Technology Trend Survey

Future Emerging Technology Trends

A Food-for-Thought Paper to Support the NATO Defence Planning Process

HQ Supreme Allied Commander Transformation,

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September 2011

Foreword

Technology is progressing at exponential speed. Moore's Law epitomizes this condition of technological improvement that drives related technosocial change. Laptops, cell phones and mobile multimedia that were a novelty some 20 years ago are commonplace today, and have become essential elements of western civilization and are growing in importance in developing areas of globe. The rapid change in technology over the coming decades will almost certainly have a significant impact on the character of war and on how military operations will be conducted in the future.

Technological superiority has been a considerable advantage in past conflicts. To maintain the superiority that the Alliance has had to date, it will be important to develop an understanding of possible emerging technologies that have the potential to be disruptive in their application and how existing technologies may progress as they are improved or as complementary technologies are developed. The uncertainty and complexity associated with the technofuture is considerable, but this should not dissuade the Alliance from, at least, describing the bounds of the possible problem space.

Tools and techniques for foresight are available to assist in this effort. Foresight can best be understood as a set of approaches that bring together long-term considerations to support present day decision-making. By engaging a broad and diverse set of informed stakeholders in a process of dialogue and analysis, the most important characteristics of the future can be derived and broad assumption can be made about the vectors of future progression. These then can be codified and disseminated in formal products.

This Technology Survey represents a holistic approach to technology foresight that can best be understood as a “guide book” to emerging technologies. It will be updated in close recurring intervals as the technological environment is sensed for signals that could lead to future disruptive technologies. This document is the first in a series that will elaborate on emerging technologies, and related threats and opportunities for the Alliance, so that NATO can exploit those areas and maintain its technological superiority as it addresses security issues in the future.

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1. INTRODUCTION

1.1 Background

"A number of significant technology-related trends – including the development of laser weapons, electronic warfare and technologies that impede access to space – appear poised to have major global effects that will impact on NATO military planning and operations." (NATO Strategic Concept, 2010)

The emerging future environment will be complex as the world shifts from one of simple systems to one where components of the environment are interconnected and make up parts of systems that can create greater impact than the sum of the individual components. Relations and interconnections within these complex environments are no longer linear as components are more strongly coupled by increasing globalisation and networking. Within these systems, there can be fundamental disproportionality between cause and effect. Small changes can sometimes result in large effects while, conversely, big changes can sometimes have little effect. Complex environments also exhibit emergent behaviour where novel properties arise that could not be predicted from examining the components of the system. Much of this increasing complexity is brought about by the increasing power of technology and its diffusion throughout societies around the globe.

Past war and conflicts have shown that technology changes how battles are fought. Strategy and tactics are changing due to the availability of new technologies. These technologies will be one of the major drivers of future kinetic and non- kinetic operations. For this reason, today's military planners and capability developers need to think systematically about possible future technological developments. This process cannot be limited only to technology in classical weapons development sense, but must extend also to possible future novel or hybrid threats and societal changes evolving from underlying technology developments. By developing an understanding of possible threats, anticipating technological change and forecasting possible emerging technologies, military organizations like NATO can manoeuvre to be able to seize the advantage and associated opportunities by making better decisions today about tomorrow’s capability requirements.

The aim of this technology survey is to propose a description of important technologies and their military implications out to time horizon of 2035. The intent is not to make predictions, but only to provide a survey of where technology could progress in the future as one of the foundations to the derivation of long term aspects of the Minimum Capability Requirements (MCR) within the NATO Defence Planning Process (NDPP). This task is even more difficult today than in the past given the exponential acceleration of progress in many technology sectors forecast in the coming decades.

To paraphrase Bill Gates, co-founder of Microsoft, people tend to overestimate technology progress in the short term and tend to underestimate its progress in the long term. This is driven by overconfidence in the first instance and a lack of acknowledgement of exponential progress in the second instance. Technology, in general, supports systems. To be successful, systems normally require several supporting or complementary technologies that must all come to fruition before the system itself becomes viable. This makes the task of forecasting difficult as one must examine progress across all the supporting technology components prior to looking at the overall system.

This paper is meant as follow-on to the initial research done in 2005 under the auspices of the Long Term Requirements Study. In addition to that work, primary research efforts have focused on leveraging the technology forecasts done by TECHCAST, a continuous technology forecasting activity conducted within George Washington University, and the Technology Horizons Program at the Institute for the Future (IFTF). This was supported by additional open source research to compile technology trends that would impact on military operations.

Research for this paper considered only open source material for two reasons: (1) to allow this paper to be considered and commented upon by the broadest possible audience, and (2) most other closed assessments do not look sufficiently far in the future to add value to this survey. Open source information provides a large amount of material that describes innovative technological developments from a variety of sources including Academia, Foresight Institutes, Governmental Agencies, World Wide Web, Technical Magazines, and Technical Reports and Papers.

1.2 Research Principles

The following guiding principles were used in the research process of this trend analysis:

- Only ***open source*** qualitative data is used throughout this paper in order to make this product as accessible as possible to peer review.

- This paper does ***not*** seek ***to predict*** the future only highlight areas where technology may impact military operations out to a time horizon of 2035.

Though a military perspective is used throughout this document in bringing forward an analysis, this survey is not focused solely on military systems. It also examines areas where the impact of technology on society may have a concomitant impact on military operations in general

1.3 Derivation of Long-Term Aspects of the Minimum Capability Requirements (MCR)

The primary purpose of deriving the long term aspects of the MCR is to describe areas that will require Science and Technology (S&T) effort today in order to fulfil current and anticipated requirements that are likely to arise in the future. These shortfalls will be driven by: (1) a current requirement that has no mid-term solution; (2) developments in the strategic environment requiring new capabilities; (3) evolutions in the threat environment that will negate a current capability; and (4) significant improvements in capabilities as a result of changing technology. Under the NDPP, the derivation of long term requirements is a joint effort that consolidates multiple inputs. Figure 1 illustrates how the different contributions are bundled in the process.

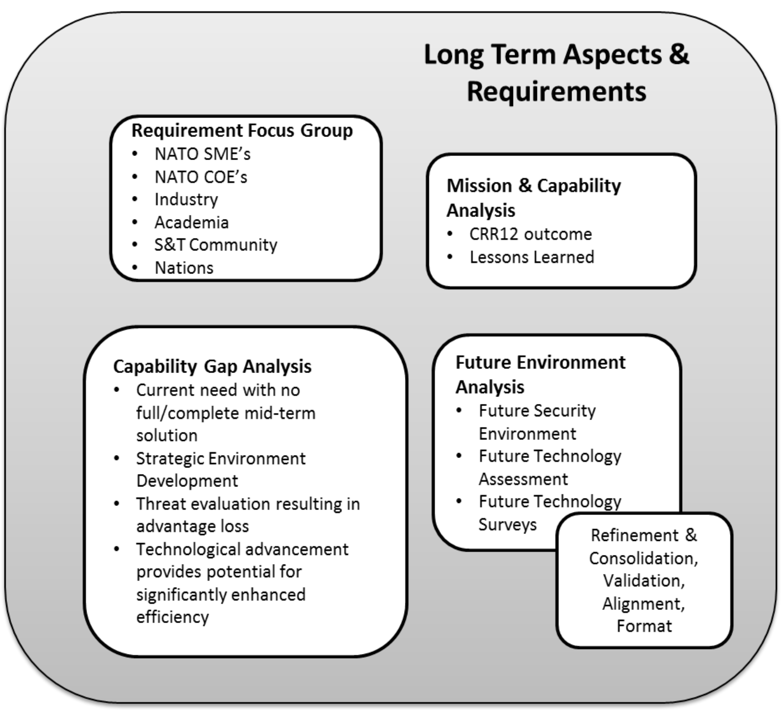

Figure 1: Long Term Capability Derivation Methodology

This survey provides the future technology input into the process of examining the future security environment.

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2. METHODOLOGY

The goal of this chapter is to describe the methodology for the technology trend analysis used in this paper. This process consists of the four steps shown in Figure 2. Prior to commencing the study, work was done to define its focus. This survey is not specifically focused on weapons systems, but is rather kept open to the description of emerging technologies, their related societal impacts and possible implications on military operations. This is the first attempt at what is anticipated to be a series of iterations. It will lay the foundation for what is intended to be a continuous process of persistent horizon scanning that will be improved on an annual basis.

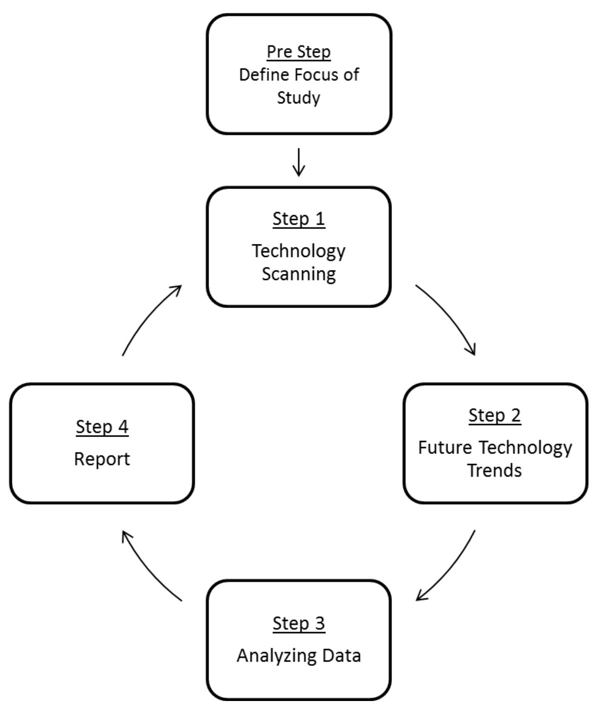

Figure 2: Research Methodology

Within Step 1, information gathering occurs. The purpose of this step is to develop an exploratory view that examines data in a structured way. In this case, scanning of the technological environment was conducted for emerging technologies that could lead to future technological threats/opportunities in six domains: Communication, Sensors, Information Systems, Platforms, Effectors and Logistics.

The objective of Step 2 is data processing. Within this step, an evaluation of the significance of gathered trends and emerging technologies is conducted. As stated earlier, the data is examined from a military perspective. The outcome of Step 3 is the future technology trend analysis and the associated linkage of the trends to the six research domains. These trends could represent threats, opportunities or both. Finally, in Step 4, the report is prepared. It acts as the connector back to the Step 1 and the recommencement of what must be a continuous technology trend scanning process.

3. TECHNOLOGY TREND ANALYSIS

Trend analysis is a steady recurring process that improves the robustness of future capability development over time.

The rate of technological progress is accelerating at an exponential rate. This is driven by a number of factors. The most important of which is rapid improvements in the computation speed of information systems. Moore's Law states that this increase in computational speed will continue to double every 18 months. Added to this is the fact that 80% of the scientists that ever lived in the history of the planet are alive today and exchanging information in real time[1] and driving improvements in manufacturing processes and materials that will continue to drive this growth supporting even more exploration and exploitation of discoveries in a self-reinforcing cycle. For the military, a generational change in how operations will be conducted could be brought about by the emergence of new technologies.

A RAND Corporation[2] study postulates that there were four Revolutions in Military Affairs (RMA) in the 20th century brought about by new technology: RMA 1 (1914-present) consisted of the development of land/air/maritime combat vehicles; RMA 2 (1930-present) involved irregular/revolutionary warfare; RMA 3 (1944-present) nuclear weapons, long range ballistic and cruise missiles were developed; and RMA 4 (1954-present) precision weapons and networked warfare became the norm. In another description of these types of progressive phenomena (Irvine and Schwarzbach), which relates technology and socio-

[1] Dr. Marvin J. Cetron, Technology's Promise, William E. Halal, 2008, p. xiv

[2] http://www.rand.org/

economic development, socio-technological progression can be graphed through a number of ages as depicted below (Figure 3).

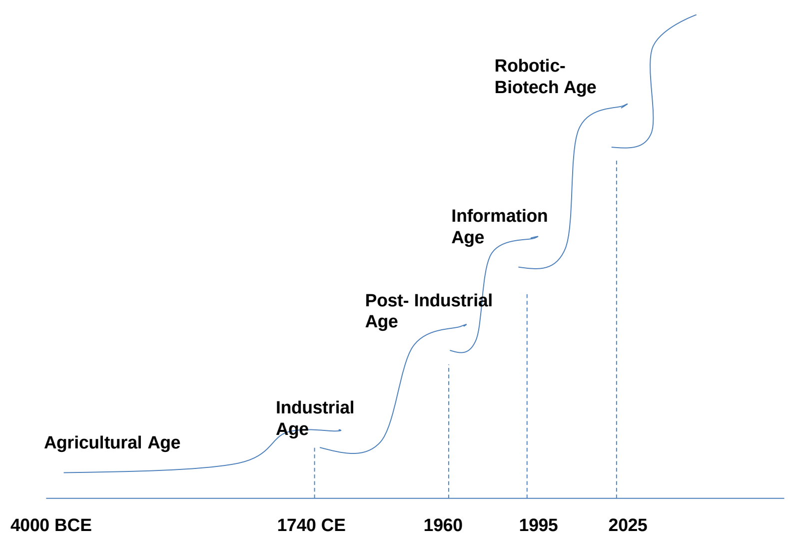

Figure 3: Socio-Technological Progression (from Irvine and Schwarzbach)

Given the increasingly rapid progress in technology, the likely introduction of new systems could bring about a new generation of military operations possibly driven by anti-access systems that negate some of the Alliance force projection strengths and, further in the future, by robotics and bio-technology.

Isaac Asimov wrote that “the saddest aspect of society right now is that science gathers knowledge faster than society gathers wisdom.” The diagram below (Figure 4) describes how unregulated areas can develop in policy and law as technology progresses faster than regulation.

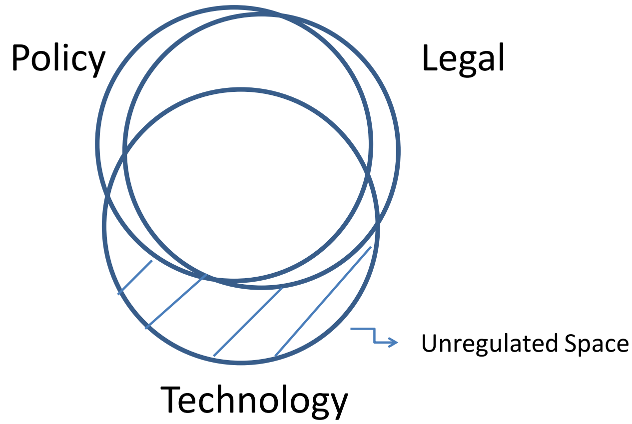

Figure 4: Venn Diagram of Law, Policy and Technology

Rapid technology advances have placed technology itself ahead of the policy and legal regimes that are required to regulate its use – leaving unregulated spaces within which adaptive adversaries have an opportunity to operate. The development of policy structures and legal regimes to regulate the use of emerging technologies requires international and interagency cooperation, which is usually a time consuming process that allows the technology to exist within regulatory vacuums for some time.

The lack of adequate legal and policy frameworks within international organizations, nations and agencies within nations allows opponents to take advantage of the unregulated space that inevitably develops between policy, legal statutes and technology.. This is particularly evident in cyberspace, which by its nature crosses many borders and regulatory boundaries. The Council of Europe Convention on Cybercrime is an example of an international instrument that seeks to define jurisdiction and procedures to be taken against criminal acts that could be initiated, conducted and completed in different nations. These regimes must be sufficiently flexible to deal with states, non-states and individuals whether acting alone or as proxies for another organization and must find a way to deal with the problem of attribution. Deterrence will require being able to identify the actors that are orchestrating the threat in order to be able take appropriate actions to deter or negate the threat.

A final point relates to the changing paradigms of conflict that have become more apparent in the last decades and will continue into the coming decades – that being the changing relationship between the use of physical force in conflict and the use of information and cognitive processes (Figure 5).

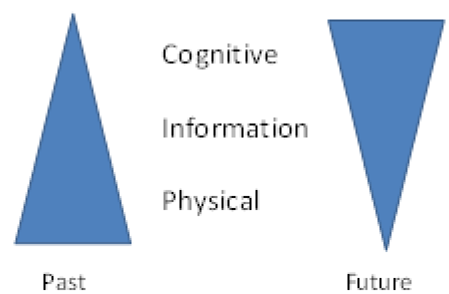

Figure 5: Changing Relationship

The nature of conflict will remain a contest of wills between opponents and will likely always include physical confrontation, but more so in the coming years might the information and cognitive domains become the primary components of most campaigns as the character of conflicts change to reduce the emphasis given to physical force.

3.1 Technology Scanning Domains

This Section describes the technology domain scanning process from Step 2 of the research methodology. Here the findings of the source scanning are partitioned into the six domains depicted in Figure 6. This table is used to graphically illustrate the cross-domain behaviour of several technologies with emerging potential. Many of the other technologies highlighted in this survey will exhibit similar behaviour across the domains, and could act as either an opportunity or a threat for NATO depending on their application.

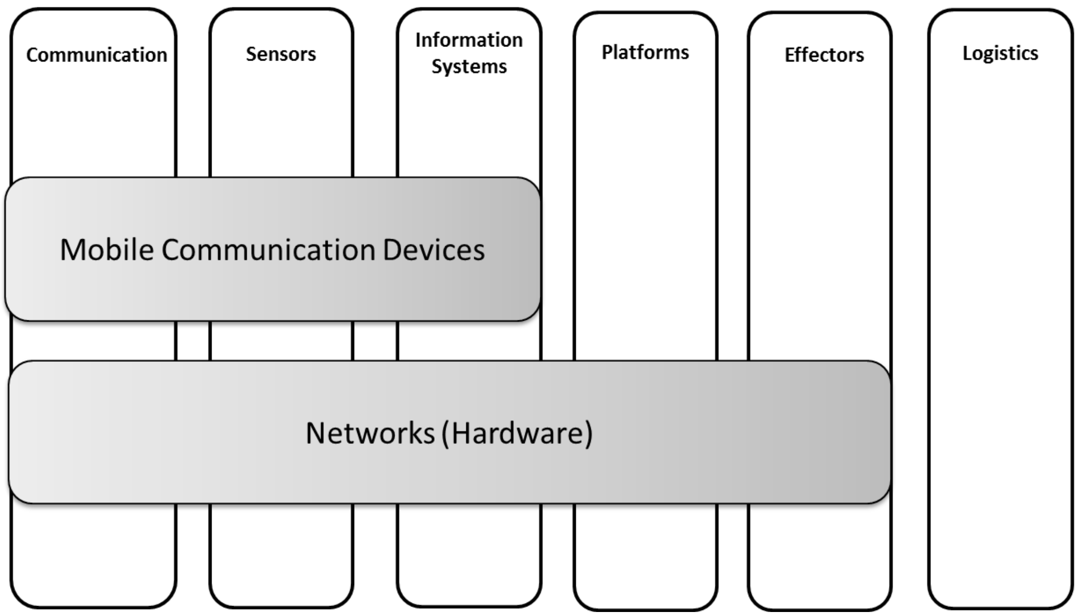

Figure 6: Technology across Domains

A particular technology could be crucial for further development of a specific capability across multiple domains by acting as a supporting or complementary technology. For example, the growing importance of mobile communications devices (MCD) as a major communications component (discussed in more detail in Chapter 4.2.1) is becoming obvious. The evolution of MCD and the increasing amount of associated applications has served to turn the “cell phone” into a revolutionary device that is capable of sensing a broad range of conditions from human behavioural emotion to geospatial location through the use of Global Positioning System (GPS). A survey of emerging, associated technologies shows that tomorrow’s mobile phones will be equipped with facial recognition and will have the computational power to perform simultaneous language translation to name just a few. Soon every person will be able to record, comment on and post video/pictures from anywhere on anything. This leads to the conclusion that MCD will play an important role in several domains - communication, sensors and information systems but also as system that provides the needed technology to influence and to impact or even change behaviour of human beings. These behaviour changes can be done in either direction, good or bad. Figure 6 includes another similar example of Networks (Hardware).

4. EMERGING TECHNOLOGY TRENDS

Emerging technology trends and new scientific discoveries will change the way future generations will spend their life time. They will broach new territory in some significant way. In many cases, it is likely that the exploitation of emerging technology developments, and their associated applications, will have impacts beyond their intended design within broad, diverse areas such as communication, games, mobility and energy. Moreover, these same emerging technologies will find their way into military systems and impact on future conflict.

The proliferation of technology and the dual use nature of most commercial-off-the-shelf electronics components also make it possible for states to incorporate cutting edge technology into indigenous sub-systems creating significant improvements in capability. It also allows non-states and even individuals to gain access to capabilities that have heretofore been held only by states. This will increase the range of actors that NATO will have to consider as it scans the horizons for technology-driven threats.

Figure 7 provides a summary, derived by TECHCAST, of the technological revolution foreseen in the year 2000 for the coming decades. It reveals very important insights to the future of technology out to the year 2040. This figure describes the confidence level assigned by experts within the specific technology domain on the timeframe when a particular technology could enter the mainstream.

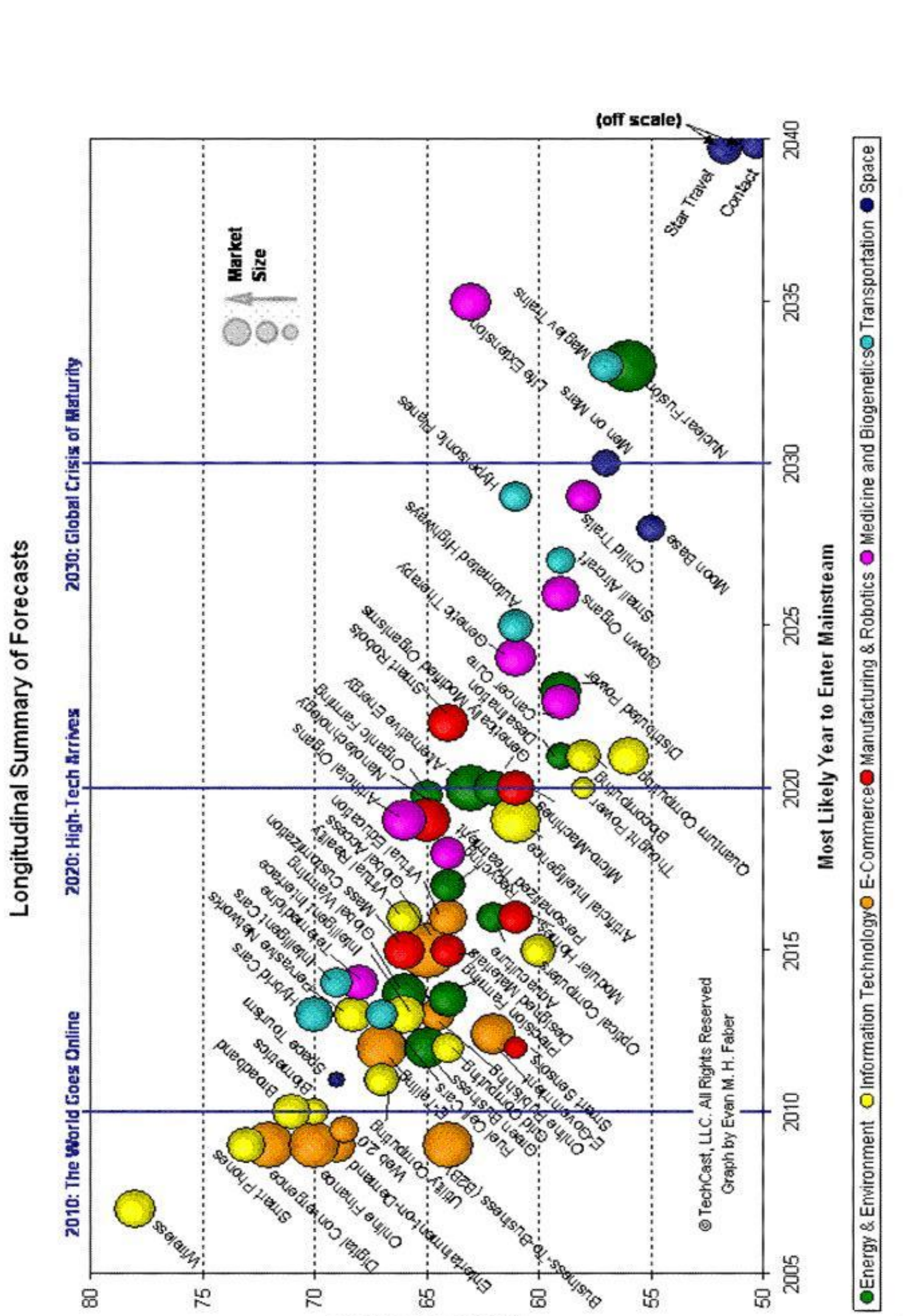

Figure 7: Technology Revolution (from TECHCAST)

4.1 Technology Evolution versus Technology Revolution

This Section looks at the definitions of the terms- evolutionary and revolutionary technology. This analysis revealed that, in many cases, a strict definition of whether a particular technology was evolutionary or revolutionary was impossible. In other areas; however, a separation between the two was useful. For this reason it is deemed necessary to be precise in how the terms are used.

4.1.1 Definition Evolutionary Technology

The definition of ’evolutionary’ found in the Oxford Concise Dictionary (COD) (online): “[Evolution is] the gradual development of something, especially from a simple to a more complex form.”

Another useful definition of this term can be found in the Merriam-Webster Dictionary: “[Evolution] is a fundamental change in the way of thinking about or visualizing something: a change of paradigm…” Furthermore “[Evolution] is a changeover in use or preference especially in technology…” (Merriam- Webster, 2011).

4.1.2 Definition Revolutionary Technology

The term revolutionary is defined by Oxford Concise Dictionary. [Revolutionary] “Involving or causing a complete or dramatic change.”

Merriam- Webster’s definition states revolution as “a fundamental change in the way of thinking about or visualizing something: a change of paradigm. It describes a changeover in use or preference especially in technology.” (Merriam-Webster, 2011)

In many instances the analysis of historic data revealed, that a single evolved technology became a revolutionary technology when other evolutionary technologies were added. It holds true that the commercialization of cell phones in the mid 1990's where discussed as an evolution of the landline phones. The development of small, powerful computer chips and rechargeable batteries made the cell phone a powerful tool which changed the cell phone user's behaviours dramatically. Today a world without cell phones is unthinkable as users have come rely on instant access to information.

4.2 Technology Trends in Communication

The Institute for the Future[3] describes the basis of future communication as an evolution of **three key technologies**: wireless communication, sensors and semantic technologies[4] within computer science. Within these technologies, a spectrum of context aware applications will be shaped. These key technologies will be incorporated into personal devices and networks. Networks are built through a combination of hardware and software. This Section discusses the findings of the trend survey in this area and its interconnections with other domains.

Of the current world population, 29% already use the Internet to interact with other people. This percentage is supported by the significant spread of high density communication lines and related hardware systems across the planet. The continued proliferation of the means, supported by new communication technologies, will increase internet penetration within current and new areas of the world. The movement toward **cloud computing** will allow multiple users and uses to leverage shared information from a network of hardware, software applications and databases. Open Flow applications, which generate a more efficient flow of information, and improvements in the capacity of networks to carry information, will significantly improve the availability of bandwidth necessary to support this growth.

Command and Control (C2) modernization heavily depends on telecommunication upgrades because most governments and militaries lease communication lines from commercial providers. Widespread construction of

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[3] www.IFTF.org

[4] Semanitic technologies bring the meaning and context behind words and sentences — to the world of computers. http://www.wisegeek.com/what-is-semantic-technology.htm

fibre-optic lines and worldwide upgrades to digital switching has improved the reliability, security, and speed of national and strategic C2 communications.

The way human beings interact with new technologies and other human beings will change over time and is influenced dramatically by new and emerging technology. One trend will see tomorrow's MCD integrated with on board technology that will be able to "sense" the behaviour, attitude, issues and needs of the user and communicate them through the network to other network users. This will be supported by **ubiquitous computing** and vast networks of machine-to-machine (M2M) interfaces that will monitor the environment and assess changes necessary to maintain optimal conditions. M2M links whereby sensors send data to a central computer using cellular networks have become more prevalent today and will continue to see significant growth in the coming decade. Currently used to monitor vehicle fleet telematics, parking meter and some health devices, they will find significant other uses in the future.

Organizations will use humans or software applications to harvest this huge amount of information that will be resident within databases. Sophisticated analytics will use this information to development knowledge on human behaviour and other issues. The use of GPS in contemporary MCD represents the initial step toward using sensors to track the motion of users and provide geo-location data that will position the user within augmented realities wherein he/she will have access to entirety of the information resident in the 'cloud'. These trends separately could be considered as evolutionary trends, but together they will drive a revolution in the uses of future MCD.

Figure 8 illustrates the progression of sensor technology from simple to smart sensors. One of the main milestones in this progression is the use of Intel's Wireless Identification and Sensing Platform (WISP). WISP combines passive radio frequency identification (RFID) together with sensors to build a specific contextual communicating and sensing device. These devices will have many commercial and military applications. For example, accelerometer measuring devices in remote and hostile places can be used to monitor and report the motion of humans and other objects. This capability of M2M will spin out a host of applications for surveillance, smart grids and system health monitoring.

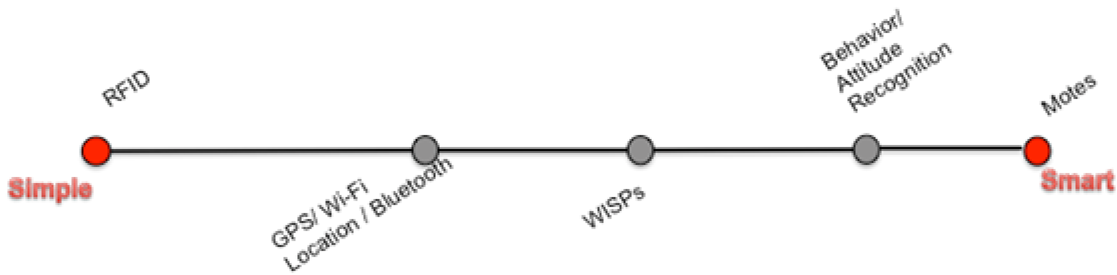

Figure 8: Sensing from Simple to Smart Sensors (from IFTF)

This change in how communications is being done is described by IFTF as a movement from closed form to open use. Figure 9 shows this evolution of communication networks from closed to open forms. Along the progression from closed to open form, technology is used in a more effective way as platforms for open networks. Zigbee[5] can be deployed in combination alongside fixed closed network services. More energy efficient than WiFi networks, Zigbee will be used in small, low-power digital radios that can be formed into networks of sensors. The size of these networks can be increased/ decreased by adding/ removing Zigbee nodes to or from the network mesh. At the open end of this progression, **Mesh networks** will be used to route messages autonomously between devices,

[5] From Wikipedia: ZigBee is a specification for a suite of high level communication protocols using small, low-power digital radios based on the IEEE 802.15.4-2003 standard for Low-Rate Wireless Personal Area Networks (LR-WPANs), such as wireless light switches with lamps, electrical meters with in-home-displays, consumer electronics equipment via short-range radio needing low rates of data transfer. The technology defined by the ZigBee specification is intended to be simpler and less expensive than other WPANs, such as Bluetooth. ZigBee is targeted at radio-frequency (RF) applications that require a low data rate, long battery life, and secure networking.

bypassing other devices and closed networks. The insertion of longer range radio systems will increase the geographic range of the network. This open form of network will be the foundation of future communication methods.

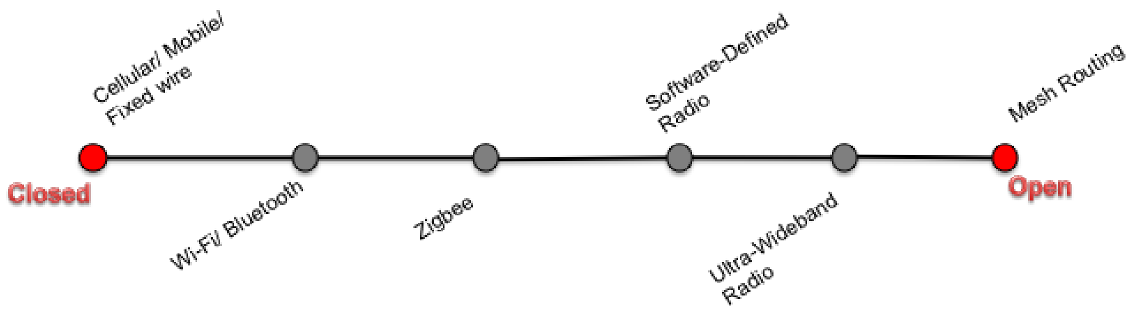

Figure 9: Communications: from Closed to Open Form (from IFTF)

Software-defined radios are computer controlled allowing them to be re-programmed to accommodate new functionality rather than requiring a costly replacement. This flexibility allows an aircraft to more easily work with other aircraft, ground and naval forces. Increased processing power also provides better security through encryption and frequency management techniques.

4.2.1 Mobile Communicating Devices (MCD)

Tomorrow's MCDs will revolutionize warfare. Forecasts show that by 2015 50% of global computing power will be done from mobile device[6]. Applications are even now being developed to **share intelligence, translate languages**, **provide navigation** and **targeting data**, and **gather** and **share biometric information**.

Exchanging information with a data cloud is now a basic operation. The development of communication nodes to allow data exchange in austere environments is more complex. Deployable wireless networks that attach to vehicles, UAVs, aerostatic balloons will provide the necessary connectivity.

[6] http:// memeburn.com/2011/02/the-future-of-smartphones/

MCD’s combined with **cognitive networks** and **software defined radios** will be able to choose from best available radio frequencies and waveforms to reduce interference and thus increase their usability. Video call functionality when combine with speech translation processing will facilitate the exchange of information between forces - reinforcing the ability of commanders to transmit their intent throughout the area of operations, and thus bring greater focus and convergence on the objectives of a campaign with all stakeholders.

Future MCDs will be increasingly versatile. **Speech recognition** will replace conventional keyboards as the primary interface with MCDs. Even today, GOOGLE[7] has demonstrated speech recognition that is very efficient. MCDs are likely to replace desktops and laptops in most applications. Open connection protocols will change the way in which these devices will be used.

Augmented Reality (AR) will become the norm in the coming decades. Either through contact lenses or eye glasses, personnel will be able to view information while maintaining visual contact with the surrounding environment. Sensors and M2M communications over networks will allow presentation of a wide variety of data to the wearer. Computer vision (CV) and auditory sensors will supplement AR with the means to begin to recognize and understand the environment. This will allow AR systems to support personnel identification through **facial recognition** and person-to-person conversation with simultaneous speech translation. Initial steps toward this AR capability are available today with systems such as Google Goggles and efforts to improve CV is on-going with experiments demonstrating very good results in bounded environments. The evolutionary development of these applications in the commercial sector will cumulate in revolutionary new capabilities for military forces.

[7] www.GOOGLE.com

The proliferation of computing devices in nearly all environments calls for significant enhancements in their configuration and interconnection. These computing nodes or hubs will be, for the most part, wirelessly interconnected in a plug & play way. Strong access control and authentication services will guarantee the integrity of these wireless networks.

Trends in Mobile Communication Devices:

Smart devices using Augmented Reality, Computer Vision, Artificial Intelligence

- Open network hierarchy, leveraging/ expanding existing communication networks
- Improved energy efficiency
- Multiple sensor implemented
- Speech recognition with language translation functionality
- Cognitive networks
- Software defined radios
- Face recognition

- **Smaller**. Increasing miniaturization will provide ever more functionality at the same cost. The integration of new technology with computing devices will enable the seamless integration of devices in a networked environment.
- **Seamless.** Computer and radio integration will allow a seamless connectivity for roaming devices. More populated areas of the developed world and more advanced developing areas will have ubiquitous wireless internet access.

4.3 Computer Technology

Abundant research has allowed transistors and circuits to continuously surpass the limits of their material foundation - silicon. This has allowed Moore's Law[8] to continue unabated resulting in exponential growth in computing power (Figure 10).

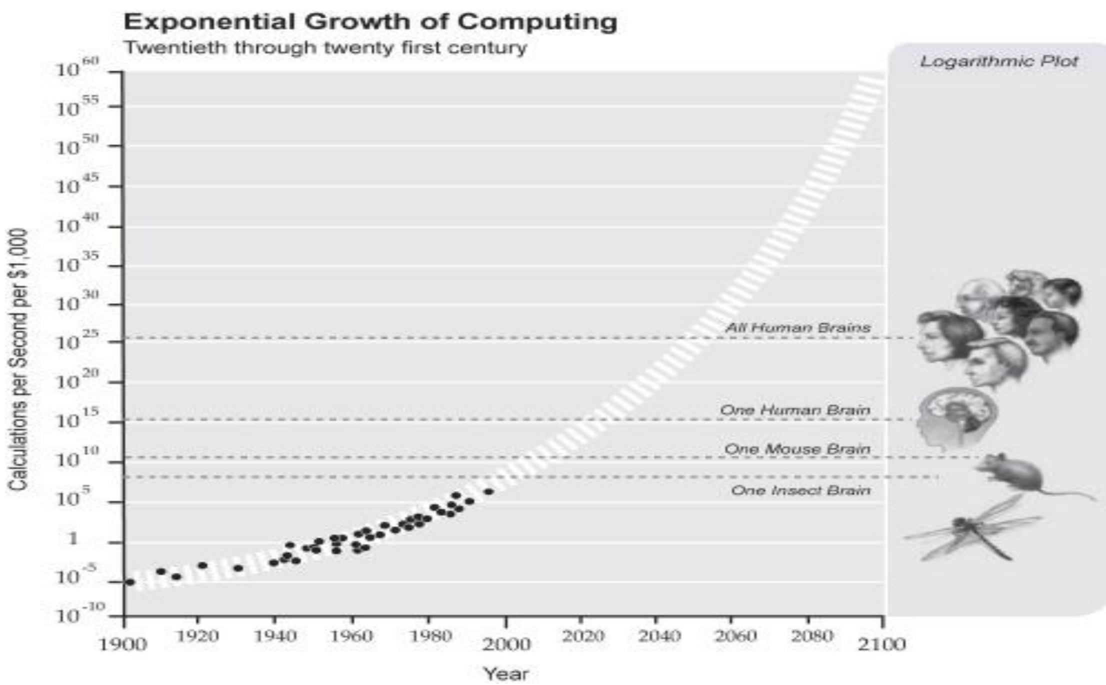

Figure 10: Exponential Growth of Computing (from Kurzweil)

While manufacturers will continue to meet the challenge of the dimensional shrinking of microelectronics, in the next 10 to 15 years, they will

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[8] The Intel Co-Founder, Gordon Moore stated :"*The number of transistors incorporated in a chip will approximately double every 24 months."*

http://www.intel.com/about/companyinfo/museum/exhibits/moore.htm begin using another foundational material. The molecular structure of silicon at the atomic level will eventually present a limit to the number of transistors that can be added to computer chips.

Development of materials such as **graphene** to replace silicon as the primary constituent of computer chips and constructing **3D chips** will allow the continued growth of computing speeds while reducing the build-up of heat within the components. Other emerging technologies, such as carbon nano tube (CNT) field effect transistors that can operate at higher speeds, will support improved computational power and the concomitant improvements in military systems. Parallel computing where the target problem is deconstructed and analysed by parallel computer chips may be part of the solution. Though there are continuing difficulties in coherently deconstructing, analysing and reconstructing the results. Figure 11 depicts some forecast deployment times for new computer processing technologies.

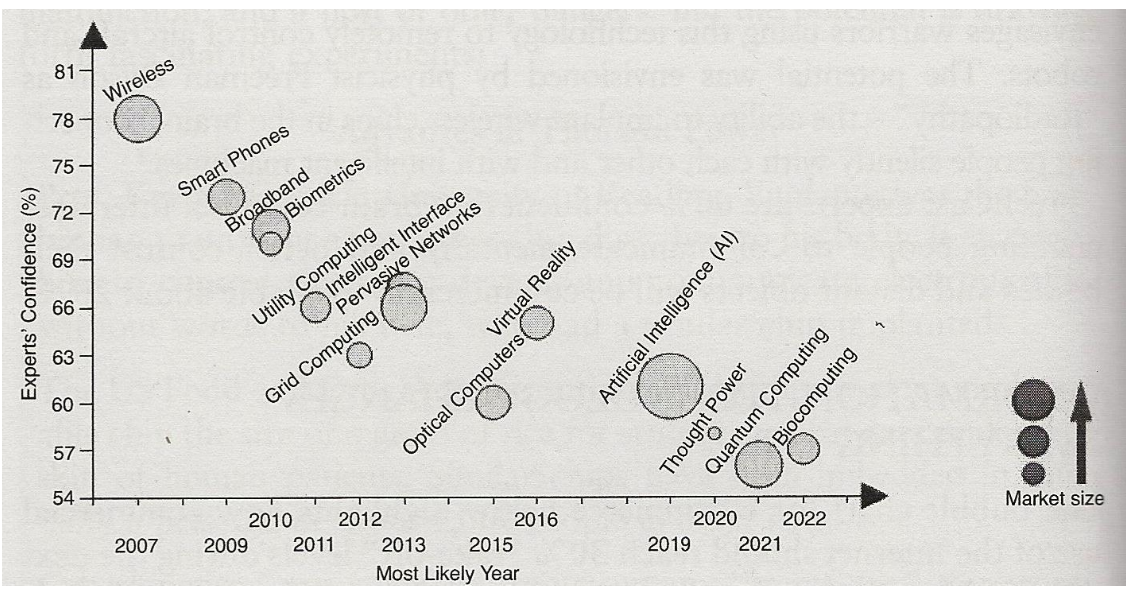

Figure 11: IT-Forecast (from Halal: Technology Promise)

Huge amounts of data flow through networks and are processed by servers that drive the communications sector. The usage of the Internet has grown by 444% worldwide in the last decade. Increased computing performance combined with improved software is key to the development and use of future technologies. Figure 12 shows some interconnections and trends between computing technology and their future use.

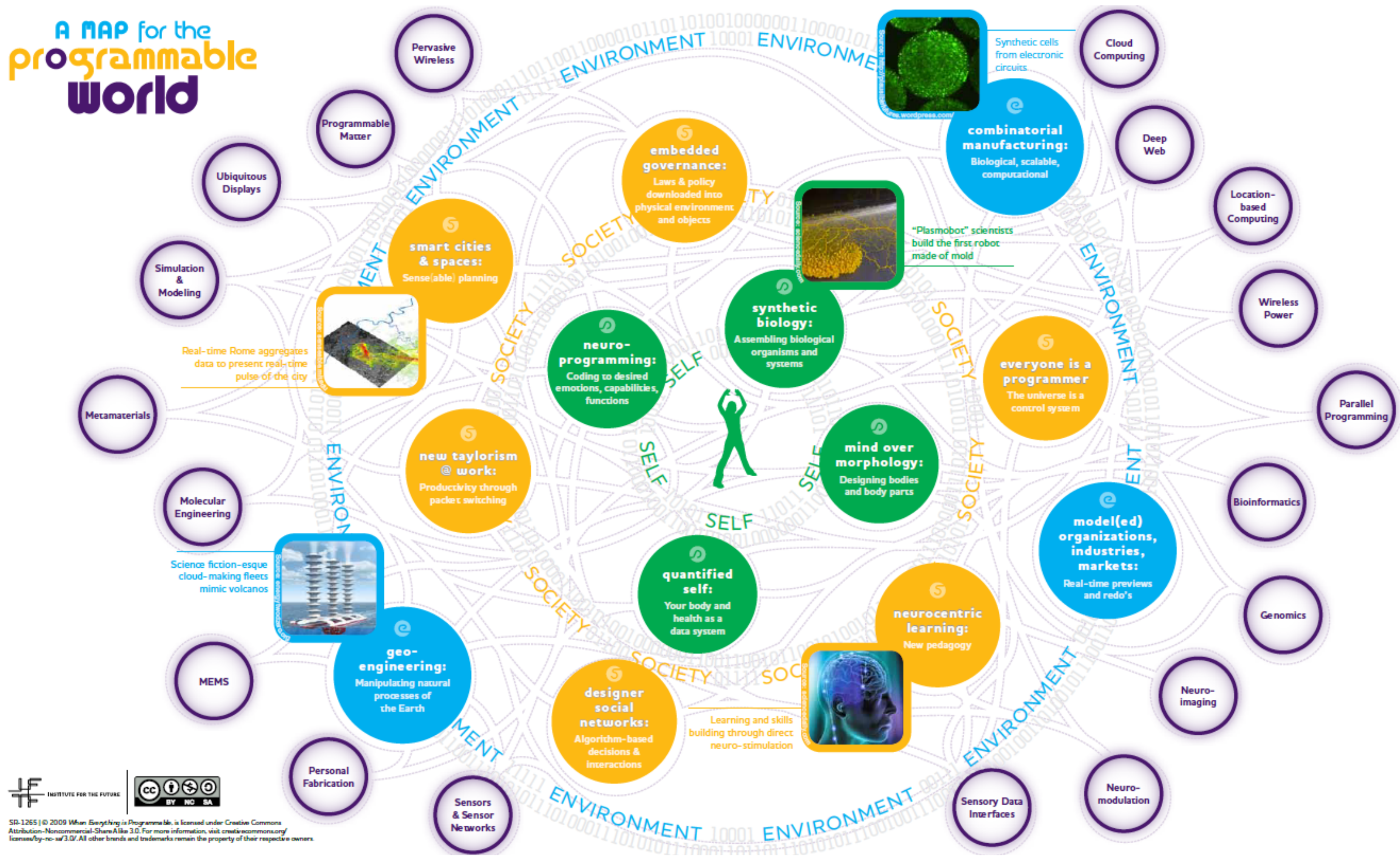

Figure 12: Influence of Computing Power (from IFTF-A Map for the Programmable World)

This map depicts an interpretation of a 'programmable world' where computer processing power and its use are the main elements that propel future technological developments. In this depiction of the future, Web applications will reach much increased levels of power and complexity. **Contextual programming** will allow search engines to find more than just the searched keywords, but also discern the intent behind the search and offer more targeted information. The implementation of AI within search engines has just started and, given the amount of research dedicated to this subject, it will likely progress during the time horizon of this study.

Ubiquitous computing[9] will come about as a result of the rapid decline in the cost of simple computer chips. As mentioned earlier, this will allow the widespread integration of chips into many items of everyday life (household appliances, clothing, houses, etc.). By allowing these chips to communicate within a network many functions that currently require human initiation will be done autonomously in the future. This will allow military systems to provide continuously updated status and other information.

Quantum computing is another promising computer technology trend. By harnessing the quantum state of electrons, computers will be able to handle multiple, simultaneous computations resulting in significant enhancement in computer speed, possibly reaching or exceeding the exaflop[10] barrier. These properties will be particularly useful in cryptography, large scale modelling and working with large databases.

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[9] Sometimes called Third Paradigm Computing, it describes the move from large main frame computer that were shared by many persons through personal computer to the new paradigm where computers will fade into the background and one person routinely accesses many computers.

[10] Exaflop is 1,000,000,000,000,000,000 (a million trillion) calculations per second.

The future of network hardware is the movement toward more effective use of cloud computing. This trend will eliminate the need for hard drives and local servers as data will be streamed to the devices themselves.

Trends in Computer Technology:

- Graphene replaces silicon in CPU's
- 3D construction of computer chips
- Quantum computing
- Improved contextual programming

4.3.1 Holistic Knowledge Bases

Future forces will have access to holistic knowledge bases that will provide numerous '**reach back' functions** for deployed forces. This is a broad research area that incorporates gathering, sorting, analysing and presenting enormous amounts of data at the right time and in the right format for end users. The capability to build a holistic knowledge base will make physical demands on bandwidth, software and underlying algorithms and will require sufficiently dense data gathering capabilities to bring the required information into the knowledge base. This will bring together many of aspects of future technology including ubiquitous computing, web-based search applications, network developments and quantum computing.

This capability will be able to aggregate structured and unstructured information (text, video, voice, etc.) into formats that can be archived, mined, fused and shared across networks. Research in knowledge representation will continue to make data accessible for automated mining/analysis. As mentioned earlier, **semantic-web** developments that can sort through large amounts of textual information and discern patterns and linkages will assist in this area.

Gathering the large amount of data necessary to populate a holistic knowledge base will use automated tools for deeply searching the info sphere including at the level of individual databases. Web tools such as bots and spiders will allow real-time monitoring and gathering data to ensure that the knowledge base is kept current. Multi-level security systems will control dissemination of the knowledge without unduly interrupting the flow of information. This knowledge base will be available through ad hoc networks that form without intervention to connect all elements within the battle space. This capability will give even small units access to a vast array of expert systems. Cultural, geographic, biometric and other information from across the PMESII[11] taxonomy will be available across the network.

Trends in Holistic Knowledge Bases:

- Reach back to all PMESII information
- Semantic web

4.3.2 Social Networks

Figure 11 showed the programmable world as an interpretation of the future of software applications and their influence on this environment, society and the human being. Software developments together with advancements in computer technology will allow more influence on opinion building and information sharing. The ability to be connected to anybody and to share thoughts and information reflects the original promise on social computing. Social research on social networks reveals the surprising power of networks and how they can shape our lives. Currently, over 47% of the western adult population uses social network applications. Research also demonstrates that individual behaviour, moods, and activities have measurable impact on others. The resulting social graph of our

[11] PMSII stands for Political. Military, Economic, Social, Infrastructure and Information Systems

network exposes the possible impact we have on one another.

The trend is to connect multiple social networking sites- each with a different purpose- to one platform. This will be supported by future developments in algorithms that will exploit individual stances on political views, consuming habits, social network depth, **pervasive power** and more. Trends show that networks will take over the opinion building role formerly played by information sources like television and newspapers. This is driven by the increased accessibility of social networks.

The power of social networks was demonstrated recently during the protests following elections in 2010 and during the 'Arab Spring' in 2011. During both of these events, social networking sites such as Twitter, YOUTUBE and Facebook were used to pass information both within and outside the affected region. Despite efforts by authoritarian governments to control old media, such as television, radio and print, protesters were able to coordinate their efforts and transmit messages to the outside world. These types of services, as well as satellite news services, will make it increasingly difficult for despotic governments to keep their populations in the dark. Increasing availability of knowledge and the resulting demands of populations will raise calls for democracy. This can be referred to as a 'dictator's dilemma' – whether to control the flow of information and accept the wrath of the population; or allow information to flow and accept a knowledgeable population. Another example of the power of social networks came about in the aftermath of the 2011 earthquake and tsunami in Japan where the use of Twitter grow by an order of magnitude as a tool to gather information and locate and reunite family members.

Figures 13 and 14 give more insight into the information that can be extracted from the Twitter platform. Figure 13 exposes, as an example, the information one can derive from an analysis of the linkages of Dima_Khatib (a

Journalist of Al Jazeera) to other influential people in the social network of Twitter during the Tunisian revolution in January 2011.

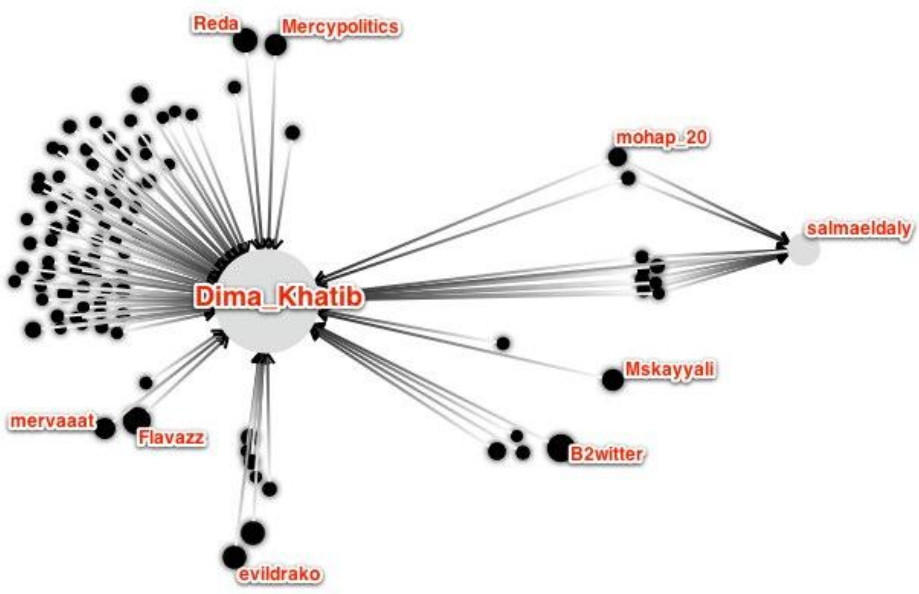

Figure 13: Social Graph based on Twitter accounts

The analysis results could be used to influence opinion makers to steer the pervasive arguments in a desired direction. Figure 13 graphically displays the most dominating words used within the user's profiles. This analysis reveals an opportunity to influence connected social network users.

Figure 14: Graphical Analysis of Twitter Users Profiles

Trends in Social Networks:

- Social networks become more pervasive
- Multiple social networks are merged into one
- Language is not a barrier within social networks

4.4 Sensors

Advances in computing power and other complementary technologies will increase the capabilities of sensors. Sensor systems will be increasingly robust under all conditions and will allow the extraction of more detailed target information. In response, of course, counter measures will also be improved to deal with this increased robustness. **Bi-static** and **multi-static radar systems** will be developed that utilize VHF and UHF broadcast and communications signals as 'illuminators of opportunity'. At these frequencies a target's stealth treatment is likely to be less effective. **Low cost night vision equipment** will be available for sale on open markets. Technology advancement will allow also for price reduction, which will increase proliferation of other sensor technology.

Multi-sensor acquisition and tracking within weapons systems have become common and are now the standard for most new systems. These sensors usually consist of microwave and/or millimetre wave radar, thermal imagers operating in the mid- and long wave infrared bands, laser range finders, ultraviolet receivers, and television systems operating in the shortwave infrared and optical bands. **Automatic Target Recognition (ATR)** will become more wide spread. This capability, in addition to allowing missiles to be fired in a 'fire-and-forget' mode, will support autonomous analysis of the vast amount of digital data that is routinely collected but currently never analysed by intelligence operators. Furthermore, more systems may have satellite navigation (SATNAV) integrated into their guidance systems, providing them with an all-weather strike option. Targeting ability of weapon systems in adverse environments will be increased using multi-spectral sensors and supporting algorithms.

A number of exciting and emerging capabilities do exist and are ready to be exploited by industry if they perceive a market. Increased digital receiver and computing capabilities mean that **software radars** are very much a possibility, giving far greater reliability and flexibility and lower costs than current systems. Element-level digitization, adaptive beam-forming and energy management is now well understood and operational in the naval and missile defence environments. This could be readily extended to the ground-based air-surveillance to provide the flexible detection of low-observable targets in complex electronic measures environments. Increased national research on **passive covert radar** technology is promising a low-cost air surveillance solution, with the potential for improved low-level surveillance (as a denser deployment of sensors becomes affordable) and enhanced detection of low-observable targets (due to the use of lower frequencies and multistatic geometries). A number of companies are offering HF radar systems with long-range, low-altitude surveillance capabilities, which could allow NATO to gain situational awareness many thousands of kilometres beyond its borders, or at low level over the sea. Whether any of these systems become operational by 2025 depends far more on the resources and priorities of the military and the perceived market, than on any technical issues.

4.4.1 Electronic Support Measures (ESM) sensors

The surveillance aspects of ESM, rather than the threat identification and avoidance roles, will be increasingly important as ESM data is fused with other sensor information.

Trends in ESM Sensors:

The following trends in technology will support these requirements:

- **antenna technology** – higher gain, dynamic directivity and wider frequency range through advanced antenna structures which are developed using modern computation and fabrication methods and digital signal processing of antenna arrays.

- **digital signal processing technology** – analogue-to-digital conversion at higher frequencies combined with spectral analysis capabilities provides enhanced sensitivity, detection of time coincident signals and intra pulse analysis.

- **precise clocks** with world wide availability (e.g. GPS) enable enhanced time difference of arrival (TDOA) and frequency difference of arrival (FDOA) direction finding and triangulation methods.

- **data communication** – high speed and wide band data links enable a network of sensors for enhanced situation awareness and geo-location of emitters.

Of course, emitter technology will also improve to compensate for the gain in ESM technology, more specifically:

- Shorter radiation times,
- Low Probability of Intercept (LPI) signals
- Passive radars using signals from TV or radio stations that cannot be detected or tracked, though their communications could be intercepted.

4.4.1.1 Impact on Military Operations

In general, higher resolution imaging systems will be available in future military operations. **Nanotechnology** may support networks of very small persistent sensor that could be widely distributed through the operations area (smart dust). A wide variety of spectrally specific sensor applications is within reach of today's technology and only need implementation as ruggedized equipment is developed to perform some of the functions discussed above. The advantages of future electro-optic sensors will include high resolution imaging systems including adaptive optics for image stabilization and environment compensation that can exploit features of targets currently undetectable, greatly improve passive combat identification at longer stand-off ranges, specific biometric recognition by high resolution imaging (detects biometrics such as facial expressions, gesture, gait, height, invariant metrics such as pupil separation, etc.).

Spectrally-sensitive technologies will detect targets in cluttered background and under camouflage. These systems will be aided by automatic target recognition. They will be capable of detecting spectrally tailored particle tags that present strong, tailored spectral signatures that could be used in a variety of scenarios such as tagging of suspect vehicles at checkpoints/border crossings or tagging of individuals entering specific environments (room, base, etc.).

For example, currently, the Gorgon Stare surveillance system consists of nine cameras attached to a pod that is designed to be carried on an unmanned aerial vehicle. It is intended to provide images of a "city size" area. Work is being done on algorithms that could potentially automatically track vehicles and even people over the whole viewing area. Thus expert systems will be necessary to analyse the significantly increased amount of digital data that will be collected by these advanced electro-optic sensors over time.

4.4.2 Space Based Systems

The technological advantage of the West in this area is eroding as globalization and proliferation foster new foreign space competitors. Global and domestic factors are having significant effects on the volatility, uncertainty, complexity and ambiguity of the strategic environment and bringing the importance of space systems to the forefront. The Alliance growing reliance on space-borne systems for communications, navigation, intelligence and weather observation could create critical vulnerabilities if these systems were lost. A primary response to this vulnerability will be a growing need for better space situational awareness.

The likely development of precise anti-satellite capabilities, jamming or other methods including electro-magnetic pulse, meant to deny information derived from space systems or access to space generally will demand that the Alliance counter with the ability to either rapidly move to alternative sources, or operate without this information. The entry into operation over the coming years of GMES (Global Monitoring for Environment and Security)/ Kopernikus[12] is likely to reinforce this reliance and the corresponding need to consider operations without access to space information. Related to this, there is a school of thought that says that satellites are inherently vulnerable and should not be depended on for critical military functions.

Development of rapid alternatives could include options to replace satellites. Rapid replacement of satellites could be accomplished by having back-up satellites parked in storage orbits waiting to be called upon. These back-up systems would have to be disguised or in some way protected (armour, camouflage, higher orbits, etc.) to ensure that they do not suffer the same fate as their predecessor prior to entering into operation. Cheaper and faster launch options that could insert new systems in orbit after the original system is lost would also be able to limit the gap in coverage. Space systems with the ability to rendezvous with and investigate other satellites to determine their purpose could allow for intervention prior to the engagement of space-borne anti-satellite systems. Investment in broadening the capability packages carried on board civilian satellites could allow for swift replacement.

Priority should be given also to development of defences that prevent the use of lasers (infrared or visible) to dazzle or blind surveillance satellites possibly resulting in permanent damage to optics or focal plane arrays. There will be a requirement to deal with a threat of laser attack that could force the need to turn the sensor away from the area of interest in order to save the asset. Measures to address the jamming of synthetic aperture radar or uplinks/downlinks also will need to be developed.

[12] The EU's Kopernikus programme – the new name for the Global Monitoring for Environment and Security (GMES) initiative – launched its first package of Earth Observation (EO) services at a forum held 16-17 September in Lille, France. The launch highlights the use of Galileo and EGNOS for Europe's environmental and security needs. http://www.gsa.europa.eu/go/news/gmes/kopernikus-launches-eo-services

Rapid deployment of long endurance UAVs or constellations of UAVs to provide interim coverage could provide for the continuation of ISR activities while other actions to replace space systems are underway. In some circumstances, aerostatic balloons or other lighter than air craft could be appropriate. Development of reliable over-the-horizon ionospheric backscatter radar may also be an alternative. Lunar basing of ISR systems, provided the appropriate international agreements are modified/ respected, may provide an unassailable high ground though the ISR coverage allowed by a lunar orbit would be limited.

Cognitive radio networks may have ability to reconfigure space linkages to other available networks to avoid interference inhibiting communications between space and space-based elements. Similarly, developing autonomous and automatic paradigms for distributed cognitive processing and autonomic computing may allow systems to seek out new connections and work-a round to continue with its tasks within dynamic environments.

The development of an accurate and continuously updated library of global positioning data (GPS) could provide an alternative for some aspects of real-time space information. This could be especially relevant to targeting and navigation tasks. This capability, which could be described as 'Google Earth on steroids', would require development of enabling technologies in the areas of video storage and retrieval, holographic presentation and artificial intelligence.

Of course, the tried and true practices of the past will still work particularly in the area of navigation. As GPS signals are a relatively easy jamming target for two reasons - known fixed frequency and very low power levels at the receiver - training may be a key element in any program to retain the ability to operate without the support of space systems. Backwards compatibility to pre-GPS generational equipment may be a non-R&T alternative. The protection of conventionally vulnerable ground segments of space systems is another important element of maintaining access to space-derived information.

Improved on-board signal processing. Spot beams provide increase flexibility over traditional fixed beams, as spot beams can be fixed over a specified area or steered to cover new areas as demand arises. Spot beams concentrate broadcast power over a smaller area which has significant benefits for the satellite and ground user: power savings increase satellite's overall capacity, high signal power allows for smaller ground terminals and higher power signals are not as vulnerable to attenuating effects in the atmosphere.

4.4.3 Computational Modelling

Computational social science and human dynamics will use modelling to bring together a depository of information related to indigenous cultures and history. Expert systems will assess the quality of gathered data as well as sort and categorize it. Network/nodal analysis and other algorithms will be developed that will automate the search for patterns and valuable insight within the knowledge base in numerous areas across the PMESII domains. Forms of these types of models have been used today to combine data on wind, waves and currents with intelligence gathered by informants, surveillance and other means on pirate habits: how far their small skiffs can travel; their assault tactics; the timing of forays to make assessments of what areas are most likely to have future incidents of piracy. These systems will support the development of a comprehensive approach by allowing the construction of high fidelity models of individuals/groups which capture intent, motivations, objectives, goals and strategy in order to anticipate realistic and unexpected behaviour under different conditions.

System of System modelling wherein modelling of adversary, self and neutrals as complex adaptive systems allows synchronization of actions with effects. This allows the identification of how to stress particular systems to achieve the goals of a campaign. This methodology allows for the development of an understanding of the multidimensional, interdependent nature of the models from the strategic to tactical levels to support Course of Action (COA) development that links kinetic and non-kinetic actions to direct, indirect, cumulative, cascading and unintended effects taking into account the temporal domain. Bayesian networks, statistical analysis and hidden Markov models have demonstrated promise in this area as well. Cognitive modelling will allow information to be gathered, formatted and presented in such a way as to be more easily assimilated by operators.

Visualization technology developed to support massive multi-player gaming and augmented/mixed virtual reality will improve the ability of users to assimilate information from the knowledge bases and take appropriate actions. Augmented reality techniques wherein actual imagery and video from the battle space can be registered with computer generated terrain data stored in geospatial databases and displayed as virtual environments will improve situational awareness. These technologies will significantly enhance decision making, mission rehearsal, communications, operational planning and war gaming from the strategic to the tactical levels. The provision of this type of knowledge base down to unit level will allow for the development of a 'Lifeguard' function whereby, through reach back, personnel at the unit level will have access to cultural, political, psychological, and bio-metric and other subject matter expertise that will facilitate mission accomplishment. Through real-time exchange of data with rear-based experts tasks requiring specialized skill sets not normally associated with small units will be accomplished. These tasks include assessment of human intelligence source validity, language interpretation and cultural assessments.

Lastly, these types of systems will allow the building of immersive training environments that will support education and training of adaptive leaders able to operate in an ambiguous environment while leveraging organizational learning. Expert systems will be able to catalogue and exploit explicit information while providing tools to distil and disseminate tacit knowledge built up by experience garnered in operations and exercises. Adaptive leadership will support organizational learning that will gather, interpret and distribute lessons learned; thereby, increasing organizational flexibility, adaptability and resilience to threats and opportunities within the environment.

Expert systems will also support areas such as risk analysis. Risk refers to the likelihood or probability for an adverse outcome. The concept of risk is applicable to an infinite set of decision problems in the military environment. Over the last several decades, the field of risk analysis has evolved encompassing methods for developing an understanding of the processes shaping the scope and nature of risks and uncertainties. New types of risks have emerged from growing complexity within the environment: inherited risk, new sources of risk (e.g. cyber-security risks), risk from combinatorial effects, risk from cascading consequences, and risk from emergent threats.

Principal Component Analysis (PCA) is an important tool that can be used to determine the primary components driving variability within a set of data. This will allow decision makers to prioritize actions, and scarce resources, on those principal components that will have the most effect on the outcome. With the reduction of complex material down to a simpler structure, decision makers will be in a better position to develop strategies to address risk.

Emerging thought on **complex adaptive systems** will allow risk structures to be analysed within rapidly evolving environments. Agent-based modelling, advanced simulation and systems dynamics will provide tools for developing appropriate responses to risk. Valid human, social, cultural and behaviour models will allow for a fuller description of risk. Resilience engineering model-based assessment and process measures may provide for the ability to anticipate changes in risk as the environment changes over time and allow for the development of timely responses. Game theory can help in such analyses by providing a framework for probing the inextricable connections between our adversaries' decision problems and those of friendly forces.

4.4.3.1 Modelling Theory Technologies

One specific modelling theory technology area that is being studied is **agent-based modelling** ("Intelligent Autonomous Agents"). Some of the most interesting, improved forms of modelling involve so-called "agent-based systems" in which low-level entities with relatively simple attributes and behaviours can collectively produce (or "generate") complex and realistic "emergent" system behaviours. Improvements in developing these types of models could lead to a potentially powerful approach to understanding complex adaptive systems generally, and military C2 in particular.

4.4.3.2 Advanced Methodology Technologies

Both war fighting and peace support operations are becoming increasingly complex. Enemies are becoming less predictable and asymmetric in nature and classic Lancaster- based models do not reflect these asymmetric aspects to the needed granularity. Thus advanced methodologies are required to deal with more uncertainty in the situations being modelled. Particular topics are as follows:

- **Characterization of uncertainty.** No matter how careful one is in preparing for a simulation, certain attributes and interactions will have some measure of uncertainty. Often, uncertainties dominate the problem. Methods to track the propagation of uncertainties are required since they can lead to large uncertainties in the output of the simulation. This is a particular challenge in heterogeneous, nonlinear dynamical systems, where uncertainties in components can interact in non-intuitive and unpredictable ways. The so-called "butterfly effect" in chaotic systems is a well-known popular example.

- **Exploratory analysis under uncertainty.** Running a simulation for one set of fixed conditions is generally not satisfactory since there are often large uncertainties throughout the system. Even normal sensitivity analysis on a one-variable-at-a-time basis does not suffice because of interaction effects. An important research area, then, is developing ways to use modern computer power to explore the space of simulation outcomes and to search for interesting regimes (e.g., regimes representing high or low risks for an operation or for especially profitable, or unacceptable, performance of a weapon). This research has implications for the design of models, search engines and visualization methods. It has even more profound implications for analysis and decision making because it encourages decision makers to ask not about best-estimate outcomes, which are often no more likely than very different ones, but rather about how outcomes of a strategy would be likely to vary as a function of the many assumptions in "scenario space." This can help by focusing attention on the need to avoid "dangerous regimes" in the course of operations, by focusing attention on the search for crucial information, and by emphasizing the need for both hedging and adaptability. This approach, of course, is quite different from the search for mythical optimality.

- **Explanation Capability.** This capability would help explain the results of a simulation by displaying the logic trail that led to the results. Realization of this capability would figure centrally in achieving the verification, validation, and accreditation (VV&A) of simulations, both in the formal sense and to the satisfaction of individual users. This capability is important for field commanders, managers, and engineers. For example, commanders using M&S to assess courses of action may need to know the following: On what assumptions do the simulation outcomes depend critically; should those assumptions be modified and the simulations rerun? Such a capability would be expensive to develop, but the capabilities required will have more general value and thus they may well be developed in the commercial sector.

4.5 Robotic Systems

Future platforms will incorporate more robotic functions and will evolve from remotely controlled platforms towards more autonomous platforms. Future demographics will force industry to develop smarter and more versatile systems to provide services to an aging population and to provide capabilities particularly suited to robots - 3D's (dull, dangerous, dirty) and the 3H's (heavy, hot and hazardous). To accomplish these types of tasks, robotics will have to develop key abilities likes vision, positioning in terrain, communication, information sharing, environmental scanning, decision-making based on some form of reasoning or heuristics.

4.5.1 Robotic systems vs. Humans

Rapidly rising personnel costs - including not only pay but pensions and other benefits and changing **demographics** – aging populations, decreasing recruitment base, possibly changing views of military service – will combine to make hiring large numbers of people less and less cost effective as compared to buying machines that are happy to remain in storage - and thus costing very little in O&M – until they are needed. Robots would reduce deployment time as they could be pre-positioned in various depots around the globe until they are activated and given a mission.

One of the main research areas in robotics is **machine vision** (the ability to see). Computer Vision is an important application as it will drive robot/human interaction and when combined with accurate **speech recognition**/generation will complete the communications loop. Applications have developed increased accuracy brought about by augmented computing power and newly developed mathematic algorithms. Recent improvements have been seen in this area due to the vast amount of digital pictures that are now available for tests. This has led to visual accuracy levels of 85% when several computing methodologies are combined. It is now possible for robots to differentiate between male/female, long/short hair, hat/no hat and different actions- riding horses/bike/using phones.

Increasingly, robots will augment human capabilities making soldiers stronger and faster while working in 3D and 3H environments. Exo-skeletal suits will enable human war fighters to carry more equipment for longer distances and time. ‘Pack mule’ robots will support units in transporting material and equipment. Drones will provide surveillance over watch and fire support. Increasingly powerful computing systems and algorithms will enable some level of decision-making within robotic systems through heuristics and enhanced **machine learning**. Further into the future, systems may be able to “think” - to evaluate possible courses of actions in order to accomplish an ordered task.

4.5.2 Unmanned Ground Vehicles (UGS)

The development of unmanned ground vehicles will support the delivery of the large volumes of materiel required to maintain a military force in the field. Generally, all fuel, water and other supplies have to be transported from some central area to forces distributed across the theatre. This is a labour intensive effort that has become more dangerous in recent theatres of operations. This is due to a move away from static front lines and rear areas where vehicles could operate with some level of impunity toward distributed and non-contiguous operations where transportation lines are more easily attacked. Autonomous capabilities will remove military or contracted drivers from this dangerous task and will, in time, allow more efficient movement of military supplies. The translation of this technology to commercial use will reduce vehicle accidents and roadway congestion.

The continued development of unmanned ground vehicles is complex. Various enhancements of aspects of propulsion, data transfer, sensors, and computer vision will be necessary to field this capability. Furthermore, multiple problems will have to be solved simultaneously during unmanned ground vehicle missions necessitating some level of decision making. Moving vehicles in unknown terrain raises problems like terrain recognition, positioning in uncertain territory, scanning the environment for possible obstacles and will demand higher levels of data processing. Developments in Artificial Intelligence (AI) will resolve some of these difficulties supported by an increased ability of the overall convoy to develop situational awareness by sharing information between vehicles.

The technology to create "**swarms**" of mini uninhabited vehicles, whether autonomous or remote controlled is becoming available. Groups of relatively simple robots, with relatively simple (and readily available) autonomous control systems (such as neural networks) have been shown to be able to co-operate to achieve quite complex goals.

4.5.3 Unmanned Aerial Systems (UAS)

Recent years has seen significantly increased expenditures on robotic systems as the advantages of robotic aerial systems have been recognized. Future UAS are designed to have reduced radar signatures, thus increasing their probability of detection. This will allow them to perform especially dangerous missions. Their time on-station or persistence is driven only by fuel capacity of the vehicle. Advances in supervisory control will increase the number of vehicles that a single operator can fly. Increases in on-board processing by artificial intelligence will reduce the analysis demands on the operators. Humans will remain in the decision loop for the foreseeable future.

These UAS will use mathematical algorithms that will allow some decision support based on automatic target recognition systems. The ability to “see” objects will be driven by enhancements to computer vision. It is likely that unmanned aircraft will be able to refuel each other by 2030, thus increasing their persistence.

4.5.4 Unmanned Sea Vehicles

Navies already have some history with autonomous systems brought about by the high speed and, possibly, number of inbound targets that contemporary air defence systems need to defeat. In some cases, this forces the human out of the loop as one is not capable of assessing and engaging these types of targets given the limited time available. Autonomous Underwater Vehicles (AUVs) have been produced for both civilian and military purposes. Current and developmental AUV applications include roles in mine detection and reconnaissance, underwater surveys and ocean data collection.

Autonomous surface sea vehicles (ASSV) will get more attention in future application like detection of semisubmersible that are used for drug-trafficking and potential delivery for weapons of mass destruction which goes hand in hand with transport and the extraction of terrorists or illegal immigrants. Future propulsion systems of ASSV will use technologies that will use environmental energy sources like sea-motion of the ocean (waves), and the broad range of alternative regenerating power sources like solar, hydrogen, wind, and/or tidal streams. Self-sustainment and the need not to be replenished during the operations within the austere environment in remote places of the oceans will make future ASSV’s ideal for covert Intelligence/Reconnaissance and Surveillance (ISR) missions on the oceans.

4.5.5 Impact of Unmanned Systems Technologies on Military Operations

In current operations, military forces are using robots to search tunnels, caves and buildings for enemy fighters and explosives. Robots are particularly suited for **surveillance functions** as they do not get tired of holding sentry positions. Robotic detection and identification of CBRN material and post-event consequence management will be particularly important with the proliferation of weapons of mass destruction and their ability to render large areas uninhabitable by humans. This will have a direct extension to civil uses for industrial settings and possible accidents. Advances in technology will allow for the development of smaller, more sensitive systems.

Other more tactical uses of robots on the battlefield will include reducing the equipment burden of individual soldiers by providing robotic ‘pack mules’. As the movement toward more small unit operations continues in the future, this type of support will become more crucial as smaller units will need to transport increasingly heavy loads.

Robotic systems will be used also to provide faster casualty recovery and extraction. This will allow the delivery of more expert care both on the battlefield and during transport to military treatment facilities within the ‘golden hour’[13].

UAS are also being tested that can bring telemedicine and other equipment to medics in the field and conduct **casualty evacuation** (CASEVAC). These systems will navigate through various terrains, select a suitable landing zone (LZ) and communicate with medical team with little intervention. Robotic

[13] golden hour : the first hour following a traumatic injury; patients who are in the operating room within one hour of injury have a much higher survival rate.
Miller-Keane Encyclopedia and Dictionary of Medicine, Nursing, and Allied Health, Seventh Edition. © 2003 by Saunders, an imprint of Elsevier, Inc.

surgery on the battlefield, during transportation or closer to the front lines is also highly possible given advances in this area.

There are some other areas of robotics where the technology may be advancing faster than the development of policy and legal discussions. Probably nowhere is this truer than in the area of autonomous use of force by robots. As all possible environments in which autonomous robots could be employed and all possible circumstances in which these robots may find themselves could never be modelled in a laboratory or developed into computer code, developing autonomous systems will not be a simple programming problem. Additionally, these programs would be extremely complex and written by teams of programmers where the overall complexity could lead to software errors and possibly to unforeseen emergent behaviours. This is part of what is termed a 'first generation problem' – one will not know what type of mistakes autonomous systems could commit until they have already committed them. It would not be difficult to imagine many paradoxical situations where robots would come up against contradictory information where even humans would have difficulty making a decision. This raises the questions of where blame for robotic mistakes would be attributed – the commander who gave the order to deploy robots, the manufacturer who built the robot, or the programmer who told it how to accomplish its tasks? Robotic systems will be unaffected by emotions, adrenaline and stress and thus less susceptible to conditions that may have driven human soldiers to over or under-react. So there may be some motivation to develop these types of systems.

Technically, for the foreseeable future, there will remain considerable problems with robotic vision, sensor systems and the ability to develop AI to support sense making in very difficult dynamically changing environments. Autonomous robots will have problems discriminating between targets for some time to come. Additionally, links between robotic systems and between systems and their operators will have to be secured.

Trends in Robotic Systems:

- Situational missions capability
- Information interchange up to swarm size groups
- Computer vision
- Added artificial intelligence
- Situational awareness
- Fully autonomous missions capability
- Approved adapted kinematic propulsion systems
- Swarming missions capability
- Ground based surveillance and reconnaissance (S&R)
- Explosive ordnance disposal (EOD) search, classification and destruction
- Automated medical aid vehicles

4.6 Effectors

4.6.1 High Power Microwave Protection

High Power Microwave weapons (HPM) are a new threat on the battlefield of the future. These weapons could be developed by states, non-states or individuals as they do not require large industrial bases to produce. More powerful versions could disrupt or even destroy sensors or communications devices. The most serious effects will be on sensors working in the RF region, but infrared and electro-optical sensors also could be impacted.

The range of these weapons could be extended through antenna design or parallelizing several emitters. Protection technology goes into two directions: (a) complete shielding of the electronics and (b) electronic circuit protection and limiters. Shielding of electronics is possible with sealed metallic containment with proper grounding. Protective circuits will have to take into account the difference of ultra-wide-band pulses and natural electron magnetic pulse (EMP) cases like lightning and nuclear.

4.6.2 Electromagnetic Pulse/High Power Microwaves/Directed Energy Weapons (DEW)

As mentioned earlier, EMP and HPM Weapons offer a significant capability against electronic equipment. The EMP effect is characterized by the production of a very short (hundreds of nanoseconds) but intense electromagnetic pulse. This pulse of energy produces a powerful electromagnetic field sufficiently strong to produce short lived transient voltages of thousands of volts on exposed electrical conductors, such as wires or conductive tracks on printed circuit boards.

Unlike electronic warfare, the microwave weapon is designed to overwhelm a target's capability to reject, disperse or withstand the energy, and will produce significant and often lethal effects on their targets. There are four major distinctive characteristics that differentiate a microwave weapon system from an electronic warfare system:

- HPW do not rely on exact knowledge of the enemy system.
- HPW can leave persisting and lasting effects in the enemy targets through damage and destruction of electronic circuits, components and subsystems.
- A HPM weapon will affect enemy systems even when they are turned off.
- And finally, to counter the effects of a microwave weapon, the entire system must be hardened, not just individual components or circuits.

Currently, the radius of these types of weapons is not as great as nuclear EMP effects. Open literature sources indicate that effective radii of "hundreds of meters or more" are possible. EMP and HPM devices can disable a large variety of military or infrastructure equipment over a relatively broad area. This can be useful for dispersed targets. The main advantages of the HPM weapons are:

- Short reaction times as the propagation of the effect is at the speed of light,
- The effect on the target is instantaneous (i.e. milliseconds).
- General insensitivity to the weather, microwave emissions can penetrate clouds, water vapour, rain, and dust.

As friendly systems and forces are susceptible to both enemy and friendly microwave emissions, these systems will have to be hardened against microwave frequencies.

Trends:

Not protecting the own sensors and in general all electronics will render the force useless against an enemy that employs HPM. Even a not high-tech equipped enemy will be able to field crude or partly sophisticated HPM weapons that could neutralize sensors and electronics for substantial time. Technology that is not vulnerable to HPM, such as optical components and fibre-optic cables, will be employed to a greater extent, in that way mitigating some of the threat.

4.6.3 Laser Technology

A major inhibiting factor in the use of lasers as directed energy weapons (DEW) is the lack of suitable, portable energy sources. Lasers often convert only 10% of the input energy to output light power, which places a heavy power demand on the energy source. As technology changes, an increasing number of vehicles are likely to be propelled by hybrid electrical drives that may provide a source for the necessary power for future laser weapons. Lasers, which are likely to be exploited in the near to mid-term, include tactical laser weapons for anti-sensor, anti-missile and air-defence roles.

4.6.4 Precision Guided Weapons

Precision attack munitions are aimed at achieving a hit with an accuracy of a meter to centimetre, depending on the attack warhead type, the target type and the military effect required. They can be launched from the ground, the air or naval platforms, including submersibles. In the future, space-based weapons are possible. Precision attack munitions aim at improving the lethal effect by aiming at the most vulnerable part of the target and at reducing collateral damage and residual effect.

Trends in Precision Guided Weapons:

- **Determining the target**

The major evolution of precision guided munitions will be linked to the ability to use these munitions on a 24/7 basis with a high degree of reliability in target determination, both in spatial and temporal terms. Technology to achieve this goal is already available through integration of the weapons system into a coherent network.

- **Approaching and hitting the target**

Almost all subsystems in precision strike missiles are expected to have technology improvements in the future.

Airframe technologies are enhancing flight performance, reducing weight, permitting higher speed, reducing cost, providing higher reliability, and reducing observe ability. Micro-Electro-Mechanical (MEM) technology will create more energy per weight. Revolutionary advancements have been made in high performance, low cost commercial off-the-shelf (COTS) processors. This is an enabling technology for guidance & control. The capability to process multi-dimensional discrimination in a low cost, small size, and low power package is beginning to emerge. Computing capability is no longer a limitation for the application of sensor data fusion and near real-time trajectory optimization to precision strike missiles.

The widespread use of satellite navigational devices and portable navigation aids will improve future guidance and control. These technologies will rely on a global use of hybrid satellite navigation (GPS) and inertial navigation (INS), in-flight guidance optimization, automatic target recognition (ATR) and derived optimal angles-of attack. GPS/INS will provide metric precision guidance that will permit a low cost seeker-less missile to be used against fixed targets. Hybrid GPS/INS navigation will ensure higher precision of position and velocity measurements, reduced jamming susceptibility, and missile attitude measurement capability. This will provide better initialization conditions for the seeker lock-on and Automatic Target Recognition process.

Low cost guidance tail kits will reduce the dispersion of the bombs to the inherent accuracy of the GPS system. These inexpensive guidance kits which do not require a seeker provide a precision strike capability at a much lower cost than weapons requiring a terminal seeker.

New seeker technologies will include multi- spectral, synthetic aperture radar (SAR), strap down, and uncooled IR seekers. Multi-spectral/multi-mode seekers provide enhanced performance for automatic target recognition, and provide enhanced rejection of false targets and ground clutter. SAR seekers have good effectiveness in adverse weather and ground clutter. The drive for IR seekers will be to obtain long shelf life high performance uncooled seekers. An emerging seeker function is real time hit assessment. Since an increasing number of seekers are imaging seekers, the potential exists to transmit pictures from the seeker to a receiving station during the flight until impact.

ATR matches observations of reflected or emitted energy from the battlefield and intelligence data about the battlefield and the target. ATR can span from detecting bright spots (jet exhaust), to complex imagery recognition (AFV half hidden behind a building). ATR in some form has been part of military systems for many years. Notwithstanding, matching the ability of the human mind to recognize military objects on the battlefield is a difficult challenge. The efforts to develop ATR as a product will require new algorithms, but also a significant investment in determining the multi-spectral signatures of relevant targets. Mission planning, and in the case of mobile targets the mission updates, are critical drivers for the success of ATR. Stationary targets can be mapped, surveyed and characterized well in advance of an actual mission. Whereas, moving targets are more likely to be targets of opportunity where the war fighter encounters them in the course of a mission not originally directed at them.

Enhanced warhead technologies for precision strike missiles include high energy density warheads, multi-mode warheads, hard target penetrator warheads, submunition dispense and powered submunitions. Changes could come in the area of submunitions due to international conventions banning their use. These are evolutions of current technologies and do not represent any significant technical challenge. Ammunition enhancements are driving most of the artillery modernization efforts. The latest technology available to artillery munitions is based on MEMS and has the potential to substantially reduce the cost, weight, and space required. Numerous new ammunition types make these weapon systems extremely lethal and flexible. Advances in shaped-charge design and production will continue to stress armour developers. Targeting ability of weapon systems especially in adverse environment will be increased by using multi-spectral sensors and supporting algorithms.

In the area of pyrotechnic decoys, much current effort is devoted to developing decoy compositions that are spectrally matched to their platforms. An assessment of the situation in 2030 depends upon the relative rate of progress in advanced IR decoys and the “intelligence” of missile seekers. On balance, the advantage is likely to remain with the missile.

Antiship Cruise Missiles. The continuing development of ASCMs with improved design features such as supersonic speed, evasive manoeuvres, and advanced terminal seekers will present on going challenges to NATO forces.

Submarines. It is highly likely that new construction submarines equipped with Air Independent Power (AIP) propulsion systems will constitute an increasingly greater percentage of worldwide launches and proliferation to new user countries. AIP systems enhance a submarine's mission effectiveness through reduced probability of detection, increased survivability, and increased time on station.

Torpedoes. Improvements in propulsion signal processing, sensors, signature reduction, explosives, and fusing may enable torpedoes to be used in ways that will modify the traditional concept of a torpedo attack.

4.7 Bio-Technology/ Chemical, Biological, Radiological, and Nuclear Weapons

The convention on the prohibition of the development, Production, and stockpiling of bacteriological and toxin weapons and their destruction (also known as the biological weapons convention) and the chemical Weapons convention are counter-proliferation treaties. Unfortunately, these conventions are hampered by the “dual-use” issue, in which the technologies used to develop and produce biological or chemical weapons are very similar to those that would be needed for human and veterinary healthcare research and production and the agricultural industry. Unanticipated diversion of biological agents from agricultural, industrial and medical areas could lead to threats.

Verification inspections and confidence-building measures have had limited success, but efforts continue to strengthen the conventions. While it would be difficult for a country to mass-produce classic chemical warfare agents in large quantities without detection, it would be very easy for a country or organized group to develop the technological capabilities to produce biological agents. Possible adversaries could also bioengineer and deliver new organisms using the latest advances in technology. Counter-proliferation is hampered by the difficulties in identifying enemy capabilities and limiting their development. Increasing populations in global mega cities and continuing migration of populations to urban centres will increase risk and rate of infection during biological attacks.

There are two general categories of CB detectors: point detectors and stand-off. A point detector will detect CB agents that are physically present at the detector. Most point detectors draw in air and sample it by various methods, and there are a few detectors that work by sampling surfaces contaminated with CB agents. Stand-off detectors are optical systems, usually equipped with a laser, that detect the presence of CB agents at a distance of hundreds of meters or kilometres. Stand-off detectors are recent developments and there are only a few systems fielded at present. Very recent advances in Terahertz wave technology open up possibilities for robust stand-off detection of bio agents. Special laser techniques have been demonstrated that can detect trace amounts of explosives contaminating the vehicles which are prepared as IED carriers.

Neither stand-off nor point detection systems are capable of detecting all threat agents with one device. In general, chemical agent groups are detected by a particular technique and several techniques are used in parallel to detect most threats. Biological agents have much more complex chemical signatures than chemical agents, and real-time bio agent detection is very challenging. Effective and economical stand-off CB detection will greatly improve detection and warning times in a CBW environment. Improvements in nanotechnology will allow the development of 'laboratories on a chip' that will be able to detect very small amounts of any agent.

4.7.1 Bio-Technology

Breakthroughs in genetic engineering have allowed genes to be substantially altered and combined with other genes in ways that have benefited mankind tremendously. For the military, knowledge of man's specific genetic defects or vulnerabilities (or ways to create such defects) and the ability to modify microorganisms or toxins that would increase pathogenicity take on added concern. Bio-technology theoretically provides opportunities for adversaries to modify existing organisms with specific characteristics, such as increased virulence, infectivity, or stability. Modern advances also allow for the inexpensive production of large quantities of replicating microorganisms for weaponization through recombinant methodologies, and the possibility to create “new” agents for future warfare that bypass current preventive or therapeutic interventions.

4.7.2 New Medical Countermeasures

Advances in technology allow for more directed and coordinated approaches in vaccine development against biological warfare agents and endemic diseases. The development of combination vaccines that eliminate the need for multiple vaccinations is of practical importance to the military.

It looks impossible to provide protection against every conceivable agent, but it seems likely that future medical protective measures will need to be more broadly based if they are to provide the best protection against bio warfare agents in the future. Since it is likely that several agents will be used simultaneously, Antimicrobial drug supplementation may also provide added benefit for immediate or short-term protection.

Biological warfare is of great concern for several reasons:

- Many potent agents are readily available. Theoretically, any microorganism or toxin capable of inflicting death or disease has the potential of being adapted for use as a biological weapon.

- Naturally occurring infectious agents could be used to generate epidemics among susceptible troops, creating confusing disease situations on the battlefield. Naturally occurring or deliberately disseminated spore forming microbes could continue to persist in the environment, and some aerosolization might occur during military manoeuvres; environmental detectors may not necessarily be able to differentiate between natural and man-generated contamination.

- Many classic agents can be mass-produced in a short time using very basic laboratory techniques. Large fermenters may not be necessary if a small amount of agent is all that is required.
- Theoretically, biological agents can be genetically altered to escape detection.
- Biological agents require no precursors for development, unlike chemical and nuclear agents, and a covert program is much more difficult to detect.
- Biological agents can be used to aim for specific genetic targets.

Carefully followed decontamination procedures will reduce the possibility of further injury and allow medical personnel to render appropriate care to casualties.

At first glance, drugs and vaccines appear to offer promise for defence against specific biological agents. If the biological agent or toxin that may be used is known in advance, stocks of antibiotics and vaccines can be created. Major problems occur, however, when uncertainties exist on the precise nature of the biological agent or toxin that will be used. Even if the agent is known in advance, the efficacy of a drug or vaccine in effectively defeating the agent is rarely known because of the difficulty of adequately testing the drug or vaccine for this purpose and because of the unpredictability of variables such as levels of exposure and the condition of the victims at the time of the attack, and adverse reactions to the treatment. By 2025 computer simulations will provide some insight to the efficiency of treatments but controlled laboratory experimentation will still be required to validate results.

4.8 Radiological Weapons

The purpose of a radiological weapon is to spread radioactive material over the target and hence present a radiological hazard to those in or entering this zone. The contaminated area could quickly be traversed by protected troops, particularly those in vehicles with collective protection - overpressure and filtration packs. However, the use of radiological material to disrupt and delay a force might be attractive. A relatively unsophisticated adversary could acquire material and in extreme cases might use it to disrupt military forces or terrorize civilian populations.

As a terrorist weapon, the effect of panic and lasting disruption may well yield results out of all proportion to the casualties and damage caused. It is actually much more difficult to spread a cloud of radioactive particles than commonly supposed. Use by terrorists or other non-state actors is a much more likely prospect. In many parts of the world, control of radiological hazardous material, including research, medical and other radiation sources, is unreliable or non-existent; there is little security and little audit.

The following radio-isotopes are widely used and so are most likely to be present in contaminants:

- **Cobalt 60** is found in hospitals, research facilities and in engineering test facilities where it is used as a radiographic source. It produces very penetrating gamma rays and has a half-life of 5.34 years. Shielding themselves from the gamma rays whilst the bomb was built and placed would be a problem for terrorists.

- **Caesium 137**. Also used in hospitals, for radio therapy including cancer treatment. It has a half-life of 30 years and emits gamma and beta rays that are very penetrating.

- **Strontium 90**. Has a half-life of 28.7 years and emits beta particles. The isotope is used for medical research and in nuclear power sources for remote weather stations.

4.8.1 Non-Lethal Weapons

NATO defines Non-Lethal Weapons (NLW) as "weapons which are explicitly designed and developed to incapacitate or repel personnel, with a low probability of fatality or permanent injury, or to disable equipment, with minimal undesired damage or impact on the environment"[14]. This section discusses some promising technologies and related current developments.

4.8.1.1 Technology of Non- Lethal Weapons

Most sources envisage that NLW have two principal roles: **anti-personnel** and **anti-materiel** (or anti-infrastructure). An anti-personnel role typically includes tasks such as: crowd control, incapacitate individuals, Deny an Area to personnel, and clear facilities, structures, or areas. Similarly, the anti-material (or anti-infrastructure) role includes tasks such as: deny an area to vehicles, vessels, or aircraft, disable or neutralise vehicles, vessels, aircraft, or equipment, and radio frequency devices (Electromagnetic).

These systems will include RF devices that cause intense heating sensation stops only if the individual moves out of the beam's path, or the beam is turned off. Acoustic devices that cause intense discomfort will also be refined. Stun Devices (Electromagnetic) such as the "Sticky Shocker" that involves a blunt projectile that sticks to the clothing and imparts a short burst of high voltage pulses. The "Sticky Shocker" characteristics are similar to well-established safe electrical shock devices (Taser).

[14] http://www.nato.int/docu/pr/1999/p991013e.htm

Anti-Traction (chemical) that spreads a highly slippery, viscous gel to inhibit the movement of individuals or vehicles on treated surfaces such as asphalt, concrete, grass and wood will be available. The obstacle it creates enables military or law enforcement personnel to stop or delay crowds and equipment, and isolate facilities such as embassies, loading docks, piers or other restricted areas.

Rapid Barriers & Nets (Mechanical) currently include systems that spring up from the ground in an instant to block a road. It is claimed that these barriers can stop a 7500 pound truck travelling at 45mph. These concepts can be extended to boats and ships. These systems will be very promising in the future of ant piracy missions where they can cause pirate boats and ships stop , by blocking the ships propeller, with a suitable net.

4.9 Cyber Protection

The three dimensions of war are expanding while the fourth – time – is contracting and the fifth – cyberspace - is becoming more important. Currently, within this new dimension of conflict 'Moore's Outlaws' may retain the advantage. A lack of common legislation and policies directed toward curbing cyber threats and the cross-organizational nature of the threat has led to disjointed attempts at defending against the rising use of this dimension by criminals, non-state and state actors.

The increasing complexity of the underlying code and systems supporting cyberspace and the increasing connectedness of the global environment is making it easier for potential adversaries to exploit cyberspace. In many instances, opponents need only create chaos rather than cause real damage to achieve their objectives. This is made even more difficult when the Alliance relies heavily on networked systems and does not hold the initiative and must defend against all attacks while opponents may only need to be successful once. Defence against these types of threats will be expensive while attacks with cyber weapons will be cheap – essentially free.

This last point means that cyber-attacks could be initiated by anyone. Therefore, attribution of any attack will be difficult. Plausible deniability can be built into any attack due to the lack of an effective tracking system within the current construct of the internet. Authentication of personnel and processes will be essential to keep networks safe from intrusion and attack.

Future development must seek to increase the level of difficulty and costs for any attacker. Security must be built-in from the ground up with hardware, software and network technologies. It has been said that defeat in the first cyber battle may create the defining conditions for overall defeat; thereby making developments in this area especially critical to the defence of the Alliance.

User authentication technologies also show some improvement and password authentication should at some point be replaced by personal devices that are able to perform cryptographic operations. Smartcard proliferation, and wireless personal communications devices are developments that could easily be used to achieve better authentication. Such devices should be combined with another authentication factor depending on something the user knows, and could possibly include additional factors such as biometrics. This should be both more secure in a system perspective as well as more convenient for the users. Three levels of security will relate to something that the user has – a key card, something the user knows – a password, and something the user is – biometrics.

Developments in cryptology will continue. For example, developments in elliptic curves can speed up asymmetric cryptography while keeping the security level constant. Many of the tools that are currently used both for information system protection and vulnerability detection, as well as many other security systems, are targeted towards static, homogenized systems. As wireless technology and personal devices become more outspread, systems will increase both in dynamicity and diversity. This will lead to many of the security systems being redesigned in order to provide the required security services for dynamic systems.

Multi-level security systems that are able to handle different classifications on the same system are still a long way in the making, and systems might not become available until close to or after 2025. However, technologies such as virtual machines might aid in creating systems that can give some of the same functionality to the end users in a less practical way.

4.9.1 Cyber Protection Technology

Centralized network management systems (especially if they are heavily based on human interventions) will not be able to cope with new military challenges. In order to enhance change management capability dynamic planning mechanisms based on artificial intelligence will assist in the pro-actively provision of service delivery at the right place at the right time. In the first instance pattern recognition methods seem promising. To solve this, systems will be developed that will have enhanced self-monitoring capabilities, such as

- **Self-diagnosis/Self-adaptive/healing platforms and networks**. These self-managing attributes could be defined as follows:
- **Self-configuring** – To adapt automatically to dynamically changing environments. Self-configuring components adapt dynamically to changes in the IT system, using policies provided by the IT professional. Such changes could include the deployment of new components or the removal of existing ones, or a dramatic increase or decrease in the workload.

- **Self-healing** - To discover, diagnose and react to disruptions. Self-healing components can detect system malfunctions and initiate policy-based corrective actions without disrupting the IT environment. Corrective actions could involve a product altering its own state or effecting changes in other components in the environment.
- **Self-optimizing** - To monitor and tune resources automatically. Self-optimizing components are able to tune themselves to meet end-user or business needs. The tuning actions could mean reallocating resources to improve overall utilization or ensuring that particular business transactions can be completed in a timely fashion. This includes adapting to dynamically changing workloads.
- **Self-protecting** - To anticipate, detect, identify and protect against attacks from anywhere. Self-protecting components can detect hostile behaviours as they occur and take corrective actions to make themselves less vulnerable. The hostile behaviours can include unauthorized access and use, virus infection and proliferation, and denial-of-service attacks.
- **Intelligent agents** and remote (self) management features.

4.10 Logistics

Emerging intelligent systems will enable the deployment of advanced systems able to sense, analyse, learn, adapt, and function effectively in changing or hostile environments. Intelligent systems typically consist of a dynamic network of agents interconnected via spatial and communications links that operate in uncertain and dynamically changing environments using decentralized or distributed input and under localized goals that may change over time. Intelligent systems must be capable of gathering relevant information about their environment, analysing its significance in terms of assigned functions, and defining the most appropriate course of action consistent with programmed decision logic.

One specific application of intelligent systems to the logistics domain will be to simplify and automate the acquisition process. In most, if not all nations, the time to purchase major pieces of equipment is not only long, but it has been steadily increasing.

On a smaller scale, an intelligent system will be able to automate the resupply and replenishment process. The “purchaser” need not be a human being, rather it could be a microchip embedded in a weapon system or part of an inventory control system that tracks the use of consumables.

A smart part could detect the fact that it was about to fail and through a communication system (e.g. satellite) initiate the order for a replacement. An integrated system of systems would automatically make assessments of the requirement for that part and then identify appropriate budgets, schedule of space at a repair facility, assign tasks to maintenance personnel, tap in to supplier databases for procurement and delivery. Human interface would only be required when built-in systems encountered a problem that could not be resolved without intervention. The keys to success will be an automated and integrated system of systems enabled by a world-wide, satellite-based communication system.

This system of systems is readily adaptable to the provision of “just-in-time logistics” where the warehousing function is greatly reduced and the distribution and movement processes becomes primary. The result is a significantly smaller logistical footprint that makes entire process more economical.

This concept can be further developed to the idea of a “smart package”. These smart containers would hold a microchip that, once loaded with materials needed in a theatre of operations, would know the contents and be responsible for arriving at the correct final destination by the optimal path. Authentication would be required before the smart package would release its contents and once opened would automatically inform the originator (again through a satellite link) that delivery had been made. It would even be conceivable to pre-position these packages, for instance on the ocean floor off the coast of a region for potential use. When a military operator (or indeed the intelligent system) decides that a particular container is required, a signal could be sent and an integrated transportation system on the container would be activated. The package would move itself to the nearest relevant logistics depot for further handling. The vulnerability of the stockpiled supplies to enemy attack would be reduced compared to the current pre-positioning ships and warehouses, as would the long-term leasing costs.

4.10.1 Strategic Lift

Future projections vary, but by 2030, using advanced hull designs, high power, fuel efficient machinery and advanced structural designs using light weight, high strength materials, it should be technologically feasible to build a ship capable of reaching speeds up to 40 knots, with a range of 10,000 nautical miles and carrying a payload of 5,000 short tons and some reports [Spivey] claim speeds of 60 knots up to sea state 7.

To resupply this force, ultra-large airship will provide a significant ability to deliver a very large sustainment load. One such lighter than air (LTA) ship that will be in service by 2025 is the SkyCat1000 (http://www.worldskycat.com) with a projected capacity of 1,000 short tons, a speed of 100 knots and a range of 8,000 nautical miles. World SkyCat Ltd claims that the costs of using LTA rival and exceed those of current conventional aircraft or sealift capabilities Figure 15.

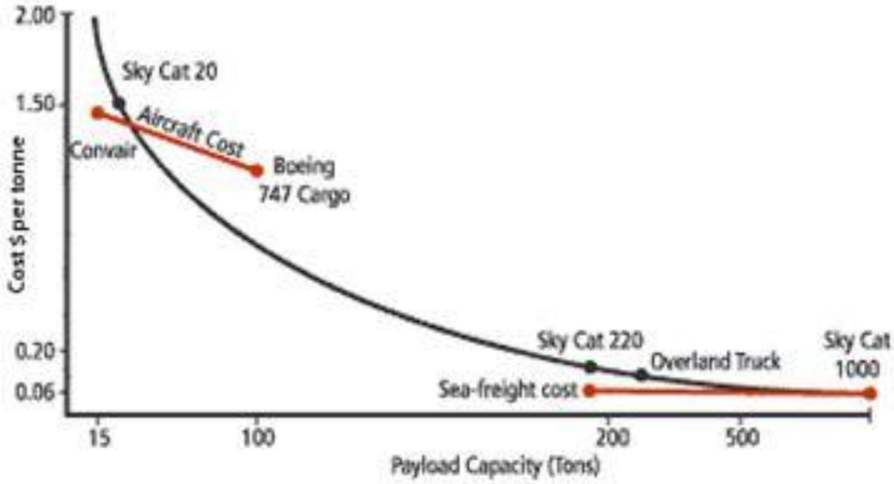

Figure 15: Cost Comparison for Lift (from World SkyCat)

4.10.2 Open Fabrication

New collaborative design processes that apply crowdsourcing principles will bring some of the rapid, lightweight innovation potential of open source and do-it-yourself (DIY) knowledge-sharing platforms like DIY Wikis to industrial design. New products will be able to break free of long lead time design cycles that are pervasive in many industries. Widespread online availability of object design files will allow users themselves to modify and adapt goods to suit particular needs or to address unforeseen problems in the product's implementation.

The future of collaborative production is largely contingent on two things: (1) the development of communities of interest such as ***Thingiverse*** (a design sharing platform), which are aimed at fostering an open exchange of design files and ideas about how objects are to be made, and (2) improved accessibility of ever more powerful design software to individuals with limited or no design experience. The potential to build weapon related parts such as triggers or fuses for improvised explosive devices (IED) or the IEDs themselves is present today and will be enhanced in the future. The ability to build low cost objects with only limited construction materials, basically plastics, will reduce the amount of materiel that needs to be transported to a theatre of operations. Parts can be produced on-site when required rather than carried in stock.

4.10.2.1 Three Dimensional (3D) Scanning

3D scanning devices that are currently openly available (e.g. XBOX KINECT scanner) can be used to produce copies of existing products. This equipment unleashes the large open fabrication community to produce an increasing variety of technical products even if detailed constructions plans are not available.

4.10.2.2 Three Dimensional (3D) Printing

3D printing has particularly high potential in the area of open fabrication. The ability to print 3D objects to scale is a very promising tool for the future of DIY. Combining technologies like 3D scanning, 3D photography, and 3D shareware computer-aided design software will add up to a powerful application to produce parts and pieces for almost every purpose. Currently, 3D printing is restricted to printing only small objects generally from plastics, but larger objects, even complete houses, can be ‘printed’ from concrete using technology similar to 3D printing. This particular technology allows for the rapid replacement of building destroyed by natural or other disasters in severe or austere conditions.

3D scanners, together with 3D printing and photo synthesis technology, will allow users to create 3D models out of multiple photos of an object. These technologies offer another path for increasing the usability of desktop fabricators. The ability to produce relatively high-fidelity approximations of existing objects, when combined with the ability to modify and refine digital designs within a restricted set of parameters, creates an opportunity for fabricators to rapidly identify and use objects in the real world as the basis for their particular niche needs. Imagine seeing something you like, taking a series of photos with your phone, uploading them to your computer, and then asking it to create a 3D design of the object and then print it. It is only a matter of time before the computational power of cloud computing will make it possible for high-resolution images of any existing object to be transformed into a 3D printable model.

4.10.2.3 Human Tissue Printing

Advances in computing over the last quarter century were the key to unlocking the science of life. Future generations are likely to view bioinformatics as the most important and far-reaching application for computing. 3D printing using biomaterials will allow us to **produce living tissue** cheaply, cleanly, and efficiently, transforming the way we think of organisms, bodies and food.

4.10.2.4 Computer Aided Design (CAD)

The next generation of CAD software will take into account the physical and molecular capabilities of objects used in printing. Users will be able to indicate the stresses that will be placed on objects and will benefit from computational processes built into the software that will help the user create designs that are durable and representative of the desired final aesthetic. Software is being created that internalizes real-world physics and material capabilities into the designs it creates.

Trends in Open Fabrication:

- 3D printing of human organs likes hearts, livers, lungs etc.
- 3D printing using a diverse set of materials other than plastics.

- Fabrication of high complex parts and technological systems is open for everyone.
- Printing adhoc spare parts for the military.

4.11 Biomimetics and Nanotechnology.

Biomimetics is the application of methods and systems found in nature to study and design of engineering systems and modern technology. This technology transfer is desirable because evolutionary pressure typically forces natural systems to become highly optimized and efficient. It makes use of the 4 billion years of product improvement that has occurred over the life of the planet.

Several of today's technological problems could be solved using nature as a model. These types of natural concepts can provide solutions for several problems that are related **technical design**. This need not be restricted to just technology solution but also provides answers to the ways that nature would use to overcome a particular technological problem.

One example is the reduction of fixed wing UAV's stopping distance. Today's fixed wing UAV's require long landing airstrips for landing and stopping the craft. These crucial requirements often cannot be met within military operations. Since the use of military drones is getting more important, a solution for landing drones on very short airstrips must be found in the future. This problem also can be transferred to all other fixed wing planes. For fixed wing aircraft, aerodynamics does not allow certain angles of plane's wings and a minimum airspeed is needed to create lift. Using an innovation found in nature, control systems have been developed that allowed model aircraft to touch down on a wire perch like a bird. The control systems apply the same stalling method birds use while landing on a spot. Future landing systems could be developed that incorporate this type of natural innovation to allow UAV's or even larger planes to land in the same manner as birds.

Materials and structures of intricate complexity that exhibit remarkable properties are found throughout the biological world. Many of these biological systems derive their functionality from fabrication through several levels of self-assembly involving molecular clusters organized into structures of different length scales. The result is an optimized architecture tailored for specific applications through molecular, nano-scale, micro-scale, and macro-scale levels that is unobtainable through conventional, equilibrium-based, synthetic fabrication methods. The superior strengths and other properties such as non-corrosiveness and light weight of biomimetic materials lend themselves to solving and reducing numerous logistics burdens.

Nanotechnology will achieve dramatic, innovative enhancements in the properties and performance of structures, materials, and devices on the nanometre scale. Fabrication of structures at this small scale will enable manufacturing of more reliable, lower cost, higher performance and more flexible electronic, magnetic, optical, and mechanical devices.

4.11.1 Smart Structures.

Smart structures demonstrate advanced capabilities for modelling, predicting, controlling, and optimizing the dynamic response of complex, multi-element, deformable structures used in land, sea, and air vehicles and systems. Smart structures offer significant potential for expanding the effective operations envelope and improving critical operational characteristics for weapon systems. Logistics applications include a "self-healing" area for structural damage detection and mitigation systems.

In addition to the reduced logistical footprint that a lightweight, distribution-based logistics supply chain will afford, Annex A, Table 1 portrays some of the potential value added for logistics from the application of these technologies.

4.12 Energy

Winston Churchill said "safety and security in oil lie in variety and variety alone." Energy security will likely come about with a rise in interdependence of power sources rather than driving toward energy independence. This interdependence should be pursued in four strands: (1) energy efficiency, (2) diversity of supply, (3) develop supply/demand partnerships that recognize the global interdependence, and (4) increasing renewable supplies. Military energy costs are enormous so efficiency efforts have a short payback period. From an operational point of view, energy lines of communication are vulnerable and expensive so efficiency pays off quickly. This is shifting focus from supply side to demand side – making systems more energy efficient to lower demand.

The overwhelming percentage of the energy grid (95%) in western nations is privately owned and its Supervisory Control and Data Acquisition (SCADA) systems are vulnerable. A small incident in one part of the grid could cause a cascading failure of large portions of the electrical grid. Several trends have increased this vulnerability – open protocols, common operating systems, interconnections to other systems and the increased capability of field equipment. In the future, several concepts will reduce this vulnerability, including Smart Grids, energy islands (grids that are not connected to the overall grid), wireless transmission of energy reducing reliance on the grid and use of nanotechnology and other emerging technologies to improve the overall efficiency of the electrical grids. A possible security implication related to this is assured access to the rare earths that are required for many of these technologies, which are for now mostly found in China, though other sources have begun to be exploited.

Further into the future, hydrogen and nuclear fusion may become viable energy sources. Hydrogen does not have the energy content of fossil fuels and is difficult to transport in large amounts. Given that the source of hydrogen power will be the oceans, a virtually unlimited resource, hydrogen's many positive attributes – lack of pollution principally among them - will drive solutions to these problems. Once the production of hydrogen can be accomplished through renewable means – primarily solar – it will become much more viable. The unlimited power offered by fusion will also drive continued research to overcome the significant scientific hurdles that must be vaulted to make this a viable energy source.

4.12.1 Compact Power Sources.

New power sources will achieve significant improvements in the performance (power and energy density, operating temperature, reliability, and safety) of compact power sources through fundamental advances relevant to current technologies (e.g., batteries and fuel cells) and the identification and exploitation of new concepts. Efficient, long-life, durable, and quiet compact power sources are a critical requirement for electronics, communications, heating and cooling, weapons, and propulsion systems. It is envisioned that future power sources will have energy densities as much as 10 to 100 times greater than current batteries.

In the future demand for man-portable electrical power supplies is likely to exceed the capabilities of current battery technology. To meet these requirements current research is focused on advanced batteries, such as nickel-metal hydride and lithium ion chemistry batteries, and man portable hydrogen fuel cell systems. Given the emerging market for electric vehicles and the increasing military demand for advanced portable power sources, battery technology may become an issue of strategic security importance to NATO.

4.12.2 Fossil

Most alternative-fuel technologies are unproven, too expensive or too far from commercial scale to meet the military’s needs over the next decade. Exploration has focused on experimental biofuels derived from sources like algae or the flowering plant camelina. More focus should be placed on energy efficiency as a way of making cost savings and combating greenhouse gas emissions.

A recent RAND study noted that if such alternative fuels are to be pursued, the most economic, environmentally sound and near-term candidate would be a liquid fuel produced using a combination of coal and biomass, as well as some method for capturing and storing carbon emissions released during production. The full life-cycle emissions of many plant-based fuel alternatives are still not fully understood, particularly the degree to which they cause, directly or indirectly, changes in land use around the globe. Alternative fuels made from plants also compete with food crops for land. Producing just 200,000 barrels of such fuels a day — or about 1 per cent of total oil consumption in the United States — would require an area equal to about 10 per cent of the croplands currently under cultivation in the United States.

For now there is no alternative to fossil fuels, primarily oil, for global transportation needs. Today, there are 800 million cars on the world's roads, by 2050 that number could reach 4 billion, mostly in the rapidly developing countries of India and China. This will significantly increase overall demand for a stable or possibly declining resource that has climate changing characteristics and will demand associated infrastructure improvements. A viable alternative to fossils fuels may come in the form of electrically driven cars provided the electricity is generated in some renewable or energy-efficient fashion.

4.12.3 Solar Power

The use of solar power will continue to be more prevalent in the coming decades and has potential to solve the rising energy shortages coming about as a result of declining reserves of fossil fuels. The cost of concentrated photo-voltaic power is declining 20% per year while the cost of traditional power sources is increasing 6-9%/year. It is expected that parity with grid power for two-thirds of US will be reached by 2015. The energy efficiency of solar is 100-200% higher than other alternatives and improving. With new energy storage systems in place and the functionality even to produce solar energy during night times, it is possible that solar power may replace most fossil fuel sources for electrical generation within two decades and that electrical cars will have fully replaced combustion engines by 2028. Future solar power energy storage systems are under development. Currently a very promising technology can be found in molten salts, these enable solar power system to store the gained thermal energy in molten salts. These molten salts are liquid at atmospheric pressure and are comparable cheap, non-flammable and non-toxic.

4.13 Future Medical Technological Developments

Recent advances in body armour, the evolving ways that Alliance forces are being engaged – primary through improvised explosive devices - and advances in casualty evacuation and medical attention mean that more soldiers are surviving after suffering grievous wounds in the field. This is creating momentum to improve prosthetics. In the future, the connection of neuro-feedback and robotic limbs will allow much easier and smoother control of prosthetics limbs. Even more advances are coming in returning tactile sense to the limbs that will allow wearers to actually ‘feel’ or sense that they are touching something by producing electrical signals that mimic the biological sense of touch.

Robotic surgery exists today where surgeons use robotic systems to more accurately perform some procedures. The additional of tactile sensing and reduction of time delays in remote systems will improve the ability of robotic systems to expand to a greater array of functions. Remote systems could be used to provide care to wounded soldiers in the field increasing the likelihood that this treatment would be delivered within the ‘golden hour’ without exposing medical personnel to increased danger.

Nanotechnology will allow the delivery of targeted agents to attack specific ailments within the body increasing the effectiveness of treatments. DNA chips are already being developed that will cheaply detect the presence of even miniscule numbers of cancer cells in the blood so that appropriate treatment can commence prior to the cancer becoming a much more serious problem. Continued research into the human genome, supporting by the exponential increase in computing power, will allow for treatments to be designed that are specifically tailored to each individual. Life expectancy will be increased through the results of these types of research.

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Annex A

Table 1: Logistics' Applications of Future Technologies [US Army]

Nanotechnology	Smart Structures	Intelligent Systems	Biomimetics	Broadband Communications	Compact Power Sources
Changes concept of manufacturing—do anywhere	Vibration damping and reduction via embedded sensors	Execution of logistics system tasks without human intervention except when desired	Medical applications to include immediate repair of broken/ crushed bones and combat injuries	Provide field users with flexible, mobile, and easily deployable com-munications conduits	Reduce fuel and power storage and distribution requirements significantly
Synthesis from local materials	Reduced maintenance, resupply and transportation requirements	Unmanned ground/air vehicles decrease force structure and improve system response time	Repairs to combat damaged equipment	Untether logistics processes from fixed wire sites	Increased operational capability of the soldier as a system
Sophisticated, extremely lightweight material	Improved storage with ambient temperature control	Robots to handle materiel that is dangerous, heavy, or sensitive	Designer vaccines and drugs for quick return to healthy status	Increased data pass capability	Handle power requirement of dismounted soldier: heating and cooling; computer use;

					Com-munications trans-missions
Quantum computing at very high speed	Secure system containers for critical resources with reduced damage to material by adjusting containers and structures for various shock and impact conditions	Decision support system "brains" to monitor individual weapon systems and prevent failure	Lightweight structures and system components with ultra–reliability and virtually frictionless	Reduce frequency of data reporting	Reduced dependence on fossil fuels
Prophylactics and cures for chem/bio agents	Structures respond to external stimuli and adapt accordingly	Reduced logistics distribution require-ments by accurately assessing potential component failures and using collective knowledge of entire weapon system	Impact resistant material that can be grown in combat area	Integrate weapon system sensors reporting prognostic information on a broad scale	Reduced resupply requirement for power sources
Ultra–strong fibres	Retain history of access and denials/auto-	Improved logistics planning	Lightweight armour—reduced	Evaluate the "health" of entire groups of	Reduce environ-mental

	matic inventory	via multi-sensory perception develop-ment	logistics footprint across the board	common weapon systems individually and independently	issues associated with battery disposal
Programmed ultra–reliability	Reduce logistics requirements for chem/bio-defence	Improved exo-skeletons to reduce force structure for materials handling equipment —increased lift capability	High resolution sensors to detect imperfections and for trouble-shooting	Improve timeliness of the logistics com-munications support structure	Required to develop containers with micro heat pumps and long term power capability for independent operations
Reduced logistics demand	Immediate battle damage assessment and failure reporting	Reduced hazardous exposure during critical item operations or repair	Development of super-conductor material could lead to propulsion without motors or gears as we know them		
Environ-mentally enhancing	Biomedical applications including "in vivo" sensing and control		Non-corrosive and non-erosive		
	Rapid non-destructive testing				

	responses (less out of service time)				