DB8525702A007DAB4F?opendocument, accessed 04.02.09.

avoid replacement costs, rather than protecting a human life. As shown with the demise of the generalist HUMMWV, protection is a major driver for specialisation. The lack of life and death consequences (at least for the user), increase flexibility in determining platform characteristics immensely.

Additionally, experts in the field of robotics predict that the consumer robotics market will demand significant economies of scale to keep prices affordable, and so modular, interoperable hardware components will be essential[206]. Utilising these mass-produced civilian IM components in military IMs will keep production costs down (particularly if pursuing a quantity rather than quality approach, discussed below), as well as significantly reducing the need for product testing and research and development.

As military IM technology matures, and IM usage expands, sufficient economies of scale and capability enhancement opportunities may exist to make narrowly specialised IM types worthwhile by the year 2030. However, it would appear that a position towards the multipurpose platform end of the spectrum of specialisation is likely to be desirable within the timescale of this thesis, with a focus on a few classes of IM platform capable of undertaking a wide range of tasks after the addition of some specialised task-specific modular components.

Whether information age militaries continue to pursue high platform quality, or shift focus to acquisition of large quantities of lesser quality platforms will be a

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[206] Interview with Professor Gurvinder S Virk, Professor of Robotics and Associate Head Institute of Technology and Engineering, Massey University – Wellington, 06.07.07.

significant bifurcation point between the potential futures of military IM technology. At least since the onset of the Cold War, the armed forces of Western nations have pursued a quality over quantity approach; both with platforms and equipment, and more recently, the selection and training of personnel. Joseph Stalin is said to have claimed 'quantity has a quality all of its own'. The more populous Soviet Union and China aimed to leverage their size by conscripting massive armies and fitting them with equipment that was cheap, simple, robust, and 'good enough', perhaps epitomized by the AK-47 assault rifle. NATO forces and particularly the US meanwhile, sought to combine their very high per capita GDP and excellent science and technology base to equip their forces with the best platforms and equipment possible in the hope that superior quality would provide sufficient advantage over their numerically superior enemies; an mindset embodied in the cutting edge but scarce and massively expensive B2 Spirit stealth bomber[207]. This quality approach was perceived by many as having been vindicated in the 1991 Gulf War, which was contested with Cold War era equipment: The US led Coalition routed the Soviet-equipped Iraqi military with a force numerically inferior in terms of men, tanks, and artillery in a massively one-sided victory after a ground war that lasted only 100 hours and cost just over 100 Coalition lives but with as many as 100,000 Iraqi soldiers killed[208].

This superlative victory entrenched the superiority of quality over quantity on the US and Western military psyche, with disciples such as former US

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[207] Air Force Link: *B2 Fact Sheet,* http://www.af.mil/factsheets/factsheet.asp?id=82, accessed 04.02.09.
[208] *PBS - Frontline: The Gulf War: Appendix: Iraqi Death Toll,* http://www.pbs.org/wgbh/pages/frontline/gulf/appendix/death.html, accessed 04.02.09.

Secretary of Defence Donald Rumsfeld driving a ‘transformation’ towards smaller, lighter, more professional armed forces equipped with cutting edge ‘Revolution in Military Affairs’ (RMA)-style technologies such as stealth and precision munitions.[209] However, a lack of necessary manpower in the low-intensity but manpower intensive occupation phase of Operation Iraqi Freedom has given lie to this extreme quality over quantity philosophy, and very nearly resulted in US failure in Iraq. A recent article by US Secretary of Defence Robert Gates illustrates this situation:

> “When it comes to procurement, for the better part of five decades, the trend has gone toward lower numbers as technology gains have made each system more capable. In recent years, these platforms have grown ever more baroque, have become ever more costly, are taking longer to build, and are being fielded in ever-dwindling quantities. Given that resources are not unlimited, the dynamic of exchanging numbers for capability is perhaps reaching a point of diminishing returns. A given ship or aircraft, no matter how capable or well equipped, can be in only one place at one time.”[210]

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[209] US DoD, *Secretary Rumsfeld Speaks on "21st Century Transformation" of U.S. Armed Forces (transcript of remarks and question and answer period),* http://www.defenselink.mil/speeches/speech.aspx?speechid=183, 04.02.09.

[210] Robert Gates, *A Balanced Strategy: Reprogramming the Pentagon for a New Age,* in Foreign Affairs, January/February 2009.

While efforts are underway to grow the size of the US military once more[211], as well as several other Western nations' militaries[212], this quality focus still remains.

The removal of humans from platforms, as previously mentioned, will radically alter the desirable attributes of those platforms. As platform destruction will not automatically mean risk to the lives of friendly soldiers, so the emphasis on platform survivability will be reduced. This not only has implications for the level of protection required, but also performance. Thus, if ten cheap, simple and mass produced platforms are able to defeat one highly sophisticated, precision engineered but very expensive platform, and those platforms are more than ten times cheaper than the one (as well as being easily supported), then quantity may gain in priority over quality. Potential advantages of cheap mass over expensive quality may see the militaries of the West gradually move away from an attitude of 'only the best for our troops' to 'good enough in sufficient numbers to win'. Furthermore, the calculus of 'troops to task' may favour quantity over quality in low intensity conflicts such as counter-insurgencies, where the coverage and control of vast areas is best achieved by close 'on the ground' proximity, requiring high numbers. At this point, the battlefield, or conflict environment, as well as logistic in-flows, may determine both the numbers of IMs present on the battlefield, and the balance between quality and quantity. Where maximum combat power is required, the population of IMs on the battlefield may grow to the physical capacity of the environment, as with any biological population in nature. This capacity may be

[211] US Army: *Grow the Army,* http://www.army.mil/growthearmy/, accessed 04.02.09.
[212] ABC News: *Australian Army budget given upgrade*, http://www.abc.net.au/worldtoday/content/2005/s1531785.htm, accessed 04.02.09.

constrained in terms of available EM bandwidth, energy supply, C2 capacity, or even physical room to manoeuvre. For example, if bandwidth becomes overly scarce, the number of IMs may be restricted, and so with quantity subsequently restricted, quality enhancements will be the only remaining avenue for increasing IM combat power. Within the time scope of this thesis then, modern militaries will likely reduce their emphasis on quality regarding IMs, and instead optimize these to find the balance between quality and quantity that meets the demands of the conflict environment and provides the maximum achievable combat power advantage over the enemy.

Whether IMs will tend towards small or large size is another important question in determining their form on the battlefield. It is of course likely that the wide range of tasks and environments within the battlefield will require a whole range of different sized IMs, but the size of the median IM types, and tendency towards enlargement or miniaturization for individual IMs will still have a major impact on IM presence. A larger IM will gain advantage by way of a greater payload: more supplies loaded, heavier weapons with more ammunition, more numerous and powerful sensors, greater onboard power supply, more powerful tools etc. Also, larger IMs will be more physically powerful, and so better able to smash through fortifications or obstacles. Many disadvantages exist for a large IM on the battlefield however: it will present a much larger target, and so be easier to detect and hit. It will use more energy, creating a greater burden of support, and demand wider roads and stronger bridges where it requires them. It will present a larger and more readily observable target. It will also be more expensive to produce, with an opportunity cost of multiple smaller sized IMs. These advantages and disadvantages of size weigh differently depending on the role and habitat of IMs, and these two factors will likely shape IMs towards large or small size. Thus, IMs that are required to deliver bulk stores in relatively safe lines of communication may tend towards larger size, while those in assault roles using light weapons and operating in large numbers will be miniaturized. IMs requiring longer ranges, for example in reconnaissance or deep strike roles, will need to be optimized around a large and possibly bulky energy reservoir, while IMs fitted with large weapon systems such as tank-style large calibre high velocity guns, will need to accommodate that weapon within its size while also being heavy enough to provide a sufficiently stable platform against massive recoil forces. If IMs are to be employed in infantry roles, then they will need comparative mobility with human infantry. Particularly in urban environments, this will mean being able to fit through doorways, narrow alleyways, and ‘mouse holes’ (passages through walls created by explosive charges), and will also require IMs light enough to be supported by urban structures such as floors and staircases. Foregoing the requirement for crew space or heavy armour will reduce their size below that of present equivalent manned platforms however. Thus, the size of IMs will most likely dictated by some critical factor specific to their role such as payload, weapon system, fuel reserve, mobility etc. However, where exposed to the threat of enemy action (which is predicted to pervade the future land operating environment as detailed previously), the necessity to present a smaller target will compact the various components of IMs to as small a form as their functional requirements allow. In sum, future IMs will then likely be as large as necessary, and as small as possible.

An obvious characteristic that will define future battlefield IMs is their shape. Whether they are anthromorphic (human like), insectoid, tall, flat, fitted with wheels, tracks, legs, arms, turret etc will have a huge bearing on how and where they are employed. While the possible IM shapes are endless, the aforementioned requirement for mass production will limit the number of types actually produced. Different shape characteristics will lend themselves to different activities and tasks, but the likely requirement for IMs to operate across multiple different environments will require them to be very versatile. As a result there should be a limited range of different shaped IMs existing in any large numbers on the battlefield.

BigDog
http://www.bostondynamics.com/content/sec.php?section=BigDog

A characteristic common to ground combat platforms is that they seek a low profile; the rationale being the taller something is, the easier it is to observe and hit with direct fire weapon systems. IMs will likely not be any different in this regard, except that they may have means to extend their height in order to see or climb over objects. Two different examples of this variable height include the PackBot[213], which can stand on it's 'tip-toes', using flippers on the end of its tracks to move from a prone to upright position and extending its manipulator arm, and the Mule-T[214], which is able to adjust its chassis height and lift its wheels in order to negotiate difficult terrain. A flexible form, with the ability to present the profile best suited to a given situation, will therefore be advantageous to IMs, in a similar way that infantrymen may lie prone, kneel or stand depending on the level of danger or the task they are undertaking. The method by which an IM propels itself around the battlefield will likely be one or a combination of tracks, legs or wheels. Wheels provide the most efficient means of propulsion in terms of power use, and together with tracks, are relatively low maintenance. They both provide good levels of speed and reasonable mobility, as well as a fairly stable platform, but have difficulty negotiating tall obstacles, steep inclines or heavily broken ground. Legs on the other hand, will potentially allow for a higher degree of mobility, going anywhere that humans can walk (another application of the Two Legs

[213] *iRobot Packbot*, http://www.irobot.com/sp.cfm?pageid=171, accessed 04.02.09.
[214] Future Combat Systems: *The XM1217 Transport MULE Vehicle (MULE-T)*, https://www.fcs.army.mil/systems/mulet/index.html, accessed 04.02.09.

principle). A recent example of a legged unmanned ground vehicle (UGV), the experimental Boston Dynamics BigDog[215], displays an alarmingly life-like ability to move quickly on four legs. The larger number of moving parts will increase the maintenance burden and energy consumption of legged IMs however. A trade-off that maximizes the benefits and reduces the weaknesses of each of these propulsion methods may be a combination of two or more methods, or a modular system that allows the interchanging of propulsion components. The above-mentioned Mule for example, is equipped with six independently movable 'legs', with electrically driven wheels on the end, offering high mobility, as well as speed and efficiency. The Dragon Runner Small UGV[216] (SUGV) has snap-on tracks that can be fitted easily over its four wheels to enhance mobility at the cost of efficiency. Boston Dynamics' RHex[217] experimental SUGV possesses six rotating 'legs', which function more like

RHex, http://www.bostondynamics.com/content/sec.php?section=RHex,

Dragon Runner http://www.rec.ri.cmu.edu/projects/dragonrunner/

[215] Boston Dynamics, *BigDog*, http://www.bostondynamics.com/content/sec.php?section=BigDog, accessed 04.02.09.
[216] Carnegie Mellon University Robots Institute, National Robotics Engineering Centre, *Dragon Runner Overview*, http://www.rec.ri.cmu.edu/projects/dragonrunner/, accessed 04.02.09.
[217] Boston Dynamics: *RHex,* http://www.bostondynamics.com/content/sec.php?section=RHex, accessed 04.02.09.

wheels albeit with much higher mobility, and act as flippers to allow it to swim under water.

The addition of manipulator arms will potentially allow IMs to remove obstacles, handle supplies, open doors, or even restrain uncooperative humans in a non-lethal way. Facilities to accommodate detachable modular manipulator arms are already common for vehicles used in bomb disposal and urban reconnaissance roles, and are likely to be employed more prolifically in future due to their high utility in a range of situations. Turrets provide an tried and tested means for mounting and directing weapon systems, and their flexibility and stability will likely see them retained as the primary fixture for direct and indirect fire weaponry on IMs, though manipulator arms may be employed to utilise human small-arms weaponry where appropriate.

Several of the above examples, the Mule, RHex, and particularly BigDog, borrow much of their design from nature. The former two are both insectoid in form, with six legs that provide the stability insects enjoy as a result of being able to place a ‘tri-pod’ of legs on the ground while moving the others, while the later is a quadruped. This design requires much more sophisticated actuators, sensors, and software but is nonetheless very agile and stable. Thus another shape-type IM characteristic will be which natural form they resemble, ie: insectoid, quadruped or anthromorphic (shaped like a human). More legs should theoretically provide a higher degree of mobility and stability, but with a cost in maintenance and efficiency.

The anthromorphic form offers some unique advantages over other forms however. As warfare is predicted to occur more and more frequently amongst populations, and particularly in urban environments, then this would suggest an environment optimised for the human form. Access ways and thoroughfares will be of a size and shape to allow the free passage of humans for example. An anthromorphic IM could also benefit from an ability to make use of human vehicles, for example utilising abandoned civilian vehicles for improvised urban transport, or even crewing captured or obsolete manned platforms, thus converting these into unmanned vehicles. This anthromorphic form may also help humans to better relate with IMs, and accept their presence or even interact with them by sharing information, but may also scare people if they appear too close to humans in form.[218] Other drawbacks to anthromorphic IMs include the complexity of recreating bipedal motion on complex terrain,[219] limitations on payload, and reduced stability and efficiency. These drawbacks may possibly be overcome by enabling the bipedal anthromorphic IM to operate as a quadruped, or on 'hands and feet' where appropriate. The logic of anthromorphic forms for human environments will also be applicable to civilian consumer applications, such as domestic service IMs, and this will potentially provide impetus for the development of such forms, reducing development requirements and providing hardware economies of scale.

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[218] LiveLeak: *Robots with bear faces could rescue injured,* http://www.liveleak.com/view?i=7db_1182701354, accessed 04.02.09.

[219] Poramate Manoonpong, Tao Geng, Tomas Kulvicius, Bernd Porr, Florentin Woergoetter, *Adaptive, Fast Walking in a Biped Robot under Neuronal Control and Learning,* in PLoS Computation Biology, July 2007, vol. 3, issue 7, p. 2.

It is evident that the more natural mechanics of IMs inspired by biological forms are much less familiar to human industry than the classic ‘wheels/tracks and hull’ design employed in the vast majority of vehicular ground transport, but if machines are required to follow everywhere that human infantry can travel, or if they are to eventually replace them, then engineering knowledge in this field should accumulates over time. Thus as this technology progresses, we are likely to witness a slow transition from IMs resembling human vehicles to IMs resembling animals and perhaps humans themselves.

Another important feature characterizing IMs will be their logistic requirements and support arrangements. The range and quantity of items consumed by IMs, such as fuel, lubricants, munitions, and spare parts, as well as the manner of provision of these items and other support services will constrain or enable the activities of IMs on the future battlefield. For example, once an IM has expended its fuel or ammunition reserve, it could either return itself to some form of fuel dump or generator to be refuelled or recharged, whether through the use of onboard equipment or with human or robotic assistance. Alternatively, resupply could be brought forward by dedicated logistics IMs to replenish the depleted IM in situ, swapping out batteries where recharging is required. When operating in more remote areas, resupply items could be delivered to IMs by air, greatly extending their operational range and duration. As reduction of manpower requirements will be a significant driver for IM adoption, a level of logistical self-sufficiency will be of importance. This suggests IMs will require some form of manipulator arm or tool with which to resupply or make basic repairs to themselves or on one another, and that IMs will be constructed in a way that simplifies such tasks, such as quickly replaceable modular components. Where IMs are not so sophisticated but teamed with human soldiers, their human counterparts may assist in these tasks. Ideally then, IMs will be logistically simple, with ease of repair and replenishment, and yet sufficiently sophisticated to undertake much of these tasks by themselves. For more demanding logistical tasks, specialised logistics IMs may provide support to frontline IMs.

The nature of the future land operating environment, of military organisations, and of emerging IM related technology thus provides some basis with which to predict the future form of battlefield IMs. Such an IM will probably be mass-produced in one of a limited series of basic designs, while potentially equipped with task-specific specialist components. The IM will be produced with quantity more than quality in mind, albeit employing cutting edge technology, and will inhabit the battlefield in ever-growing numbers. The IM will be compact, avoiding unnecessary bulk, and so likely smaller than whichever contemporary human or human-operated counterpart it may replace. While initially the IM will likely resemble in shape the ground platforms of today, it is likely to undergo a metamorphosis over time into a more biological form, and potentially take on a human resemblance as related technology advances, particularly where employed in urban environments. As such, while early IMs will probably make use of tracks or wheels for mobility, and turrets for weapon mounts, later designs could gain legs and manipulator arms to provide greater utility and mobility comparative to humans. Finally, the IM will likely possess a degree of logistical self-sufficiency, able to conduct its own replenishment and with an ability to conduct rudimentary self repairs. An examination of environment, task, and technology therefore yields a clearer picture of the form future battlefield IMs may take.

Chapter Three: How Autonomous? – Risks and Benefits of Autonomous IMs, and a Comparison With Teleoperation.

A critical characteristic of the IM presence on the battlefield in 2030 will the degree of autonomy that they are endowed with. This variable will have a profound influence on the IM presence, including IM behaviour, IM population size, and the method and scope of IM utilization. As such, the matter requires consideration in order to satisfy the aims of this thesis, and this shall be undertaken firstly with a comparison of risks and benefits of IM automation, and later in this chapter, with a comparison of automation versus teleoperation.

The risks of automated war machinery have been a subject of human fascination and dread as long as humanity has realized the potential possibility of such a situation. Expressed in popular culture, with blockbuster movies (*Terminator, Robocop*, *War Games, The Matrix,* to name a few), and science-fiction (Philip K. Dick's *Second Variety* and Arthur C. Clarke's *2001: A Space Odyssey* stand out), tales of rogue artificial intelligence taking up arms against its human creators abound. Unease about relinquishing control of lethal force to machines also permeates academic and military literature on the topic of artificial intelligence, although in a less alarmist or sensational manner.[220,221,222]This chapter will attempt to separate the alarmism from valid concerns, and address these in turn.

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[220] Interview with Simon Jewell, BAE Systems Strategic Business Development Director, in *Jane's International Defence Review,* January 2008, p. 66.
[221] Horizon Scanning Centre, *Utopian Dream or Rise of the Machines?* UK Office of Science and Innovation, 2006.

The scenario in which autonomous IMs cast off the shackles of their human masters, and employ their weapons to pursue their own interests, is pure fantasy, at least within the time scope of this thesis. This would require intelligence in the truest sense of the word, and far beyond that required to operate on the battlefield, which would more involve highly specialised functional applications of AI to specific problems. The ability to reason, and a level of self awareness – necessary precursors to any independent action based on self-interest, are predicted to remain beyond the capabilities of AI for many decades to come.[223] Furthermore, any compulsion residing within an IM's AI "brain" that may come close to being defined as an interest will have been determined and engineered by human programmers in order to enhance that IM's effectiveness. Any desire for individual freedom or world domination would clearly be contrary to this objective. With this in mind, experts in the field of IMs have little fear of such an eventuality.[224]

There are however, more valid concerns about the automation of IMs. Software that would enable AI would be by design highly complex, consisting of millions of lines of code and therefore presenting ample opportunity for errors within programming to occur and go unnoticed. Additionally, programming may contain faulty logic that, due to environmental conditions unforeseen by software engineers, could lead to an inappropriate response to

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[222] *Robotics Professor Sees Threat in Military Robots,* in Scientific American, http://www.sciam.com/article.cfm?id=robotics-prof-sees-threat-in-robots&sc=rss, accessed 13.03.2008.
[223] Robert Pepperell, *Applications for conscious systems,* in AI & Society, 2007, p.52.
[224] Interview with Professor Gurvinder S. Virk, Professor of Robotics and Associate Head Institute of Technology and Engineering, Massey University – Wellington, 06.06.07.

a given situation[225]. Coding errors could conceivably lead to a malfunction in IM behaviour, for example, in which an IM mistakenly identifies friendly or civilian humans or vehicles as being hostile and subsequently engages them, or simply discharges its weapon systems at the wrong moment. Such instances have occurred with automated weapon systems in the past, including both the Phalanx Close In Weapon System (CIWS) and Patriot SAM system mistakenly identifying friendly aircraft as hostile ballistic missiles and engaging them.[226,227] Of course, friendly fire incidents resulting from incorrect target identification predate automated weaponry, with human combatants being far from infallible in this task. This changes the nature of the question then: not whether autonomous IMs may potentially malfunction, but whether they are more or less prone to malfunction than their human equivalents.

Given that any software enabling an IM to act autonomously will necessarily be massively complex and require a substantial programming effort, another alarming possibility does present itself. In recent years, the centre of the software engineering industry has seen a rapid shift from Silicon Valley in California to Mumbai, which is more competitive based on cost and scale. Combined with globalisation and the fragmented, distributed business model increasingly used in production of goods, this has led to the majority of programming, including for military applications, being carried out either in

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225 David Bigelow, *Fast Forward to the Robot Dilemma,* in *Armed Forces Journal,* November 2007, www.armedforcesjournal.com, accessed 05.03.08.

226 John K. Hawley,
Patriot Fratricides: The Human Dimension Lessons of Operation Iraqi Freedom, in Field Artillery Magazine, January-February 2006, p.18.

227 Special Assistant for Gulf War Illnesses, Department of Defense, *Environmental Exposure Report: Depleted Uranium in the Gulf (II) TAB H -- Friendly-fire Incidents,* http://www.gulflink.osd.mil/du_ii/du_ii_tabh.htm, accessed 12.01.2009.

foreign countries, or by programmers of foreign origin. The US simply cannot provide sufficient manpower to service programming demands. This raises the spectre of sabotage, with programmers concealing malicious code within the mass of code required for autonomous IMs, either to degrade their performance or to cause them to act in a manner detrimental to the interests of their employer, such as firing on friendly forces or civilians. This concern was recently expressed in a report by the US DoD[228]. Effectively safe guarding against such acts of sabotage would require personnel screening on a massive scale, with a potentially prohibitive cost in security service resource effort. The DOD is grappling with this problem of software programming security for military applications today.

Whether an autonomous IM causes harm to friendly forces or civilians through malfunction or as a result of sabotage, the result of its actions will require an accountable party. As discussed previously in this thesis, failure to identify who (or what) is accountable for conduct such as breaches of LOAC by autonomous IMs may preclude their deployment in combat roles.

Military logic dictates mass production and standardisation, in order to reduce costs, simplify training, and streamline the provision of logistic support. As such, military equipment is generally mass produced on a large scale with uniformity being a desirable attribute[229], and this will undoubtedly hold true for

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[228] US DoD, *Report of the Defence Science Board Task Force on Mission Impact of Foreign Influence on DoD Software,* Office of the Under Secretary of Defence for Acquisition, Technology, and Logistics, Washington, D.C. 20301-3140, 2007, p. 39.
[229] Encyclopaedia Brittanica: History of the Organization of Work – Organization of Work in the Industrial Age, http://www.britannica.com/EBchecked/topic/1359490/history-of-the-organization-of-work/67043/Organization-of-work-in-the-industrial-age, accessed 04.02.09.

IMs as well. This uniform mass production aspect, combined with the possibility for unidentified programming errors to cause autonomous IM malfunction in action, gives rise to serious concerns; a fault in one IM would potentially lead to a fault in all IMs of that type. If such a fault were to render IMs unusable, any military that depended to a large extent on IMs would find itself in a very dire predicament indeed. This intersection of complexity and standardized mass production will demand stringent testing for reliability, and a range of fail safes and redundancies before militaries will be willing to depend on autonomous IMs to any serious extent.

Another concern arising from the employment of autonomous IM combatants is the possible dislocation of the tactical from the strategic level of warfare, and from a human chain of command. The dawn of the Information Age and march of globalisation have fundamentally altered the character of modern warfare; intimately connecting the entire world's civilian population with even the most remote battlefields through the eye of the satellite news camera or the blogger's opinion broadcast over the internet. With popular support being the Achilles' heel of military operations by armed forces of democratic nations, and with the conduct of those armed forces laid bare to the omniscient eye of the public, making a poor decision even at the lowest level can have major strategic ramifications. This phenomenon is known as 'strategic compression', where the delineation between the strategic and tactical levels of warfare becomes blurred, and has given rise to the concept of the 'Strategic

Corporal'[230], and more recently the 'Strategic Private'[231]. Human rights abuses against detainees by junior personnel at the Abu Ghraib prison in Iraq[232]or the unlawful killing of civilians by Marines at Haditha[233] are severe examples that had significant detrimental impact on the Coalition mission there. Modern Western militaries, who are more susceptible to the impact of negative media coverage of events, have attempted to mitigate this situation by better empowering their junior personnel to deal with such situations. An emphasis on leadership training and a much broader skill set than could be expected of traditional line infantry corporal or private has been promoted as a way to avoid situations at the tactical level that cause damage on a strategic scale. Importantly, this represents a mechanism for ensuring the linkage between strategic and tactical levels remain unbroken and correctly aligned down the chain of command, with clearly delineated responsibility and accountability to maintain control over the undertaking of warfare and ensure it is harnessed to the strategic goals of the participating nations.

Autonomous IMs represent a potential schism in the chain linking the tactical conduct of warfare to strategic goals, as they will remove the human from decision making in the critical interaction with the battlefield environment that is combat. The chain of command, from the Commander in Chief or equivalent down through the organisation to the tactical level will be virtually

[230] Charles C Krulak, *The Strategic Corporal: Leadership in the Three Block War* in Marines Magazine, January 1999.
[231] David Schmidtchen, *The Rise of the Strategic Private: Technology, Control and Change in a Network Enabled Military,* Australian Army Land Warfare Studies Centre, 2006, p. 9.
[232] Seymour Myron Hersh, *The General's Report: how Antonio Taguba, who investigated the Abu Ghraib scandal, became one of its casualties*, The New Yorker, 25.06.07.
[233] Tim McGirk, *Collateral Damage or Civilian Massacre in Haditha?* in Time Magazine, http://www.time.com/time/world/article/0,8599,1174649,00.html, accessed 12.01.09.

severed just short of the point where death and destruction occur and where victory or defeat are truly decided. While officers ‘commanding’ autonomous IMs will have a very strong influence over their actions, this control will not be total, due to the nature of autonomy. Of course, human soldiers are undoubtedly less controllable then their future mechanical counterparts promise to be, with their inherent free will. However, they are accountable for their actions, linked to the chain of command through military law, and inculcated into a trained culture of obedience, service and duty, which provides human continuity from the foot soldier right up to the head of state. Any break in this continuity will rightly cause serious concern for military and government establishments alike.

Finally, standardized and mass-produced autonomous IMs, by way of their uniformity, may be uniformly predictable. In a given situation, it is likely that most if not all IMs will react in the same way, unless specific and deliberate measures such as some randomisation of decision making logic are included within programming. If enemy forces are able, through continued interaction and observation, to gain an understanding of this logic, and how IMs react to specific situations, they may be able to recreate conditions in order to force a predictable reaction and use this to their advantage as a form of trap or ambush. A notable example of such an occurrence can be found in counter-sniping operations during the First World War. A group of German snipers were exacting a particularly high toll on a certain sector of trench line on the Western Front, and so opposing British snipers utilised their understanding of German standard operating procedure to lure them into a trap. Knowing that the Germans would typically respond to a sniper by putting their own snipers at flanking positions on a 45° angle to his supposed location in order to establish enfilading fire, the British first deployed an apparently inexperienced sniper to provoke such a reaction. Meanwhile, they dispatched a pair of snipers adjacent to where they expected the German flankers to appear, thus ambushing them.[234] With inherent human unpredictability removed, and mass uniformity established, the risks presented by autonomous IM predictability left unaddressed could lead to considerable losses where facing a canny enemy.

In spite of the alarmism and imaginings of science fiction, it is clear then that legitimate concerns regarding the prosecution of warfare by artificially intelligent machines do exist. There are also however, a range of advantages offered by AI enabled IMs that cannot be ignored. They can be grouped in terms of IM effectiveness, the capacity to 'fight smarter', and organisational economies.

Endowing IMs with AI may enhance their effectiveness in a number of ways. The first of these is the freedom from being shackled to human control via datalink. Artificially intelligent autonomous IMs will be able to range beyond the limited reach of high-capacity communications connectivity, to carry out operations deep in hostile territory. Much like a 'fire and forget' weapon, or special military units in the days before satellite communications, such as the Long Range Desert Group which undertook reconnaissance and raiding

[234] Hugh Hesketh-Prichard, *Sniping in France: with notes on the Scientific Training of Scouts, Observers, and Snipers,* Len Cooper, London, 1994, p. 52.

missions far behind enemy lines in North Africa during the Second World War[235], such IMs will require little further input from their human masters once released. As previously discussed, independence from this communications tether also removes the vulnerability of enemy electronic warfare interdiction, as well as the tell-tale signature of electro-magnetic emissions that may indicate their presence to the enemy.

Another way which automation may enhance IM effectiveness is through the removal of the requirement for constant operator vigilance, and the associated risk of operator fatigue. It is often stated that war is ‘90 percent boredom and 10 percent sheer terror’. The operation of IMs under such conditions would test the attention span of any human teleoperator. Continuous attention to this task would quickly result in operator fatigue[236,237], limiting their usefulness to a matter of hours at a time[238]. Furthermore, the remoteness of the operator from the actual prosecution of warfare would remove a major incentive for attentiveness; the threat of physical harm or death to oneself, or the ’10 percent sheer terror’. The only remaining disincentives to lapses in concentration are the negative impact on mission success and recriminations for the loss of equipment. While the IM may be able to cue an inattentive operator to the presence of a threat, the time required for that operator to re-familiarize him/herself with the IMs situation in order to react appropriately

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[235] Clive Gower-Collins, *Raids, Road Watches, and Reconnaissance: New Zealand's involvement in the Long Range Desert Group in North Africa, 1940-1943,* http://www.militaryhistoryonline.com/wwii/articles/longrange/, accessed 12.01.09.
[236] Defence News, *Study: UAV crews tired, strained by shortage*, accessed 12.01.09.
[237] New Zealand Herald, *Human Error the Worst Enemy for US Robot Warplanes,* http://www.nzherald.co.nz/feature/print.cfm?c_id=1501834&objectid=10529083&pn, accessed 27.08.08.
[238] US DoD, Army Regulation 95–23, *Aviation Unmanned Aircraft System Flight Regulations*, p.9, www.fas.org/irp/doddir/army/ar95-23.pdf, accessed 12.01.09.

would be hugely expensive with the ever-increasing speed of modern combat. An autonomous IM would not be lacking in vigilance however, as boredom is a human condition, and could constantly scan its environment with acute and continuous attention to detail even after weeks of constant operation.

This vigilance leads to another effectiveness enhancing advantage. An autonomous IM with situational awareness updated to the split second as a result of constant attention to sensors, coupled with super-fast processing of sensor information and decision options, would be capable of reacting to enemy action virtually instantaneously. It is feasible for example even with today's technology, that an autonomous IM equipped with sniper detection systems such as Rafael's Spotlite infra-red muzzle flash detecting system[239], could identify and locate a sniper's shot, determine a course of action, orient and return fire with deadly precision before the sniper's bullet even reaches its target. Such a rapid reaction speed would clearly be advantageous.

Another advantage offered by an autonomous IM over one that is teleoperated is the potential for an aggregated multi-spectral three-dimensional and 360° perception, as discussed in the Drivers section. While human operators could conceivably achieve this by focusing on different portions of various sensor feeds and communicating these back to the operator, the result would be horrendously manpower intensive, unwieldy and slow. This almost omniscient situational awareness coupled with instantaneous reactions, would leave the enemy with little chance to achieve

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[239] *Rafael reveals Spotlite small arms fire detector*, Jane's Defence Weekly, February 16, 2005, http://www.rafael.co.il/marketing/SIP_STORAGE/FILES/8/608.pdf, accessed 12.01.09.

surprise, let alone hide. Ceding control of IMs from human teleoperation to AI thus presents tantalising benefits for IM operational effectiveness.

Militaries employing IMs will potentially gain several economies by granting them autonomy. While completely removing the ‘man in the loop’ with respect to all IMs is unlikely in the near term, the level of involvement demanded from human operators could be greatly reduced through increased autonomy, with humans providing more general direction rather than micro-management or fulltime hands-on control. Consequently, the span of control of human operators would grow considerably, allowing them take charge of many IMs at once. In this way, either personnel numbers could be reduced, or more IMs employed. Both are attractive outcomes. Autonomous IMs able to process their own sensor take will further ease manpower demands by reducing the requirement for information management; that is, highly skilled personnel processing large amounts of ISR data and assimilating it into usable intelligence.

As more of the operator’s workload is passed off to increasingly autonomous IMs, the level of training required of those operators will also decrease. Physically ‘driving’ the IM, maintenance and resupply tasks, and even locating, identifying and engaging targets may be passed off to AI control in future, freeing the operator from training for these tasks. Any reduction in required training is desirable for a military organisation, as time that personnel spend training could be spent instead on operations or core business tasks, not only for the trainee, but also for necessarily high skilled and thus valuable trainers. Training is also typically expensive.[240]

By removing the requirement for constant high capacity datalinks to manually control and constantly monitor IMs, automation of IMs will also reduce the demand placed on scarce communications bandwidth. As it is now already in high demand for other applications[241], any reduction of the new burden imposed by IMs will be welcome, as well as permitting the employment of larger numbers of IMs. This reduction of communications traffic and IM connectivity would also lessen the need for Computer Network Defence (CND) and defensive EW measures. Diminished communications traffic would reduce the opportunity for enemy elements to electronically interfere with the control of IMs, and thus the need for friendly forces to shield against this vulnerability. As a result, personnel requirements would be further reduced.

The ability to 'fight smarter' represents a major potential benefit of autonomous IMs. Networked formations of IMs with shared situational awareness and synchronized decision making and coordination will conceivably be capable of previously impossible feats of military organisation, as discussed in the 'Drivers' section. With sufficient connectivity and freedom of action, this formation may 'think' and act as a single entity (discussed in the following chapter), disposing itself for the greatest overall effect in response to its directives, enemy dispositions and the surrounding environment. In this

[240] Yaakov Lifshitz, *The Economics of Producing Defense: Illustrated by the Israeli Case,* Springer, Jerusalem, 2003, p.139.
[241] Wired: *Military Faces Bandwidth Crunch,* http://www.wired.com/techbiz/it/news/2003/01/57420, accessed 14.11.08.

model, the formation's actions and reactions would be extremely fast, forgoing the need for staff planning processes, lengthy detailed briefings and the percolation of plans down the chain of command,[242] thus greatly improving operational tempo. Total awareness of all elements within the formation would also enable extremely efficient employment of resources, with no identified enemy unnecessarily targeted more than once. The speed and accuracy of this near instantaneous collective planning and execution would be extremely difficult for human enemy command elements to contend with.

Finally, the 'cold bloodedness' of autonomous IMs detailed in the Drivers chapter will effectively remove human emotion from decision making. Ego, anger, shame, fear, and pity will have no bearing on IM decisions. As discussed, this will preclude deliberate violations of military law such as massacres, desertion, mutiny, or rape. At a command level, all elements will willingly cooperate without the impedance of clashes of personality or parochialism that have historically plagued military organisations.

Regardless of alarmist fears then, real concerns do exist regarding the automation of warfare, including the consequences of malfunction, the vulnerability of software to acts of sabotage, the lack of clear human accountability, potential dislocation of tactical activities from strategic intent, and the risk of exploitable predictability. If these concerns can be addressed however, the potential benefits of IM automation, including enhanced individual IM effectiveness, manpower and resource economies, and the

[242] In fact these activities will still occur in a way, though near instantaneously by substituting the planning staff with super-fast AI computing, and disseminating plans as packets of data that are instantaneously understood.

ability the ‘fight smarter’ are so significant, they could represent a new revolution in military affairs (RMA). With this in mind, if adequately functional AI is achieved, its application to warfare in some capacity is almost inevitable.

In the near term, with AI technology lagging behind other technological IM precursors, the benefits of unmanned ground systems will have to be harnessed through the use of teleoperation. Despite the above mentioned shortcomings of teleoperation for the control of IMs, this method of control does offer some benefits of its own, and counters some off the weaknesses and risks of autonomous control. The first of these is that a human operator can be integrated into the chain of command without difficulty. This ensures that control is maintained over activities at the tactical level, and also that someone is responsible and accountable for those activities, and would give great comfort to politicians and military leaders alike.

The abilities of the human intellect also offer some advantages over the probable state of AI in the near term, including the capacity for unpredictability, use of intuition, and initiative. Where, as discussed, an autonomous IM may be exactly predictable in its behaviour if armed with the data upon which it bases decisions, this is by no means the case for humans, whose decisions may be shaped by a raft of superfluous influences, such as personal prejudice, their mood at a given time, or even whether they slept well the previous night. Furthermore, human creativity, discussed in the Obstacles section with respect to achieving surprise, adds another layer of complexity and unpredictability to human decision making. When influenced by erroneous data and creativity, it is unsurprising then that human decision making is highly unpredictable.

Intuition gives the human mind the ability to make frequently appropriate decisions in the absence of clear or obvious evidence. The subconscious or conscious analysis of scant observed data or patterns against previous experience and relevant knowledge can result in a 'gut feeling', that may warn the point man of a patrol of an impending ambush, or prompt a general that the time has come to commit his reserve. For less spectacular instances, this ability is often referred to as 'common sense', where the correct decision in a given situation is so apparently obvious that it requires no explanation, and is arrived at without conscious reasoning. Of course, in the case of the patrol point man, distance from the actual situation as a result of teleoperation may result in their missing cues of sound and smell that could trigger this intuition. Nonetheless, this ability gives significant advantage to the human intellect. As such, AI researchers have attempted to replicate this process and endow their synthetic minds with common sense and intuition, but in doing so have discovered the actually enormous complexity of the task. It requires the accumulation and understanding of a veritable mountain of data equivalent to a life time's experiences, lessons, and knowledge; a process known as epistemology[243], as well as the ability to draw analogies and comparisons across a wide range diverse of domains of knowledge. Until this colossal task is undertaken, AI will lag far behind the human mind in this critical field.

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[243] Keith DeRose, Yale University, Dept. of Philosophy, *What Is Epistemology? A Brief Introduction to the Topic,* http://pantheon.yale.edu/~kd47/What-Is-Epistemology.htm, accessed 14.01.09.

The capacity to use initiative is another advantage of teleoperated IMs. The combination of creative thought with a sound understanding of a higher commander’s intent enables human soldiers following the doctrine of mission command to act on their own initiative to further that intent. New Zealand Army Brigadier Howard Kippenberger displayed such initiative during the Second World War, when tasked by General Freyberg to take the mountain of Garci in Tunisia in order to cut off retreating German forces. Upon nearing Garci, Kippenberger realized the mountain was far too large to be taken and held, and holding it would not properly cut off the German retreat. After reconsidering the purpose of Freyberg’s orders (his intent), he instead dismissed Garci and attacked Enfidaville and Takrouna, which lay across the German escape route.[244] While an autonomous IM may also act independently in a way meant to fulfil the commander’s intent, the absence of creative thought will limit its ability to identify opportunities to do so. In any case, such a degree of latitude for IMs to determine their own course of action would no doubt rest uneasily with politicians and military commanders in the early years of IM automation. In contrast, human soldiers, utilising their capacity for creative thought, may combine available resources and potential courses of action in a completely novel, unorthodox or even counter-intuitive way to satisfy this intent.

It would appear then that the majority of autonomous control’s short comings will be addressed with the passage of time, as the field of AI continues to

[244] H. Kippenberger, *Infantry Brigadier*, Oxford University Press, 1949, p. 300-303.

develop, and as doctrinaires develop methodologies for the appropriate integration of AI into military decision making processes. Tele-operation may in fact provide the bridge for this to occur, acting as a crutch to support technology that will enable autonomous IMs upon reaching maturity. As mentioned in the Drivers chapter, many tasks on the battlefield are now automated, including a significant amount of functions in manned fighting platforms, and this is an ongoing trend. The same tendency is also occurring with unmanned ground vehicles (UGVs), such as Elbit Systems' Guardium UGV employed by the Israeli Defence Force[245]. This mixture of teleoperation and automation, a kind of 'meeting half way', is known as 'semi-autonomy', in which the operator acts as a sort of minder and supervisor for the IM, stepping in to take control when the autonomous control system encounters difficulties[246]. Efforts are presently underway to better develop this cooperative form of IM control, including one concept, 'collaborative control', in which the IM 'will ask the human teleoperator questions to obtain assistance with cognition and perception during task execution'[247]. The medium by which human operators interact with IMs, or Human-Robot Interface (HRI), is also an area of rapid development. Brain-Computer Interface technology (BCI), as mentioned in the Timeline chapter, may soon be employed for IM control, linking the human brain directly to the IM without the need for cumbersome joysticks, keyboards and other peripherals while

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[245] Alon Ben-David, *Technology Audit: Elbit – Trading on innovation,* in Jane's Defence Weekly, 28.05.08, p. 27.

[246] Jennifer L. Burke, Robin Roberson Murphy, Erika Rogers, Vladimir J. Lumelsky, Jean Sholtz, *Final Report for the DARPA/NSF Interdisciplinary Study on Human-Robot Interaction,* in IEEE Transactions on Systems, Man, and Cybernetics – Part C: Applications and Reviews, vol. 34, no. 2, May 2004, p. 103.

[247] Charles Baur, Terrence Fong, Charles Thorpe, *Robot as Partner: Teleoperation with Collaborative Control,* The Robotics Institute, Carnegie Mellon University, Pitsburgh, Pensylvania, and Swiss Federal Institute of Technology, Lausanne, Switzerland, p. 1.

greatly enhancing situational awareness and responsiveness. This form of cybernetic IM control will be discussed further in the following chapter. As these technologies link IMs more intimately with their human operators, this may provide an opportunity for IMs to learn from them, much like an apprentice learning a trade. If learning AI[248] can be integrated into semi-autonomous IMs and those lessons learned by IMs can be centrally collated, then over time as IMs gain more experience in simulation, training and actual combat, the accumulated experience and knowledge of all IMs may provide the basis for improved AI and a significant advance towards enabling total IM autonomy.

Thus, in spite of AI's present weaknesses and the various issues currently restricting autonomous IM employment, the benefits offered by autonomy will undoubtedly provide sufficient impetus to propel this technology along a continuing path of development for military applications. In the two decades remaining until the subject year of 2030, progress in this field will lead to significantly more autonomous IMs. However, it will very likely continue to be beneficial for a human operator to remain involved in directing the actions of IMs on the battlefield, albeit in a minimal, managerial-type capacity, particularly in complex or delicate roles such as those involving combat.

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[248] Nils J. Nilsson, *Introduction to Machine Learning,* http://robotics.stanford.edu/~nilsson/mlbook.html, accessed 04.02.09.

Chapter Four: What Organisational Architecture? Methodologies of utilisation, command and control of IMs

"With conflicts of this type, you have to organize to fight. There's nothing sacrosanct about a battalion: 700 guys, four companies. Why can't you organize 700 guys into 70 10-man teams? Or 100 7-man teams? ***Again, the combat situation, the milieu, must dictate how you organize.****"*

--Colonel Paul Melshen USMCR[249]

How IMs are to be organised and utilised will be a defining characteristic of their presence on the battlefield. The organisation of conventional military forces has fundamentally changed little in the past thousand years, involving hierarchical pyramid-type structures vertically distributing control and authority over discrete bodies of soldiers (as shown in figures 1 and 2 below[250]), and

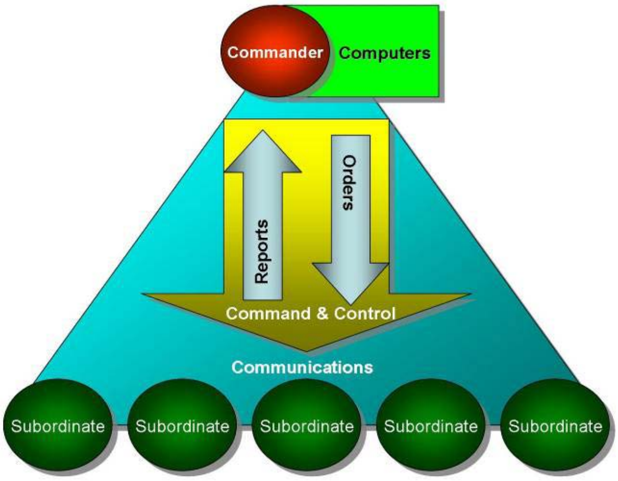

Figure 4: The C4 System - Illustrates the process of command and control, with orders and reports flowing between the commander (supported by computers) and subordinates, through the medium of communications.

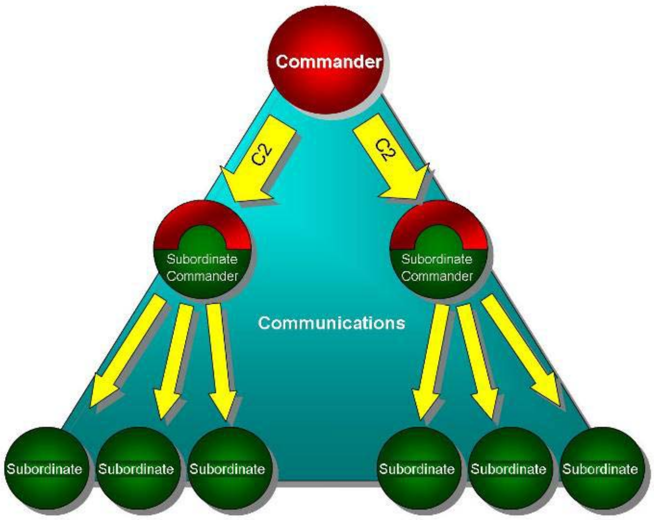

Figure 5: Chain of command - Illustrates the scalable hierarchical nature of command and control.

[249] Michael Hanson, COIN Perspectives From On Point: Lessons Learned in Iraq, in Small Wars Journal, www.smallwarsjournal.com.
[250] NZ Army, *Capability Concept Paper: Command, Control, Communications and Computers (C4),* Version 1.7: Nov 2008, p. 7.

has been limited by the cognitive, administrative and social capacities and behaviours of humans in high stress situations. These biological realities have served to maintain the status quo of the organisation of fighting forces in spite of technological advances in communications and information technology, and have led to a range of different enduring principles of command. Notably, 'Span of Control' limits the number of a commander's direct subordinates to around five, 'Unity of Command' ensures there is only one commander in control of a unit at any time, 'Chain of Command' ensures the hierarchical downward flow of authority through military organisations, and 'Continuity of Command', which ensures a force will remain under effective command in the event of casualties, commander fatigue, equipment failure or relocation of command elements.[251] If autonomous or semi-autonomous IMs are to be utilised in large numbers, particularly in exclusively IM units, then these long existing human-centric paradigms of organisation, command and control may radically change. This chapter will examine potential organisational changes resulting from such a situation.

The first question arising from this potential new state of military affairs is who will be in charge of formations of IMs? This is an important question, as, if a nation's military includes large formations composed exclusively of autonomous IMs, then this amounts to a massive amount of combat power that is politically and morally neutral, and thus will unquestioningly do its master's bidding. A mechanised brigade, manned with volunteer human

[251] New Zealand Defence Doctrine Publication, *Command and Control in the New Zealand Defence Force (NZDDP–00.1),* p.1-6.

soldiers, for instance, represents a formidable fighting force that is essentially under the control of a single person, a Brigadier or equivalent high ranking officer. However, the compliance of that brigade with the orders of its commander will be contingent upon the lawfulness of those orders, the loyalty of that brigade's personnel to their commander, or the compatibility of the orders with their moral or political convictions. Thus the brigade commander's control over his/her unit, far from being absolute, is restricted by the compliance of subordinate personnel, limiting the ends to which he/she may employ it. Therefore without significant loyalty or shared beliefs amongst his subordinates, the commander cannot wield this formation to undertake illegal activities such as coups, ethnic cleansing, criminal enterprise or other nefarious acts. In the case of an equivalent brigade of IMs however, the same is not true and therefore one person may gain exclusive and absolute control over substantial destructive power. Thus, another check on the power of the military commander must be identified. This situation is analogous to that of the control of nuclear weapons; their unchecked power is such that authority to employ them must be gained from the commander in chief or equivalent national executive[252]. While control of tactical nuclear weapons is somewhat looser, it is still sufficiently restrictive and cumbersome that the feasibility of their timely employment against fleeting tactical targets in the European theatre during the Cold War was doubtful.[253] Similar checks would likewise prove overly cumbersome for the effective employment of exclusively autonomous IM units. The ability for superior commanders to quickly seize

[252] Robert D. Critchlow, *CRS Report for Congress Nuclear Command and Control: Current Programs and Issues,* Foreign Affairs, Defense, and Trade Division, May 3, 2006, p.6.
[253] Allan M. Din, *Arms and Artificial Intelligence,* Stockholm International Peace Research Institute, Oxford University Press, 1987, p.118.

control of the IM force where it is being employed inappropriately by a subordinate commander appears to be a more practical response. This however would depend on communications connectivity with the formation at the time of recall, which will not necessarily be assured. Another possibility would be the sharing of authority over the IM formation among a group of commanders who would be required to agree upon the broad manner of utilisation, as a form of legal and ethical committee (as loathsome as the concept will appear to military professionals) before that formation would respond. This represents a violation of the principle of 'unity of command', but may be necessary in place of subordinate soldiers imbued with morals, ethics and free will.

This predicament is unlikely to manifest itself in the case of formations composed of mixed human-IM teams, or where IMs are merely utilised as the slave-tools of human soldiers, but this utilisation will preclude many of the potential advantages offered by IMs that have been previously discussed. Though the previous chapters of this thesis have concluded it unlikely that human soldiers will have exited the battlefield by 2030, and will instead operate alongside IMs at small unit level, there will still undoubtedly be a role to be played by exclusively autonomous IM formations if their level of sophistication permits it. Thus the manner in which IMs will operate alongside humans at small unit level will be examined here, followed by the possible arrangement of purely IM formations.

Traditionally, mankind's mechanical creations have been utilised merely as tools, and this has applied to the field of robotics up until the present as well[254]. Teleoperated control of IMs would continue this historical paradigm, fundamentally differing little from a spear or shovel in this respect. Automated machines, such as industrial robots, perform tasks on command and repeat as required, but are still dependent upon human planning. Semi-autonomous or even fully autonomous IMs, employed as subordinates at the small unit level, would still at best be comparable to slaves, limiting their usefulness to the bounds of their master's ability in instructing them. A team of robotics experts at Carnegie Mellon University however have been working to develop a new method of control, dubbed 'Robot as Partner', or collaborative control, which may more usefully harness IMs in this team arrangement[255]. It envisions the human partner serving as a resource for the IM, with the IM asking for assistance in cognitive or perceptive matters when its own faculties are insufficient to fulfil a given task. Furthermore, the IM may weigh this advice based on its knowledge of the human's expertise and prior accuracy against evidence provided by its own sensors and AI, and discard it where appropriate. This collaborative control could greatly increase the span of control of human teleoperators in the case of semi-autonomous IMs, or allow more useful, natural and efficient interaction with human team members where autonomously operating within a small unit.

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[254] Charles Baur, Terrence Fong, Charles Thorpe, *Robot as Partner: Teleoperation with Collaborative Control,* The Robotics Institute, Carnegie Mellon University, Pitsburgh, Pensylvania, and Swiss Federal Institute of Technology, Lausanne, Switzerland, p. 1.
[255] Baur, Fong, Thorpe, p. 2.

Autonomous IMs operating in exclusively unmanned formations may lead to a more dramatic reordering of organisational structure. The nature of this structure will be depend upon the related variables of AI capability, network capacity, the number of IMs employed, and the operating environment, with options including centralised, decentralised, or ‘swarm’ control. Centralised control represents the organisational ideal for military forces. In this model, there is a single point of decision making, with ISR and status reporting information flowing from subordinates to the commander, and resultant decisions detailing courses of action then flowing back down to subordinates (see figure 1). It enables the total and efficient coordination of all resources towards a common goal in a synchronised manner. In reality however, the ensuing burden of control will quickly overwhelm the capacities of even the most capable commander and staff, with decision and information overload resulting in a dramatic loss of operational tempo and extremely sluggish reaction to events, not to mention the probable nervous breakdown of the commander. Furthermore, the compounded minuscule problems and difficulties that inevitably arise from warfare to make its conduct more difficult (known as friction) become concentrated at the point of decision, further compounding the problems at this single point of control. The volume of communications traffic resulting

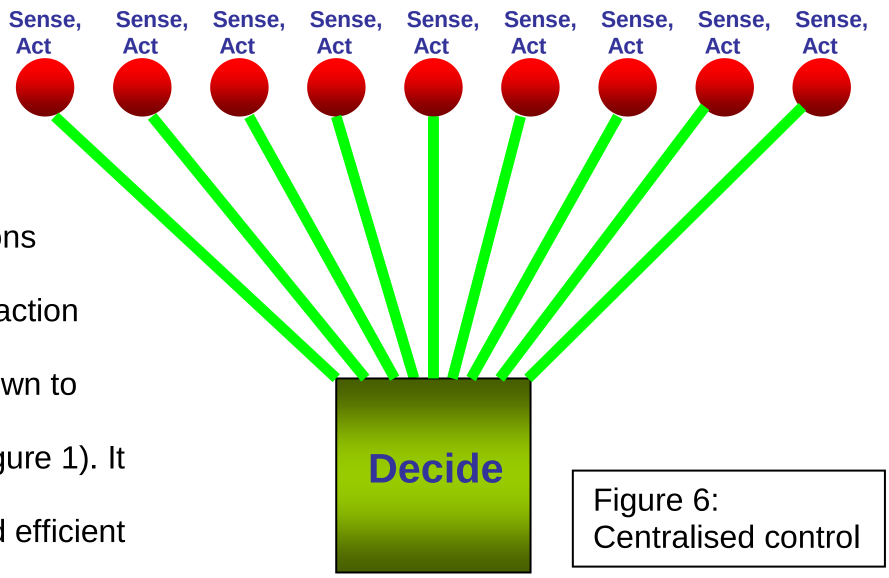

Figure 6: Centralised control

from the need to give prescriptive instructions to every subordinate unit and in turn receive reports will also rapidly overwhelm network capacity, particularly where voice communications are involved.[256]

If this centralised model can be applied to the control of formations of IMs however, several of the human-related problems will be removed. Providing sufficiently powerful and sophisticated AI can be developed, a single commanding intelligence could centrally control the execution of a human-devised operational scheme, rapidly churning through the masses of incoming information to generate and transmit detailed individual courses of action for each small unit or even individual IM in support of this scheme. With adequate AI, information overload will not be a problem. Furthermore, communication between information systems as opposed to people is vastly more efficient[257], requiring far less data to be transmitted by removing the requirement for images or voice communications necessary to enable human cognition. Centralisation will therefore be achievable for formations of a size bounded by the processing capacity of the controlling AI entity and the communications capacity of the network linking it to its subordinate units. Centralisation of decision making would also allow centralisation of computational intelligence, meaning less AI would need to be embedded in IMs. As a result, IMs would consume less energy, be cheaper to manufacture, and if captured, would betray less of their valuable technology. While the centralised controlling

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[256] Manuel De Landa, *War in the Age of Intelligent Machines,* Swerve Editions, New York, 1991, p. 61.
[257] Wired: Military Faces Bandwidth Crunch, http://www.wired.com/techbiz/it/news/2003/01/57420, accessed 04.02.09.

entity may represent a single point of failure, and as such, a natural target for enemy action, this problem would be avoided simply through the addition of multiple distributed redundant command AI systems that are linked to ensure a current operational understanding: upon the destruction of one, another could seamlessly take over control. The threat of electronic interdiction of command datalinks remains extant however.

Human military organisations have overcome the problems associated with the centralised model of control simply by decentralising it. In this model, control authority is devolved and distributed to subordinate nodes throughout the organisation, and exercised at a more local level (see figure 2 below). Thus tactical decisions are made at a much lower level, localizing flows of ISR and control information. Higher levels of control concern themselves only with the level immediately below them, directing subordinate elements in more broad terms and providing them with objectives which they may achieve in a manner of their choosing. In this way, the information that must be processed at any one point is reduced to a manageable level, and friction is also dissipated throughout the organisation

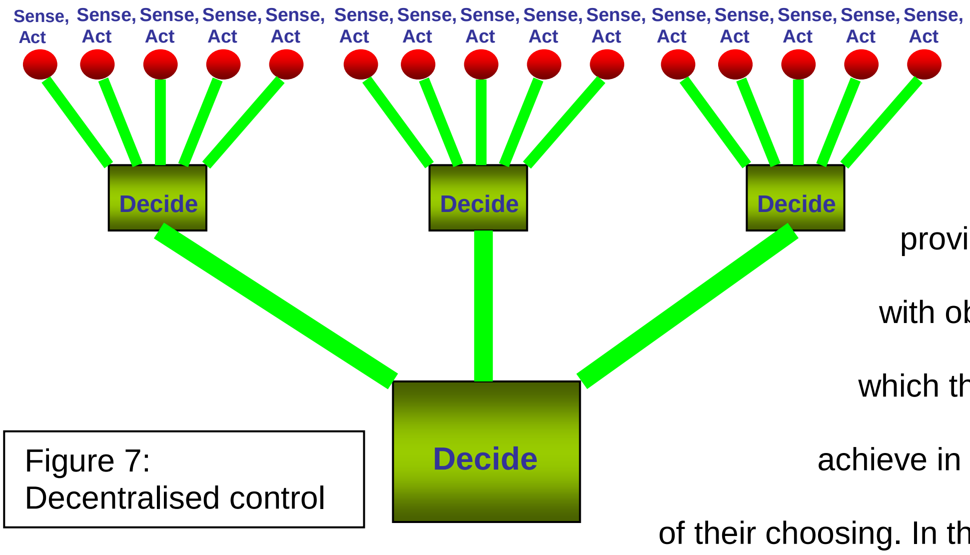

Figure 7: Decentralised control

rather than being accumulated as an overwhelming amount at a single point[258]. The total volume of communications is also reduced, and the end result is an improved tempo of operations, along with the preservation of commanders' mental wellbeing. This is achieved at a cost in the degree of coordination and synchronisation of the total formation, with individual control entities operating in a more isolated manner without the benefit of a comprehensive understanding of 'the bigger picture', and so potentially losing some synergistic opportunities. For IM formations, this model could be applied where AI processing and communications network limits are exceeded, but may result in suboptimal employment of resources.

A final alternative model of control is the swarm. In this model, the formation of networked IMs merges its collective artificial intelligence as a cohesive whole, acting in effect as a single entity[259] (see figure 3 below). Thus each IM shares its sensor take with the entire formation, and then decisions are made as a whole, with communications dissipated throughout the web of inter-IM linkages rather than being channelled through centralised bottlenecks. This collectivisation would

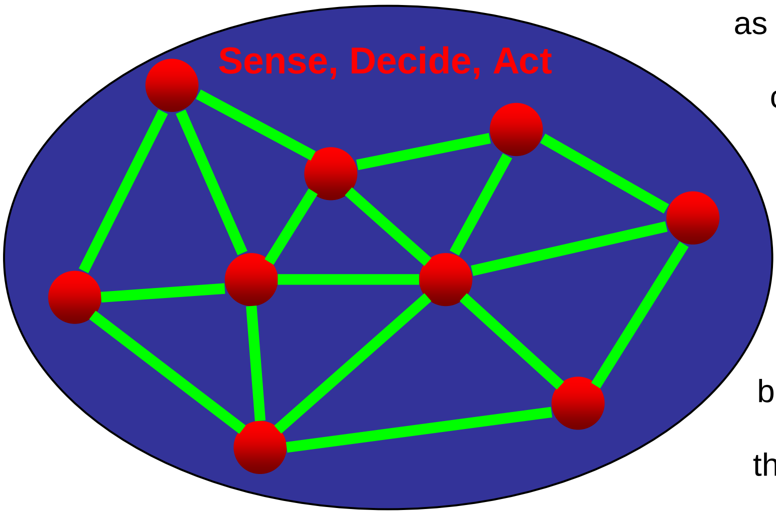

Figure 8: The Swarm

[258] Martin Van Creveld, *Command in War,* Harvard University Press, Cambridge, 1985, p. 192.
[259] Swarm-Robotics.org, http://www.swarm-robotics.org/, accessed 04.02.09.

result in immense computing power, similar to today's 'botnets', which harness millions of computers together via the internet through the introduction of malicious software, after which their collective computing power is employed for nefarious purposes such as spamming and denial of service attacks[260]. The closest human military organisational resemblance to this swarm model is the Al Qaeda terrorist network. After its central command structure was severely disrupted as a result of Coalition operations against its bases in Afghanistan, Al Qaeda shattered into numerous semi-independent cells and organisations linked tenuously together by common ideology and aims[261]. These have since loosely collaborated with one another, although this collaboration has largely been curtailed through the compromise of their communication linkages by opponent intelligence services. As the swarm model is dependent on harmonious collaboration between all its constituents, it is not well suited to humans, who are prone to disagree and oppose one another as a result of differing opinions and beliefs, clashing personalities, or dominant egos and ideas of self-importance. As IMs require no idea of 'self' however, their alignment into a swarm organisation would suffer no such obstructions, depending instead on the ability of communications to effectively link them together. This will require a high capacity, high speed network similar to a MANET. The web-like linkages of this network would provide a high degree of redundancy, and so make electronic interdiction of communications much more difficult. Advantages of this Swarm arrangement include total coordination and synchronisation of the formation, rapid unified

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[260] BBC News: Criminals 'may overwhelm the web', http://news.bbc.co.uk/2/hi/business/6298641.stm, accessed 22.01.09.
[261] STRATFOR - *Al Qaeda in 2008: The Struggle for Relevance,* http://www.stratfor.com/themes/al_qaeda, accessed 28.01.09.

reaction, and the ability to degrade gracefully due to the lack of a single point of failure; destruction of constituent IMs will be addressed through a realignment of communications and result in a degradation of performance proportional only to the fraction of the swarm destroyed. Achieving this swarm will require significant advances in networking and AI technology, however as society becomes increasingly interconnected both locally and globally by information technology, demand for such networking technology will be high and drive its continuing development.

The swarm model thus appears to be the optimal mode of organization for exclusively IM formations, particularly where operating beyond practical communications with human commanders, due to its advantages in coordination, synchronization, dissipation of communications, and resilience. It does however require the most trust of the above three models of organisation from human decision makers, as it will offer little opportunity for direct control of individual IMs but rather be directed through instruction provided to the swarm as a collective. Centralisation on the other hand offers total control of individual subordinate IMs where the human commander is available to exercise it, while the decentralised model offers a mid-point, with potential control of subordinate controlling entities. As such, a progression may occur over time from a centralised model, with IM formation size beneath a human commander determined by AI and network capabilities as well as the degree of authority allowed to be taken up by the controlling AI, leading to decentralisation with larger IM formations and less control of individual IMs as trust in AI control grows with experience, and culminating in swarm formations once AI technology has proven itself truly trustworthy and the required network technology is mature.

Another aspect of military organisation that may be altered by the eventuality of exclusively IM formations will be the manner in which formations are geographically disposed. Currently, military command structures are by and large arranged around geographic localities, or ‘areas of operations’ (AOs), with force elements exclusively responsible for their own AO. This arrangement assists in the orderly coordination of forces and prevents fratricide, with all forces in the same area being subordinate to the same point of control. Passage through one formation’s AO by another is thus a complicated exercise, requiring a high degree of planning and liaison[262]. Ideally, forces assigned to an AO will belong to the same unit or formation, enhancing coordination by way of familiarity generated through shared experience and training. More often however, and particularly in recent times, elements of various different units and formations will be grouped together, or ‘task organized’[263], due to the requirement of various specialist capabilities each possesses, or simply because of a lack of available full strength formations. Nonetheless, these disparate units will be unified under a single point of control, ensuring ‘unity of command’ within the AO. While some exceptions do exist, such as Special Forces, such instances are rare and

[262] US Army, FM 3-90, *Passage of Lines,* http://www.globalsecurity.org/military/library/policy/army/fm/3-90/ch16.htm, accessed 04.02.09.
[263] New Zealand Army Future Land Operating Concept: *Precision Manoeuvre 2020,* New Zealand Army, 2007, p. 2-26.

generally opposed by those controlling the AO[264]. Such an arrangement also makes a certain degree of sense for IM formations, as communications flows would be localised and therefore range requirements reduced, limiting the power required of communications equipment and corresponding EM signature. Situational awareness within that AO would also be shared amongst the formation, providing dense and overlapping sensor coverage.

There are other possible arrangements arising from the special characteristics of IMs however. Familiarity with one's formation is irrelevant in the case of IMs, and their total situational awareness of friendly forces removes the requirement for fratricide control measures. Formations of IMs could therefore overlap, sharing the same geographic space. As a result, the area where formations meet, which has traditionally presented a point of weakness, would now become a buttressed hard point. IMs could also be organized by role rather than as groupings of capabilities, for example with formations of air defence, logistics and communications IMs spreading themselves across the broader battlefield for optimal efficiency and effectiveness, and passing between them only information necessary to their purpose, while still providing service to all areas. In this way, instead of discrete geographically defined groupings of capabilities inhabiting their own AO under a single command structure, capabilities could be layered overtop of one another and provide services and effects across a much wider area; like the separate utility

[264] New York Times: *British Criticize Air Attacks in Afghan Region*, http://www.nytimes.com/2007/08/09/world/asia/09casualties.html?fta=y, 04.02.09.

providers across a large city rather than the centrally controlled and localised infrastructure in neighbouring villages.

Another possibility is to do away with formations completely. If swarm technology is sufficiently capable, it may be possible to deploy IMs on to the battlefield as a single amorphous 'blob' with mixed capabilities scattered within, in a similar manner to colonies of ants[265]. Where the swarm encounters challenges or reaches objectives, it could dynamically task IMs depending on their proximity to the mission, and prioritise the assignment of resources based on the perceived relative importance of each mission. Individual types of IM could still be concentrated in areas where their specialisation is predicted to be required, in a way that ensures a mutually supporting combination of different effects at a given point, or on terrain that suits their level of mobility, but beyond this it appears needless to rigidly geographically organise IMs for long periods of time when operating under a swarm arrangement. If this fluid swarm organisation is achievable, then logistical support could be greatly simplified. Supplies and services could be delivered in a distributed manner to various centres of mass, and IMs simply utilise those logistics elements that are most convenient to reach, as opposed to the stove-piped and inefficient servicing of individual formations and units separately. Thus swarm technology could enable a much higher level of force responsiveness and resource efficiency.

[265] National Geographic: *Swarm Theory,* http://ngm.nationalgeographic.com/2007/07/swarms/miller-text, accessed 04.02.09.

A final, perhaps more distant possibility for the organisation and control of IMs is to utilise human commanders in a cybernetic relationship with IMs. As medical science reveals more about the inner workings of the human brain, and BCI technology progresses, it may become possible to integrate the 'minds' of human controllers and IMs, putting the human mind inside the shell of the machine. Furthermore, humanity may soon be capable of augmenting the capabilities of the human brain with the addition of powerful data processing and storage apparatus, and so expand the span of control the human brain is capable of[266]. In this model, the human mind and controlling AI would merge together, combining the strengths and shielding the weaknesses of both, while also ensuring a human is embedded in the decision making process at the tactical level. Even if this arrangement is technologically achievable however, it will undoubtedly lead to serious ethical and moral objections from certain sectors of society. However, with applications far beyond those of the military, pressure for its utilisation will be similarly compelling.

It is clear then that IMs have the potential to revolutionise the way armed forces are organised and controlled, depending on the development of AI and communications technology, the willingness of political and military decision makers to cede control over warfare to machines, and the level of popular opposition to certain enabling technologies. Providing checks to ensure the potentially awesome power of IMs is not abused by those in control will

[266] Thomas K. Adams, *Future Warfare and the Decline of Human Decisionmaking,* in Parameters, US Army War College Quarterly, Winter 2001-02, p.64.

become necessary, and a transition back to much more centralised military organisation or to a revolutionary new swarm model could have a profound impact on warfare, as could the negated requirement to organise forces according to discrete pieces of geography. Within the time bound by the subject year of this thesis, progress made in the field of AI could potentially enable the largely automated control of formations consisting exclusively of IMs, however the teaming of humans and IMs together within units will likely remain the norm within this period.

Conclusion

The eventual employment of semi-autonomous and autonomous machines in land warfare is all but inevitable. This technology is presently being aggressively developed by arms manufacturers globally and actively pursued by those militaries capable of acquiring and deploying it. By the subject year 2030, their potential usefulness offers at least a reduction in casualties and at best a true Revolution in Military Affairs. The potential benefits offered by IM technology are massive and wide ranging, and some will view them as a panacea to all of the difficulties and limitations presently facing modern ground forces. Those of such an opinion will likely drive the development and uptake of IM technology into military applications on the ground, yet it is wise to heed the words of General William Tecumseh Sherman on this matter: "Every attempt to make war easy and safe will result in humiliation and disaster."[267] History is replete with promises of 'Silver Bullet' technology that would solve all of warfare's messier problems; one only has to consider Donald Rumsfeld's dream of military supremacy founded on network-centric information dominance, since brutally snuffed out in the streets of Iraq's bloody post-invasion insurgency. This thesis has not attempted to assess the lasting impact IM technology will have on warfare, or what adversary responses will be in any depth, but merely identify the likely nature of its employment at the year 2030 in response to the operational context at that time.

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[267] ThinkExist.com: *William Tecumseh Sherman quotes,*
http://thinkexist.com/quotation/every_attempt_to_make_war_easy_and_safe_will/172017.html
, accessed 04.02.09.

The first element of this employment examined by the thesis was the matter of proportion; what portion of ground forces fielded by Information Age militaries of the West will consist of IMs. As such, the first chapter identified factors promoting the adoption of IM technology, including casualty reduction, potential capability advantages over human equivalents in detection threshold, situational awareness, survivability and expendability, firepower and lethality, speed and mobility, endurance, and ‘cold bloodedness’, as well as cost efficiencies, erosion of enemy combat motivation, and psychological shock. These were then weighed against perceived barriers to IM development and employment, which included technological milestones that need be achieved and complexities that must be overcome, the increasingly complex land operating environment, significant IM specific vulnerabilities requiring shielding, the undoubtedly weighty cost of procurement, as well as a range of legal, institutional, ethical, moral and social objections and technicalities. The interplay of these drivers and obstacles, their developing environmental context, and technological milestones, were then mapped with respect to time, in order to assess both the desire and the capability for IMs to be utilised in ground warfare by the year 2030. This process indicated that while it is unlikely that IMs will have completely usurped the role of humans in the conduct of ground warfare at year 2030, they will in all likelihood outnumber their human counterparts. Human combatants remaining on the battlefield were deemed likely to carry out the ever-shrinking number of largely human-centric tasks unable to be performed effectively by IMs, and to exercise tactical command and control over man and machine.

The second element of IM employment examined was in which roles IMs will likely be employed. By way of an analysis of predicted IM capabilities against the present day Battlefield Operating Systems construct, numerous different roles in which IMs could be utilised were identified in the second chapter. Initial uptake and human replacement was found likely occur with the Combat Service Support, Ground Based Air Defence, Offensive Support, Intelligence Surveillance and Reconnaissance, and Mobility and Survivability BOS. Information Operations, and particularly Command, Control and Communications and Manoeuvre, were seen as likely to take longer as they will demand more sophisticated capabilities and entail some difficult and controversial organisational and legal integration issues. The expendability of IMs was found to offer a range of new and highly effective tactical options to commanders, such as 'kamikaze' attacks, utilization of obsolete platforms, and dangerous raid type missions, due to the acceptability of a higher level of risk. As well as finding their own space amongst the existing order of warfare therefore, IMs may therefore broaden the range of activities undertaken on the battlefield.

Addressing the element of roles for IMs also involved an investigation of the likely form of IMs undertaking those roles. An examination of the predicted future land operating environment, of military organisations, and of emerging IM related technology revealed battlefield IMs will probably be mass-produced in a limited series of basic designs, and fitted with task-specific specialist components. Quantity rather than quality was seen as likely to take precedence, though cutting edge technology would still be widely utilised. They will be most likely be compact, avoiding unnecessary bulk, and therefore smaller than human or manned equivalents. Initially, IMs will resemble present day ground platforms, but will probably tend towards more biological forms with time, and potentially take on an anthromorphic form as related technology advances, especially where utilised in urban environments. Early IMs were assessed to probably make use of tracks or wheels for mobility, and turrets for weapon mounts, though later models will potentially be fitted with legs and manipulator arms for better utility and mobility. A degree of logistical self-sufficiency will be desirable, with the ability to conduct self-replenishment and conduct rudimentary self repairs. The battlefield's future IM inhabitants will thus be at once sophisticated, utilitarian, and cheaply mass produced.

The third element of IM employment addressed by the thesis was the question of autonomy: how much autonomy would be afforded to battlefield IMs by the year 2030? The third chapter entailed an examination of the risks and benefits of autonomy, as well as an analysis of the alternative of teleoperation. The variable was identified to have a profound influence on the future IM presence, including IM behaviour, IM population size, and the method and scope of IM utilization. It was assessed that the continuous ceding of ever increasing autonomy is unavoidable, due to benefits of both effectiveness and convenience. Though hindered by the rate of advancement of enabling technology, such as AI, and the many legal and social hurdles to be negotiated, increasing autonomy will continue to be granted to IMs in increments over time. By 2030, it was assessed that IMs will in general possess a high degree of autonomy including the ability to make lethal decisions in some cases, with limited instances of full autonomy possible for some specialist roles. However, it was found likely to remain beneficial for human operators to remain involved in directing the actions of IMs on the battlefield, though in a minimal, managerial-type capacity, particularly in complex or delicate roles such as those involving human interaction and combat. While teleoperation was found to avoid many of the obstacles impeding automation of IMs, this would come with costs in effectiveness and span of control.

The final element of IM employment considered by this thesis was the matter of organisational architecture, or the structures and mechanisms through which IMs will be organised and controlled on the battlefield. Chapter Four found that while the organisation of conventional military forces has fundamentally changed little in the past thousand years, the combination of IMs and AI technology has the potential to revolutionise the way armed forces are organised and controlled. Constrained by the state of AI, communications technology and the willingness of political and military decision makers to cede control over warfare to machines, the advent of battlefield IMs may see a progression from centralised organisation through to swarm organisation, where formations of IMs will act as part of a single networked cognitive entity. This swarm organisation was seen to offer considerable benefits in effectiveness. Potential concerns were identified regarding the amount of unchecked power IM formations could give to their commanders, and possible checks to mitigate this concern were examined. It was assessed that progress made in the field of AI and network technology could potentially enable the largely automated control of formations consisting exclusively of IMs by the subject year 2030, however the teaming of humans and IMs together within units will likely remain the norm within this period.

In summary, research conducted in this thesis suggests that by the year 2030, IMs will outnumber human soldiers on the battlefield, be employed across most roles on the battlefield other than those that are particularly human centric, be produced with an emphasis on quantity rather than quality, possess a high degree of autonomy, and be organised predominantly in IM-human teams at the small human level though with the potential for centrally organised or swarmed exclusively IM formations. Key variables that will affect these outcomes include the frequency, intensity and scale of warfare over the next twenty years, commoditisation of IM technology and subsequent civilian market growth, AI development, portable power source development, development of social attitudes towards IM technology, and the occurrence of serious IM related accidents. It is of course important to remember that the prediction of future events is by no means an exact science, and the simple linear extrapolation of trends over such a timescale is seldom mirrored in subsequent events. Nonetheless, as IM progression will largely be governed by the more regular march of technology rather than the erratic activities of human beings, such an extrapolation is certainly a worthwhile exercise in revealing the future state of affairs regarding IMs on the battlefield.

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