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NBIC Disruptive Technology Watch

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Defence Research and Development Canada

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Introduction

Technology Watch is a process of monitoring technologies, analyzing them, placing them in proper context and, ultimately, deciding which ones are worthy of investment. Often, this is a difficult task. Making the correct technology bets has always been a difficult problem. A Technology Watch can play a vital role to increase the probability of making decisions that have attractive outcomes.

This is a formal definition of Technology Watch:

> *Technology Watch systematizes the process through which an organization maintains its view on the technology developments in the world. It serves the purpose of identification and assessment of technological advances critical to an organization's mission.* [Ref. 1]

This report presents the process, and the content derived from it, for the convergence of Nanotechnology, Biotechnology, Information Technology and Cognitive Science (known as NBIC Convergence – or simply NBIC).

The Technology Watch process, requisite innovation concepts, and analysis and context tools are discussed in the main section of this report. Annexes 1 and 2 provide concise analysis and context of the NBIC technologies resulting from the process. Annexes 3 and 4 present additional information on data collection. Annex 5 is a placeholder for technologies which do not meet the disruptive criteria but are nevertheless of interest (generally, sustaining technologies).

The intent of this report is to provide the reader with a clearer understanding of how advances in NBIC technologies can lead to new military technologies – and why those technologies might be important to the Canadian Defence community.

Background

In 2002, DRDC developed a revised approach for a Technology Watch. The objective was to identify promising research opportunities within disruptive, sustaining, emerging and surprise technologies. Additional tools and methods of analysis were subsequently developed. With a substantial interest being demonstrated in NBIC convergence, this subject was chosen as a proof-of-concept for a disruptive Technology Watch. This work was started in January 2003 with the goals being: a) to develop and refine a Technology Watch process; and b) to provide enriched NBIC content vis-à-vis disruptive technologies and investment decisions.

The end result of this disruptive NBIC Technology Watch is presented herein.

Purpose and Desired Outcomes

The purpose of this Technology Watch is to examine which combinations of NBIC technologies could be relevant and potentially disruptive to the Canadian Forces (CF) within the following time frames:

- 1 to 5 years;
- 5 to 10 years;
- more than 10 years.

In addition, this work is intended to solidify the DRDC's overall Technology Watch process. It is therefore a Technology Watch proof-of-concept utilizing NBIC convergence content.

Desired Outcomes:

The desired outcomes from this effort are:

- A list of disruptive NBIC technologies (relevant to the CF);
- An explanation as to why they are relevant to the CF;
- The manner in which they might be used;
- The effects of them on the military business model;
- Relevant performance metrics;
- Where they came from;
- Time frames;
- Canadian niche implications;
- Advisory input (upon which to make recommendations).

These outcomes are designed to be a useful tool which DRDC management can use when making technology investment decisions.

Scope

NBIC Convergence will be limited to the following: Nano-Bio (NB), Nano-IT (NI), Nano-Cognitive (NC) and higher order convergences (NBI, NBC, NIC and NBIC). The focus will be on disruptive potential of these combinations – and their relevance to the Canadian Forces. See Annex 3 for technology definitions.

Data Collection Methodology

The project mandated a systematized data-gathering process over a broad spectrum of types and sources of data. The following categories were identified as key sources (classification examples are given in brackets):

- Government Documents – Canada
- Government Documents – Allies
- Government Documents – Joint
- Science (*Science*, *Sc. American*, *MIT Review*, subject-specific journals such as *SmallTimes*)
- Academic (peer-reviewed journals)
- Conference Proceedings
- Business News (*Fortune*, *Wired*, *Fast Company*, *PR Newswire*, newspapers, newswires)
- VC (venture capital funding/promotion)
- Patent (filings)
- Personal communiqué (DND/DRDC internal communications)
- Web Publication (white papers, briefing books).

The intent of the data-gathering exercise is to identify and access key documents and research that indicate or delineate disruptive and convergent areas in the NBIC field, rather than to achieve an exhaustive survey of each topic.

The breakdown of data skewed heavily toward Science, Academic, Conference and Business categories. This was expected from the prevalence of nanotechnology in the research and business areas, and from the desired output of disruptive and convergent technologies.

The VC (Venture Capital) and Patent areas did not yield information for this stage of the Technology Watch process. They are important data points for a long-term Technology Watch, particularly to identify partnering opportunities, or to pinpoint national, corporate or academic strategies for target technologies. As an example, Japan has a long-term interest and investment in MEMs. Japanese firms have a significant body of work patented in the MEMs area. Japan's universities have dedicated considerable resources to the basic sciences around the topic, and receive government and venture funding for new ideas and processes.

Outline of the Technology Watch Process

The Technology Watch is driven by a process of understanding outcomes and requirements, convergence and innovation issues, time frames, maturity, partnering and niche applications. As such, the flow of this process is as follows:

- State *desired outcomes* for CF/DND (and their relevance to certain parts of CF/DND)
- Review *convergence issues*:
  - technology factors

  - process factors
  - infrastructure factors
- Define whether technology is *disruptive* or sustaining:
  - business model
  - performance metrics
  - incubating users
- Technology/System factors (*incremental, architectural, modular, radical*)
- *Maturity* considerations and *Technology Readiness Level (TRL)*
- Alignment with *CF/DND requirements* (desired outcomes align with organizational requirements)
- Discuss *Canadian niche* implications, if applicable
- Discuss *alliance/partnering* potential, if applicable
- Perform Economic Benefit calculation
- Provide/present *advisory input* (upon which decision-makers can base recommendations).

Utilizing this process, the Technology Watch team was able to garner new insights on NBIC technologies.

Technology Watch Process Components

Desired Outcomes

The first component of the Technology Watch process focused on the Canadian Forces' desired outcomes for a given technology. This required thinking at two different levels (at a minimum). The first level was the outcomes associated with the functionality of the technology. The higher-level outcomes related to the manner in which the technology affected the overall military operation or part thereof. This was important an important consideration from a disruptive technology perspective.

In order to address these two levels of outcomes, one has to question the overall relevance of the technology to the Canadian Forces. Technologies which were not relevant to the CF were deemed to be of less direct interest (although one must always consider the possibility that such technologies could incubate in a fringe, external market, mature, and then re-enter the military market in a disruptive fashion).

Furthermore, the timeliness of the technology was also considered. The farther out in time the technology was from realization, the less interest there was apportioned to it. This is not a deliberate attempt to be short-sighted. It is merely an acknowledgement that the farther out in time one forecasts a technology, the less likely one is to be correct about the technology.

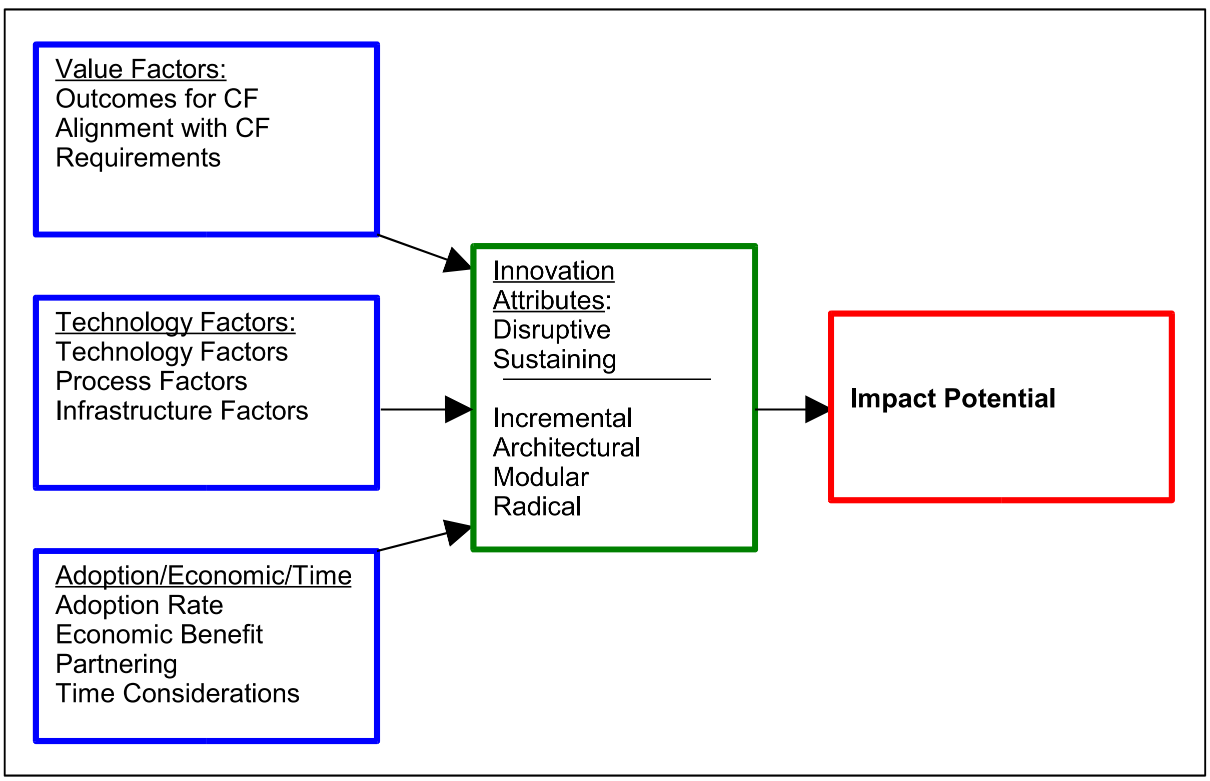
Long-term technology views are the domain of technology foresight. This activity has real and significant value in terms of organizing efforts to deal with longer-term, strategic developments. However, the current view of the Technology Watch team is to provide a more tactical view towards investment approaches (with medium-term strategic implications).

Convergence

The second component of the Technology Watch process is Convergence. This is a rather complex phenomenon which encompasses the convergence of science and technology efforts to create new value propositions. Virtually all technology deployed today has resulted from a technological convergence.

The convergence model outlined below was developed so as to provide a better understanding of convergence phenomena and to provide support to the overall Technology Watch process. Fundamentally, convergence is driven by Value, Technology and Adoption/Economic/Time factors. These flow into the nature of the technological innovation and ultimately lead to the Impact Potential.

Figure 1: Convergence Model



There is a great deal of work to be done in order to better understand technological convergence; however, this model provides a backdrop to better understand the processes involved.

Disruptive and Sustaining Technologies

Fundamentally, this process was employed to focus on disruptive technologies. There has been substantial debate regarding the definition of such technologies. For the purposes of this report, the following definition has been adopted:

Disruptive technologies – By disruptive technologies we mean new or existing technologies used in an innovative fashion that significantly alter established practices.

In addition, disruptive technologies:

1) change the "business model" of the military or part thereof;
2) are evaluated on a different performance metric(s); and
3) can incubate in fringe commercial markets that are relevant to the military – or in fringe markets within the military itself.

In contrast**, Sustaining technologies** foster improved product performance along an established trajectory. They also maintain an organization's business model. However, sustaining technologies often provide more features than customers need or want. [Ref. 2] Regardless, the majority of the capability derived from technological development is based on sustaining technologies.

Technology and System Factors

The intent of this component was to categorize the disruptive technology in terms of its system innovation considerations. Figure 2 is taken from Henderson and Clark [Ref. 11]. This research provides an elegant way of mapping innovations.

An innovation can consist of:

- A change in one or more components;
- A change in the way existing components are tied together; or
- Both of the above.

Figure 2

Core Concepts (i.e., core components)

Component Linkages	**Reinforced**	**Overturned**
Unchanged	Incremental Innovation	Modular Innovation
Changed	Architectural Innovation	Radical Innovation

The four classifications of innovation used by Henderson and Clark are:

- Incremental
- Modular
- Architectural
- Radical.

It is very unlikely that a disruptive technology would be an incremental innovation. It may be any one of the remaining three classifications. Disruptive technologies tend to be modular in nature since this allows plug compatibility with existing systems – a significant advantage. However, it is also possible that disruptions are architectural or radical in nature. Architectural innovation tend to require substantial deployment efforts. The reader is referenced to and Christensen [Ref. 2] and Henderson and Clark [Ref. 11] for a more thorough treatment of this topic.

Maturity considerations and Technology Readiness Level (TRL)

As mentioned in the Desired Outcomes section, timeliness (and hence maturity) was a consideration for a evaluating a given disruptive technology. If the technology, or the components thereof, were reasonably mature, than the probability of deploying the potentially disruptive technology in the short or medium term was considered to be significantly higher. The *Technology Readiness Level (or TRL)* is a United States Army approach to categorizing maturity. The 1 to 9 scale is summarized as follows:

1. Basic principles observed
2. Technology concept and/or application formulated
3. Analytical and experimental critical function and/or characteristic proof of concept

4. Component and/or breadboard validation in laboratory environment
5. Component and/or breadboard validation in relevant environment
6. System/subsystem model or prototype demonstration in a relevant environment
7. Subsystem prototype demonstration in an operational environment
8. Actual system completed and "flight qualified" through test and demonstration
9. Actual system "flight proven" through successful mission operations

The TRL approach has been used to better quantify the maturity of a given technology.

Alignment with *CF/DND requirements* (desired outcomes align with organizational requirements)

In order to ensure that the desired outcomes associated with a disruptive technology match Canadian Forces requirements, DND/CF policy papers and planning/priorities documents were consulted. These documents included:

- Department of National Defence (Canada), *Report on Plans and Priorities (2003-04)*
- Department of National Defence (Canada), *Capability Outlook 2002-2012*
- Department of National Defence (Canada), *Defence Strategy 2020*

Additional background was acquired from the 1994 Defence White Paper.

All technologies presented herein were in alignment with one or more of the aforementioned documents.

Discuss *Canadian niche* implications, if applicable

An effort was made to consider the technology alignment with Canadian capabilities. Such consideration included the nation's history, culture, geography, industrial focus, educational institutions and the influence of partners such as the United States and Britain.

Discuss *alliance/partnering* potential, if applicable

Based on work done by Callahan and MacKenzie [Ref. 16], partnering opportunities can be viewed along the following dimensions:

- Partner Motives (Technological, Security, National Priorities)
- Partner Capabilities (Track Record, Current Capabilities)
- Partner Resources (Funding, Investment Ramp-up)
- Development Processes (Linked to Technology of Interest)
- Organizational Cultures (Organizational Symmetry or Synergy).

Ultimately, the relevance of the technology to the CF, the activity of other partners, the international defence implications and the work currently being performed in Canada guide the evaluation of partnering potential.

Clearly, partnering can significantly influence cost and time-to-deployment of a new technology.

Economic Benefit

In order to provide a quantitative economic value to the technologies under consideration, an economic benefit calculation was developed. The parameters used in this calculation are as follows:

- Partnering Capability – this factor is related to the sharing of cost among partners. Costs could include research, development, manufacture, infrastructure, etc. Partners may be within public and private sectors as well as other nations. This parameter is rated on a scale of 1 to 10 with 1 being the minimum partnering opportunity (i.e. DND bears virtually all cost associated with the technology development) and 10 being the highest rating (DND bears only a small percentage of the development cost).
- Relevance – the relevance to the Canadian Forces must be high for there to be a solid economic benefit to them. Spin-off technologies may have significant benefits to other industries; but this work focuses on value propositions to the Canadian Forces. This parameter is rated on a scale of 1 to 10.
- Cost – specific costs for future disruptive technologies are not known. However, we have considered annual defence budgets for Canada and have classified costs in terms of relevant orders of magnitude. These are:
  - Cost Regime A: $10 million to $100 million;
  - Cost Regime B: $100 million to $1 billion; and
  - Cost Regime C: more than $1 billion.

  (These cost regimes were rated in terms of order of magnitude: Regime A = 1; Regime B = 10; Regime C = 100)

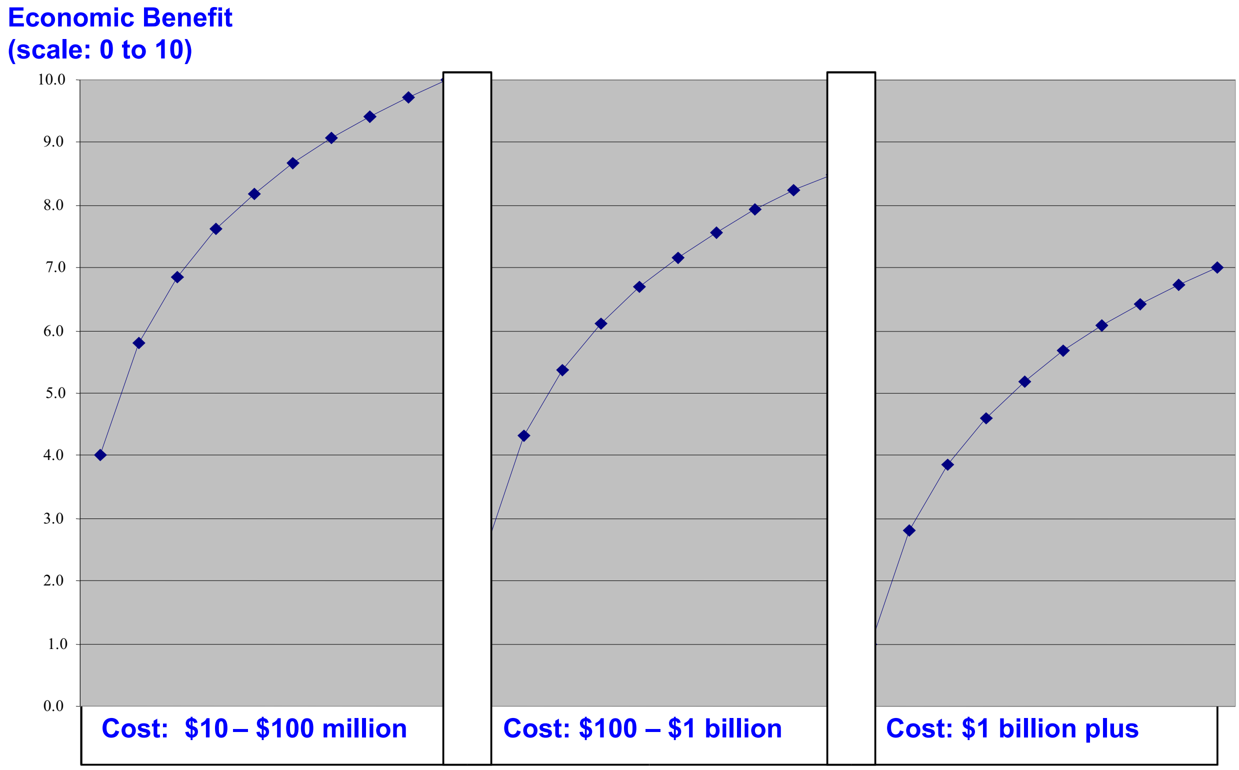
The higher the rating of partnering potential, the higher the economic benefit. This is also true of relevance. Clearly, the more relevant the technology is to the Canadian Forces, the higher the economic benefit thereof. Not surprisingly, economic benefit is adversely affected by cost.

The resulting function is as follows:

Economic Benefit = 3 x Log [21.544 x Relevance x Partnering / Square Root(Cost)]

Graphically, the function has the following form:

Figure 3



Note that Economic Benefit is plotted against Cost in this figure. Relevance and Partnering monotonically increase along each curve.

Advisory Recommendations

These recommendations flow out of the Technology Watch process. They are based on an understanding of the salient factors affecting the development of a given technology. Fundamentally, they help to answer these questions:

- Should this organization invest in this technology?
- If so what are the benefits that would accrue to the organization, and its stakeholders, as a result of such investment?

Notes on Annexes 1 and 2

Annexes 1 and 2 capture the output of the Technology Watch process for disruptive NBIC convergence. This output was divided into *Category 1 Projects* and *Category 2 Projects*.

CATEGORY 1

These are technologies which are deemed relevant to the CF and timely. This was in part a judgment call, but the implicit process took into account the product of timeliness and relevance to the CF – with a minimum standard for relevance being essential.

Category 1 Projects are presented in Annex 1. Their format follows the Technology Watch process very closely.

CATEGORY 2

Category 2 Projects are a lightweight version of Category 1. However, it was felt that they were not sufficiently strong in terms of relevance and timeliness. In addition, these technologies were lacking in terms of the availability of critical enabling technologies. As such, they did not make it into the top-tier grouping.

The format for Category 2 is designed to give the reader a concise view of the technology at hand – and why it might matter in the future.

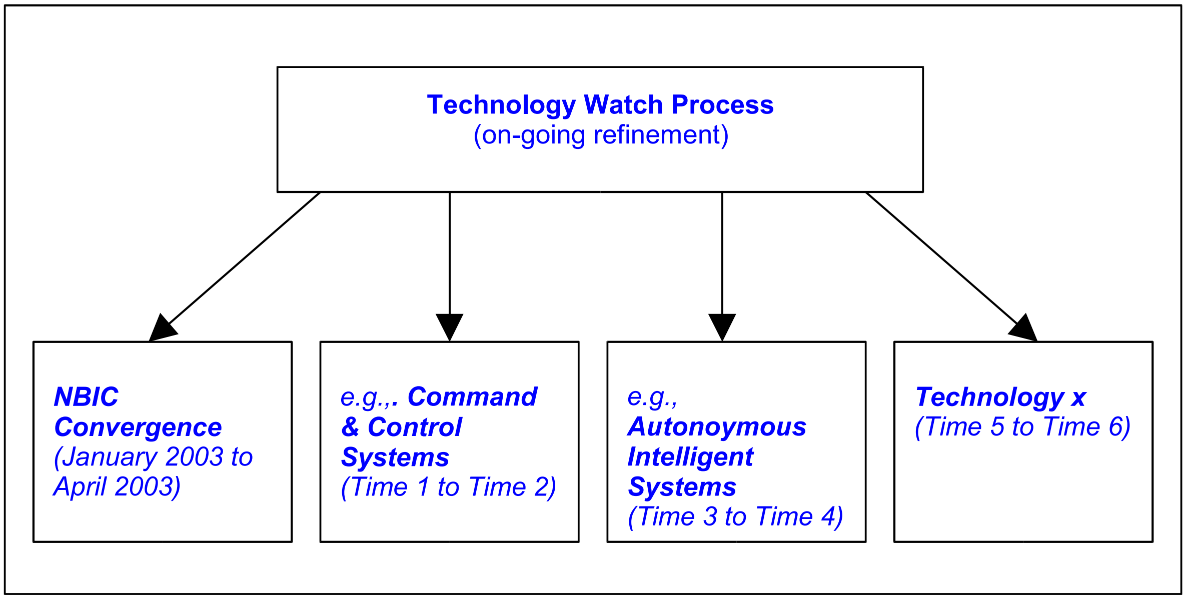
Category 2 Potential Projects are presented in Annex 2.

Technology Watch: Next Steps

This report has focused on disruptive NBIC technologies which were deemed relevant to the Canadian Forces. These filters were sufficient to reduce the amount of relevant NBIC data to a manageable size. However, one might ask how the Technology Watch process could be scaled up to encompass a broader set of technologies (i.e., fewer filters).

Clearly, ramping up the Technology Watch to capture the entire set of relevant military technologies (whether sustaining or disruptive) is a very substantial task. However, there is an incremental approach that allows both depth and breadth to develop over time. This approach is represented in Figure 4.

Figure 4



This approach offers several advantages, including:

- Allowing the Technology Watch team to focus on a manageable subset of technologies;
- Eliminating a large number of scalability issues associated with a very broad Technology Watch;
- Encouraging the identification of a particular customer or client with whom the team can work to identify desired outcomes, status, etc.;
- Striving for depth in each subject area before moving on to the next technology assignment.

As one builds a library of technology assignments, benefits are likely to accrue from an enhanced Technology Watch process and the combination of outputs from the various assignments.

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Annex 1A – Nano-Biotechnology Category 1

Technology Under Consideration: HANDHELD BIOASSAY DEVICE

Description: Using "molecular ink" to build nanostructures for bioassays, develop a compact, accurate, handheld device for detecting poisonous air, water, food.

Status: Medium-term (5-10 years); Nano-Bio integration.

Background: Work going on in US as CBRE Grand Challenge, EU, Japan.

Opportunity: Develop novel nanostructures, such as microfluidic structures, to detect poisons in water, air, food. Integrate onto common platform in a handheld device.

Desired outcomes for CF: Faster, more accurate detection and neutralization of poisonous material.

Convergence issues:

- Technology factors: Biological materials – molecular scale identification and deconstruction; tools, methods and techniques of nano-scale manufacturing.
- Process factors: Nano-manufacturing, smart materials device development, hand-held platform/device development.
- Infrastructure factors: Production facilities, adoption and training issues.

Define whether technology is disruptive or sustaining: Disruptive

- Business Model: Significantly changes decision cycle time with "in-field" analysis capabilities.
- Performance Metrics: Time: fast, in-field detection of poisonous substances Size: handheld form.
- Potential incubating users and uses: Reconnaissance forces.

Technology/System factors (incremental, architectural, modular, radical): Modular – small form factor allows for in field detection and analysis, orders of magnitude faster and more accurate than current systems.

Maturity considerations and TRL: Many methods, components, tools and techniques immature; TRL = 3.

Current Players: Nexia Biotechnologies (Montreal) Protexia anti-nerve gas protein; EU firms Biotrace, Lucigen. US R&D BioCOM chip developed at the UCBerkeley for high throughput multiplexed biomolecular analysis via chip-level microcantilever array; optical resonator-based chemical detector developed at NIST.

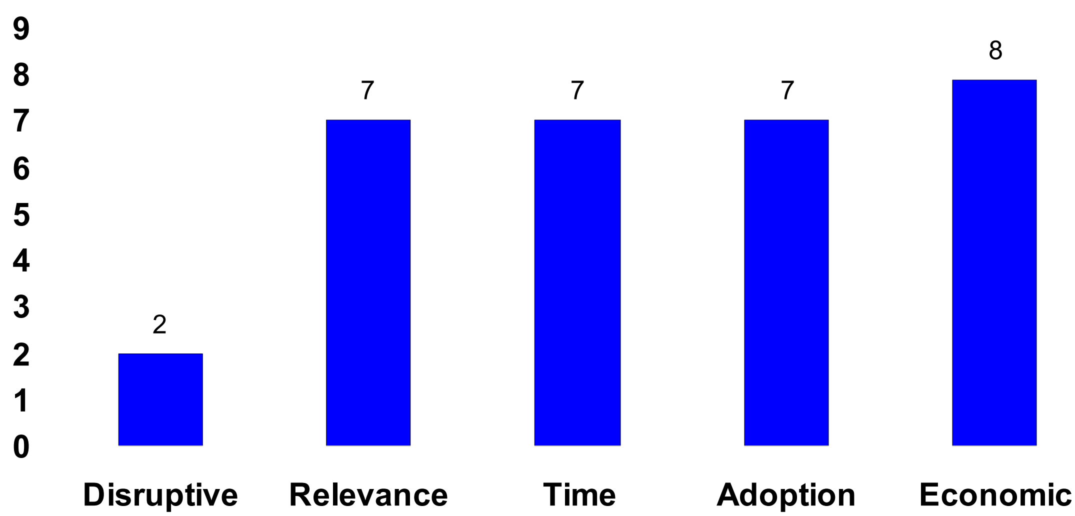
Alignment of outcomes with CF requirements: Good alignment – faster detection and of biochemical or nanotechnology threats. "Enhance counter-terrorism, intelligence, research and development, and emergency response capabilities." (From Corporate priorities for Defense 2002-2003 _page_)

Canadian niche implications: Technology fits within Canadian nano-materials niche and draws on the biotechnology (agriculture) work for substance identification.

Alliance/partnering potential: Opportunity to partner with US and EU for pharmaceutical aspects. Japan leads in nano-manufacturing applications.

Advisory input: The CF needs to fund development of this device because specific development of bioassay materials suitable for detection and protection of ground forces is unlikely in the independent public sector. The handheld device is especially applicable to ground forces, as few private entities have that degree of need for transportability. Most useful path would be to align with labs producing civil applications and target materials of military interest through parallel or directly funded development. Current solutions will evolve to smaller and more accurate devices with the integration of nanotechnology.

Disruptive Impact Potential:



Each parameter has a maximum value of 10. Maximum total value is therefore 50.

Total value for this technology: **31/50**

Technology Under Consideration: SELF-STERILIZING NANOMATERIALS

Description: Organic/inorganic hybrid materials that attack surface bacteria automatically

Status: Short-term (1-5 years); Nano-Bio integration

Background: Work going on in Canada, US, UK

Opportunity: Develop hybrid nano-materials to make sterile/clean surfaces available in field situations.

Desired outcomes for CF: Sterilized materials for medical use and sterilized uniforms automatically available for ground troops in field situations. Improved tactical deployment of combat and medical personnel.

Convergence issues:

- Technology factors: Fusion of organic and inorganic materials at the nanoscale level.
- Process factors: Need manufacturing facilities and techniques.
- Infrastructure factors: Training, adoption, deployment. Secure handling.

Define whether technology is disruptive or sustaining: Disruptive

- Business Model: Automates cleaning and sterilization of surfaces in all conditions. Narrowing Command and Control gap leads to more generalists, fewer specialists. This reduces need for specialized medical personnel.
- Performance Metrics: Infection Rate: Significantly fewer bacterial infections; Chemical reactions: reduced number and severity of chemical reactions.
- Potential incubating users and uses: Medical forces in forward areas. All front line troops can be "medics on the spot."

Technology/System factors (incremental, architectural, modular, radical): Modular – replace surfaces, uniforms, coatings for structures, vehicles.

Maturity considerations and TRL: Many components and techniques mature; TRL = 7.

Current Players: Integran (Toronto) nano-metals, EnviroSystems (San Jose) nano-concentrations and waterborne sterilizers, Anson Nanotechnology, (Hong Kong) anti-bacterial clothing, Arvind (India) nanowhiskered clothing.

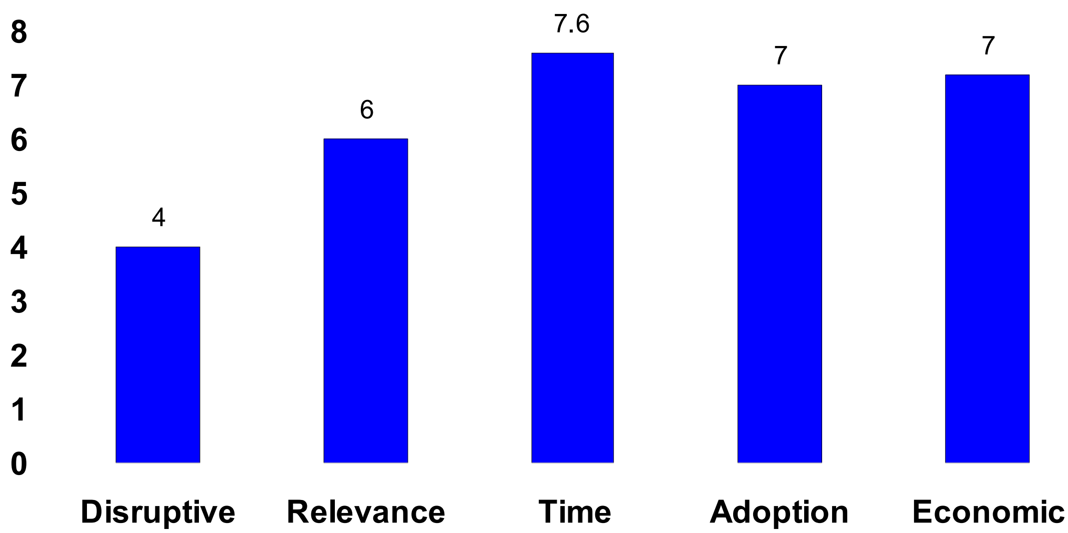
Alignment of outcomes with CF requirements: Good alignment – increases deployability, strengthens infrastructure, aids logistics. (Defense Strategy 2020, p. 13)

Canadian niche implications: R&D in agri-business and pharmaceuticals is key to the development of these materials; both are Canadian strengths.

Alliance/partnering potential: Canadian high-tech partnerships available. Opportunity to partner with US and China.

Advisory input: Fund this project because the specific development of sterilizing and/or cleaning materials suitable for ground forces is unlikely in the public sector. Some trauma center applications are translatable (e.g., "biobandages"). Most useful investment path would be to align with labs producing civil applications and target materials of military interest through parallel or directly funded development.

Disruptive Impact Potential:



Each parameter has a maximum value of 10. Maximum total value is therefore 50.

Total value for this technology: **32/50**

Technology Under Consideration: ENHANCED SIMULATION/VIRTUAL REALITY (VR) FOR TRAINING PLATFORM

Description: Integrate platform to exploit new nanoscale materials, acoustic, vision and force R&D and cognitive developments to enhance training simulations to VR state.

Status: Short-term (1-5 years); Nano-Bio-IT-Cog integration

Background: Work going on in Canada, US, UK on components, need for simulation training to model new threats and environments.

Opportunity: Integrate sensors, nanomaterials and new training technology to extend and enhance training experience. Lead the world in training and VR simulations.

Desired outcomes for CF: Simulation and VR training for Canadian and Allied forces.

Convergence issues:

- Technology factors: Nanoscale materials development; sensors and actuators integration; Virtual reality software integration
- Process factors: Integration of current and developing acoustic, visual, force devices into single platform
- Infrastructure factors: Training, Targeted simulation building (i.e. urban warfare), co-operative training agreements

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Define whether technology is disruptive or sustaining: Disruptive

- Business Model: Shifts physical training model to simulated training model. Permits parallel streams of trained units. (Replaces and/or augments traditional training.)
- Performance Metrics: Speed: Faster training available to greater numbers Cost: Cost effective training for inhospitable conditions (i.e., urban warfare simulation),
- Potential incubating users and uses: Troops involved in novel situations i.e. urban warfare.

Technology/System factors (incremental, architectural, modular, radical): Modular – Lessons learned from simulations may change C&C or combat methods.

Maturity considerations and TRL: Many components and techniques mature; TRL = 7.

Current Players: Michigan, simulations for training, Center for Wireless Information Systems – electrical signal directly to nervous system, Duke, CAVE "holodeck" room; UK private and academic research into commercial applications. Japan leads in nano-manufacturing.

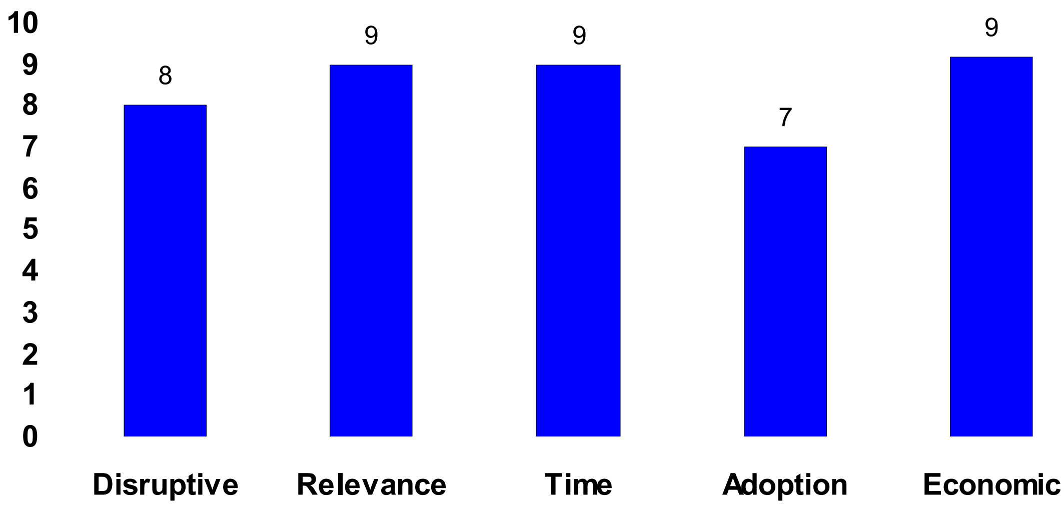
Alignment of outcomes with CF requirements: Good alignment – "A robust modelling and simulation capability will be a necessity to deal with the 2010 and beyond environment. "(Recommendations for DND's S&T Approach to 2010 and Beyond, #8)

Canadian niche implications: Canada has long provided training to Allied forces (e.g., Goose Bay LB, Shiloh MB) and can capitalize on those relationships. Strong medical research community, especially in hearing and vision advances.

Alliance/partnering potential: Opportunity to partner with US for medical and electronic R&D. Japan in manufacturing. Opportunity to become international provider of choice for simulation training.

Advisory input: Fund a new platform to integrate and exploit developing technologies. Research already underway in VR and simulation based training to extend current systems. Probability that commercial developments can be adapted to military use is high, further reducing costs.

Disruptive Impact Potential:



Each parameter has a maximum value of 10. Maximum total value is therefore 50.

Total value for this technology: **42/50**

Technology Under Consideration: COMMAND AND CONTROL (C&C) TRAINING PLATFORM

Description: Integrate new nanoscale materials, acoustic, vision and force R&D and cognitive developments to enhance training simulations for C&C applications. (note: similar to training platform development case. Potential for parallel development.)

Status: Short-term (1-5 years); Nano-Bio-IT-Cog integration

Background: Work going on in Canada, US, UK on components, need for simulation training to model new threats and environments.

Opportunity: Integrate sensors, nanomaterials and new training technology to enhance training experience. Lead the world in C&C training.

Desired outcomes for CF: C&C training for Canadian and Allied forces

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Convergence issues:

- Technology factors: Nanoscale materials development; sensors and actuators integration; virtual reality software integration
- Process factors: Integration of current and developing acoustic, visual, force devices into single platform
- Infrastructure factors: Training, Targeted simulation building (i.e., urban warfare), cooperative training agreements

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Define whether technology is disruptive or sustaining: Disruptive

- Business Model: Canada recognized as a training provider to the world for military, emergency and civil defense personnel.
- Performance Metrics: Speed: Simulated environments provide training anywhere, for any number of people in time independent setting. Cost: Cost effective, faster training for inhospitable conditions, simulated.
- Potential incubating users and uses: C&C personnel facing unique challenges (i.e., urban warfare).

Technology/System factors (incremental, architectural, modular, radical): Modular

Maturity considerations and TRL: Many components and techniques mature; TRL = 7.

Current Players: Michigan, simulations for training, Center for Wireless Information Systems – electrical signal directly to nervous system, Duke, CAVE "holodeck" room; UK private and academic research into commercial applications. Japan leads in nano-manufacturing.

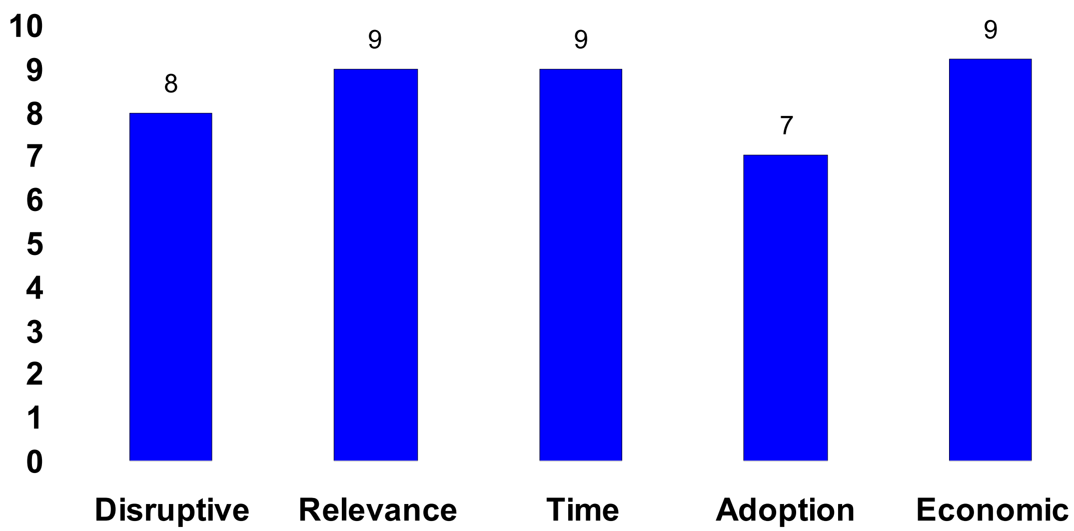
Alignment of outcomes with CF requirements: Good alignment – "Increased emphasis will need to be placed on S&T for assisting 2010 and beyond commanders with decision making, which will often be made at lower levels. (Recommendations for DND's S&T Approach to 2010 and Beyond)

Canadian niche implications: Canada has long provided training to Allied forces (e.g., Goose Bay LB, Shiloh MB) and can capitalize on those relationships. Strong medical research community, especially in hearing and vision advances.

Alliance/partnering potential: Opportunity to partner with US, and EU in R&D. Japan in manufacturing.

Advisory input: Need new platform to integrate and exploit developing technologies. Research already underway in VR and simulation based training to extend current systems. Probability that commercial developments can be adapted to military use is high. Opportunity to lead the world in simulated VR training for C&C.

Disruptive Impact Potential:



Each parameter has a maximum value of 10. Maximum total value is therefore 50.

Total value for this technology: **42/50**

Technology Under Consideration: MOLECULAR BIOLOGICAL WORKSTATION

Description: "CAD" for molecular level substances

Status: Mid-term, 6-10 years.

Background: International R&D seeking basic platform for nanoscale research. Current concentration is on nano-medicine, Note that the platform, once developed, can be used for nanoscale development, study and manipulation of any substance including organics, metals etc.

Opportunity: Build capability to analyse molecular substances and develop neutralizing tactics.

Desired outcomes for CF: Precise, directed faster response to biological and/or chemical threats.

Convergence issues:

- Technology factors: Component development, bioassay development.
- Process factors: Integrated platform for molecular level investigation and analysis.
- Infrastructure factors: Secure testing, development and manufacturing facilities.

Define whether technology is disruptive or sustaining: Disruptive (Marginally)

- Business Model: Changes reactive medicine to proactive medicine.
- Performance Metrics: Time: permits more precise analysis in significantly less time (e.g., factor of 2-3 reduction), Cost: Time reduction should reduce costs by a factor of 2-3.
- Potential incubating users and uses: Medical researchers. (DRDC Toronto, Suffield)

Technology/System factors (incremental, architectural, modular, radical): Modular – but with potential architectural changes for operations.

Maturity considerations and TRL: Some components mature; TRL = 5.

Current Players: US BrooksPRI Automation platform development; Aclara Biosciences and Protevirus, component development.

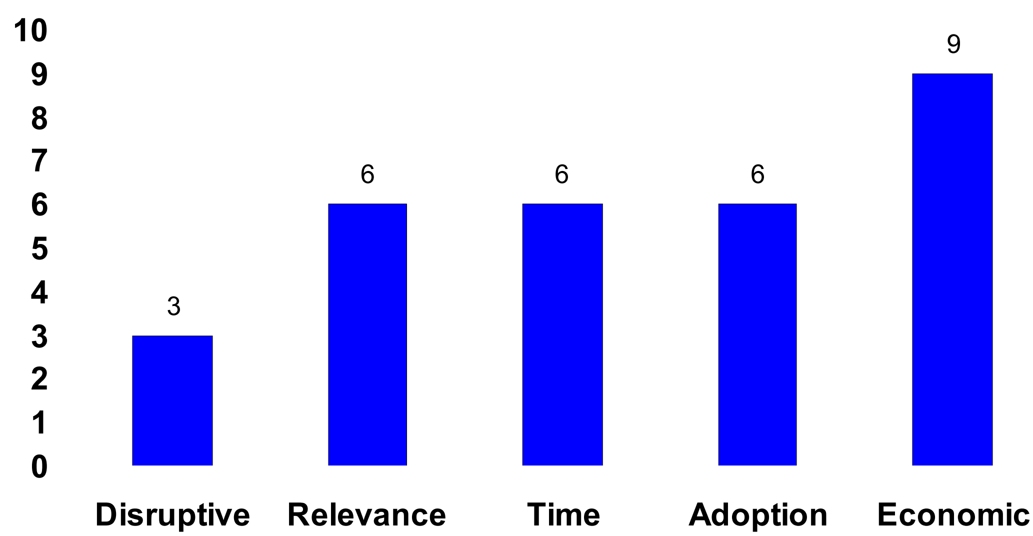
Alignment of outcomes with CF requirements: Good alignment – proactive medical research for forces health and well-being; civil defense. "The asymmetric threat is considerable and it will require dedicated national resources and close cooperation with international partners. (Recommendations for DND's S&T Approach to 2010 and Beyond, #3)

Canadian niche implications: Dovetails with molecular biology research in the pharmaceutical and agri-business areas. Can draw on materials research for novel platform solutions.

Alliance/partnering potential: Opportunity to partner with US and Britain in pharmaceutical and molecular biology research.

Advisory input: This area requires monitoring and evaluation, as well as development of expertise. The device itself will likely be fully realized for the pharmaceutical and medical industries. Investment will be needed to ensure that defense specific applications are covered. The most effective path for the CF would be partnering and subsequent development of secure, distributed production facilities as the technology matures.

Disruptive Impact Potential:



Each parameter has a maximum value of 10. Maximum total value is therefore 50.

Total value for this technology: **30/50**

Annex 1B – Nano-Information Technology Category 1

Technology Under Consideration: NANO-MICRO SENSORS EMBEDDED INTO MATERIAL (1)

Description: Wearable, wireless miniaturized GPS and physiological sensors, woven into the fabric of uniforms/body armor by 2008.

Status: Mid-term (5 to 10 years); Nano-IT-Bio integration

Background: Work going on in US universities and corporate laboratories.

Opportunity: New devices for connected combat teams will allow closer monitoring of personal and enhanced command and control as a given operation progresses.

Desired outcomes for CF:

- Operational awareness and monitoring of CF personnel's physical location and physiological condition during operational activities by command authorities
- Team members will be more aware of each other's locations, allowing for greater tactical maneuverability.

Convergence issues:

Technology factors: 1. nano-biology advancements 2. computer visualization graphic for C&C.

Process factors: Manufacturing miniaturized sensors to fit combat outfit material via molecular assembly; developing a robust, cost effective software and IT infrastructure to receive/send data; affordable longer life power sources.

Infrastructure factors: Field support, training and adoption factors; new wireless networks; compatible with allies.

Define whether technology is disruptive or sustaining: Disruptive

Business Model: Changes force awareness/recognition, response and communications, permits alternate response/deployment patterns.

Performance Metrics: Real time information on all personnel location and physical state as opposed to intermittent reporting from single source.

Potential incubating users and uses: SWAT, SAR and reconnaissance units. Could be used for combat casualty monitoring and location finding.

Technology/System factors (incremental, architectural, modular, radical):
Architectural – a disruptive innovation because of the potential C4ISR impact on CF personnel and operations

Maturity considerations and TRL: Components not yet mature; TRL = 4

Current Players: I-Stat, Micralyne, Stanford, Berkeley and IBM.

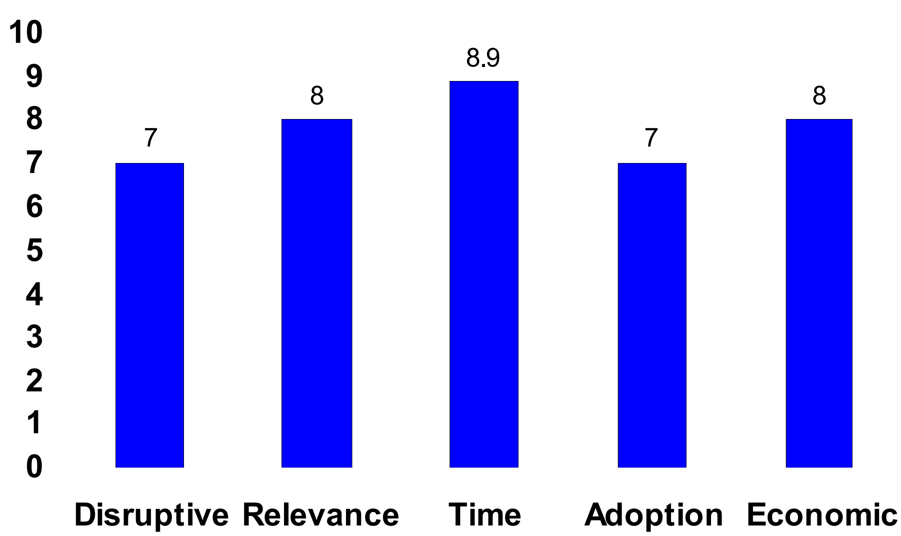
Alignment of outcomes with CF requirements: Enhanced sensing and communication for CF personnel; fits with DND/CF emphasis on compatible, integrated C4ISR equipment with allies, open architecture platforms, and improved ties with industry. (Department of National Defence. *Canadian Defence Beyond 2010: The Way Ahead 2003-2004 Report on Plans and Priorities*)

Canadian niche implications: Some Canadian component technologies (Lightyear, QLT, Iatroquest, and UBC) provide expertise in sensors and communications over large geographic distances.

Alliance/partnering potential: Opportunity to partner with US, as a CF S&T priority, in terms of developing such sensors and influencing their interoperability.

Advisory input: Fund development provides value as specific development of nano-micro sensors suitable for detection/protection of CF personnel is unlikely in the independent public sector. They are especially applicable to ground forces but could also be modified for civilian healthcare, emergency response and public safety (ie. police, firefighter) use. Aligns with labs producing civil applications and target materials of military interest through parallel or directly funded development.

Disruptive Impact Potential:



Each parameter has a maximum value of 10. Maximum total value is therefore 50.

Total value for this technology: **39/50**

Technology Under Consideration: ADVANCED MATERIAL VEHICLES

Description: Lighter weight or more stealthier air/ground/naval platforms using smart materials with accompanying Artificial Intelligence by 2010.

Status: Mid-term (5 to 10 years); Nano-Materials integration.

Background: Work going on in US government research and university laboratories.

Opportunity: Use developing advanced material technologies and manufacturing for new, lighter vehicles that will be easier to transport and operate in various environments.

Desired outcomes for CF: Vehicles could operate more efficiently during SAR, humanitarian assistance, PKO, sovereignty enforcement, and joint combat operations.

- Remotely or self-piloted vehicles could help alleviate personnel deployment issues, as well as reduce potential combat casualties
- Such vehicles will be faster and stealthier than predecessors.

Convergence issues:

- Technology factors: Stable nanotubes and polymers, stronger advanced materials, AI software with almost perfect reliability.
- Process factors: Integration of cost effective manufacturing new advanced materials with AI software. Such software integration required for these robotic vehicles, particularly if there are embedded sensors.
- Infrastructure factors: Control and tracking of remotely piloted or autonomous vehicles; field support, training and adoption factors; compatible with allied forces.

Define whether technology is disruptive or sustaining: Disruptive

- Business Model: Risk calculation changes as CF personnel are no longer always required to operate certain vehicles. They also change transport requirements for operations abroad. New lighter weight, smarter platforms will enhance “in-field” capabilities and permit alternate response/deployment patterns.
- Performance Metrics: Weight- Much lighter; Cost- Potentially cheaper materials for vehicle assembly and maintenance; Speed- enhanced velocity and acceleration due to reduced drag, especially for underwater or air vehicles; Unpiloted- Larger fleet/inventory.
- Potential incubating users and uses: Naval operations, aerial reconnaissance units.

Technology/System factors (incremental, architectural, modular, radical): Modular

Maturity considerations and TRL: Components mature; TRL = 6.

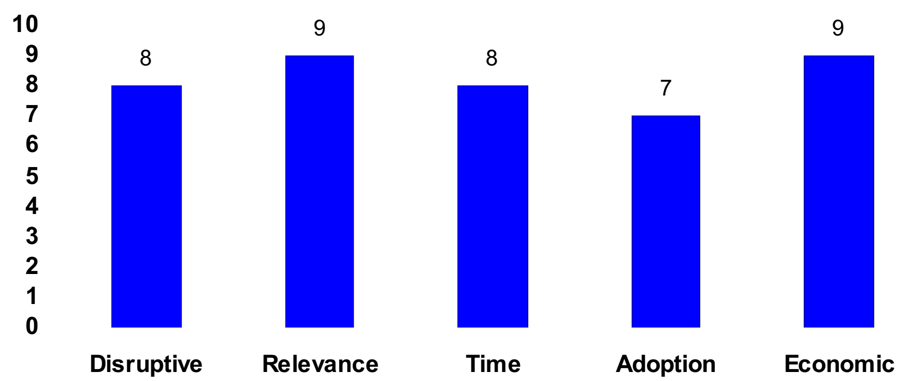
Current Players: NASA, DARPA, Carbolex, Espin, NanoEnergy, Nextech, C Sixty, Quantum Technologies, and Integran.
Alignment of outcomes with CF requirements: New transportation, surveillance, and combat vehicles for CF personnel fits with DND/CF emphasis on compatible equipment with allies, using open architecture platforms, unmanned platforms, and improved ties with industry. (Department of National Defence. *Canadian Defence Beyond 2010: The Way Ahead* and *Department of National Defence: 2003-2004 Report on Plans and Priorities*)

Canadian niche implications: Some component nano-technologies (C Sixty and Quantum Technologies) are derived from existing strengths in manufacturing and material sciences.

Alliance/partnering potential: Opportunity to partner with US and allied firms/researchers, as a CF S&T priority.

Advisory input: Good investment opportunity to fund research and prototype development of lightweight vehicles/platforms as Canada has niche expertise in vehicle manufacturing and operating in harsh environments. Dual use applicability to civilian applications (eg. Natural resources exploration and transportation, Arctic and other remote regional activities)

Disruptive Impact Potential:



Each parameter has a maximum value of 10. Maximum total value is therefore 50.

Total value for this technology: **41/50**

Technology Under Consideration: ADVANCED MATERIALS FOR GROUND TROOP WEAPONRY

Description: New advanced materials will produce new weapons for future conflicts.

Status: Mid-term (5 to 10 years); Nano-Materials integration

Background: Faster firing, more lethal weaponry provides CF personnel with enhanced capability during combat operations. If, however, used by potential enemies, poses greater threat to CF personnel.

Opportunity: Develop and deploy new weaponry to engage enemy forces more effectively.

Desired outcomes for CF: Nanomaterials will lead to lighter, faster firing weapons (laser rifle and double cannon rifle, both with laser range-finders able to distinguish between dust, smoke and fire) and corrosion resistant camouflage.

Convergence issues:

Technology factors: More accurate rangefinders, higher velocity rifle cartridges, stable nano-materials. Producing cost-effective self-healing polymers that incorporate nanosensors.

Process factors*:* Molecular bonding in new materials will be dependent on the surrounding environment as other dipoles may interfere with desired bondings. Future nanotube production will require a non-metal catalyst. Carbon nanotubes also must integrate a sufficiently broad range of colors for camouflage purposes.

Infrastructure factors: Field support, training and adoption factors; also repair of weapons.

Define whether technology is disruptive or sustaining: Sustaining

Business Model: Changes force projection capabilities during field operations; permits more varied deployment against a greater variety and more complex targets.

Performance Metrics: Faster rate of fire for smaller, lighter weapons and greater ability to penetrate protected targets.

Potential incubating users and uses: SWAT/hostage rescue units.

Technology/System factors (incremental, architectural, modular, radical): Modular

Maturity considerations and TRL: Components not mature; TRL = 5

Current Players: UC-Berkeley, University of Washington, RMC, MIT, NJIT and DRDC (precision weapons, weapons performance, countermeasures).

Alignment of outcomes with CF requirements: Greater firepower and lethality during combat operations; and fits with DND/CF emphasis on compatible equipment with allies, using open architecture platforms, and improved ties with industry. (Department of National Defence. *Canadian Defence Beyond 2010: The Way Ahead* and *Department of National Defence: 2003-2004 Report on Plans and Priorities*)

Canadian niche implications: New materials and nano-technologies are building on Canadian competencies in weapons development and new materials. Would allow improvement in Canadian military industry.

Alliance/partnering potential: Possible opportunity to partner with US and Britain, as a CF S&T priority, in terms of "off-the-shelf" capability and future performance trajectories and interoperability

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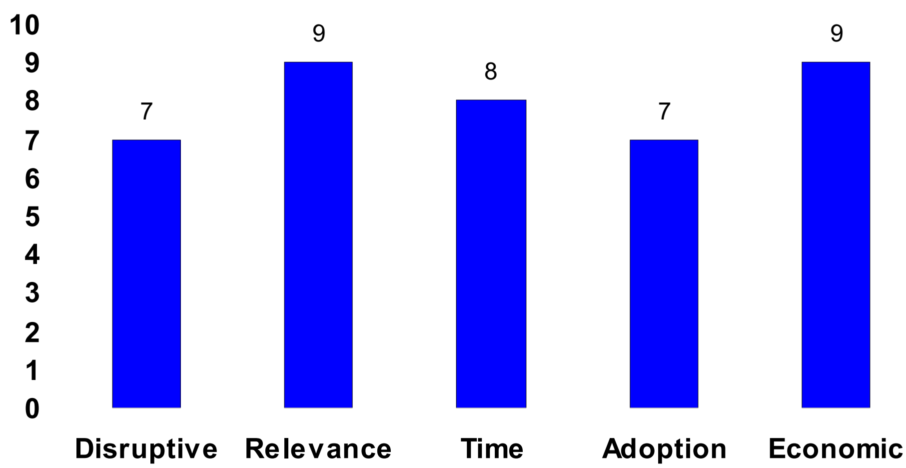
Advisory input: Opportunity to develop new explosive weaponry for CF personnel. As well, a successful product could be exported to allies. It is really an integration exercise with a sound value proposition and short time horizon.

Disruptive Impact Potential:



Each parameter has a maximum value of 10. Maximum total value is therefore 50.

Total value for this technology: **40/50**

Technology Under Consideration: NEW UNIFORM/WORK SUITS MATERIALS INCLUDING EMBEDDED SENSORS (2)

Description: More durable and multi-purpose combat uniforms and work suits, that may contain embedded sensors by 2008. In addition, each soldier could have voice dialogue with embedded nano-computers, 3D retinal displays, and nano-fiber helmets with polymer face-shields.

Status: Mid-term (5 to 10 years); Nano-IT-Materials integration

Background: Proliferation of advanced material technologies will allow CF personnel to be better camouflaged and protected during combat operations.

Opportunity: Uniform or combat gear nano-fibers will aid against chemical-biological (CB) threats, provide active chameleon camouflage, and offer improved protection from ballistics.

Desired outcomes for CF: Less easily detectable, therefore less vulnerable CF personnel.

Convergence issues:

Technology factors: Requires continued development and application of nanomaterials and their integration in combat uniforms and work suit. Integration of developing visual and data transmitter-receivers for helmet, face-shield and clothing. Developing long life, robust power sources for embedded sensors.

Process factors: Integration of uniforms and combat suits with communication and sensor devices, vision functionality.

Infrastructure factors: Field support, training and adoption factors. Will require new manufacturing infrastructure.

Define whether technology is disruptive or sustaining: Sustaining with potential to be disruptive

Business Model: Changes CF personnel ability to resist various attacks; operate in a greater variety of field environments; permits alternate response/deployment patterns.

Performance Metrics: Stronger, more resistant work suit and combat uniforms offers greater protection with less weight, with potentially embedded nano-sensors or nano-computers.

Potential incubating users and uses: JTF-2

Technology/System factors (incremental, architectural, modular, radical): Modular

Maturity considerations and TRL: Some components not yet mature; TRL = 4

Current Players: UC-Berkeley, University of Washington, MIT and NJIT for DARPA.

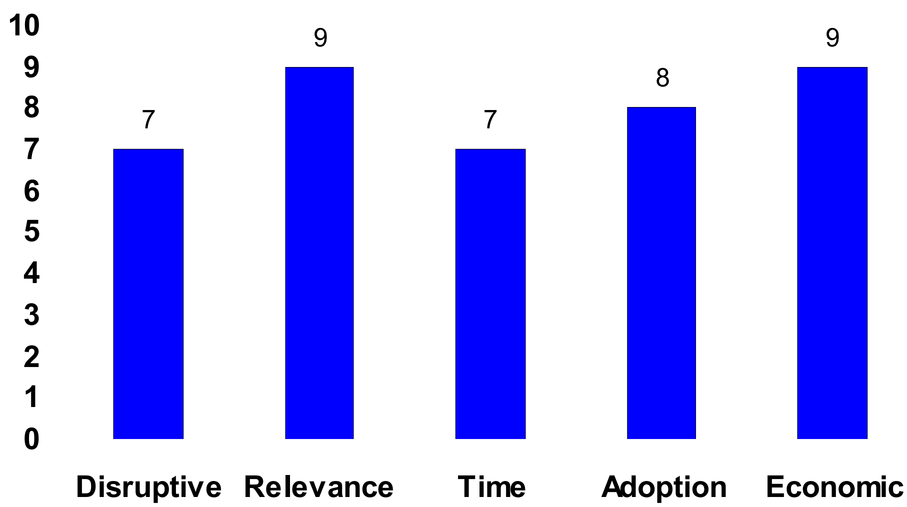
Alignment of outcomes with CF requirements: Enhanced personnel protection fits with DND/CF emphasis on compatible equipment with allies, using open architecture platforms, and improved ties with industry. (Department of National Defence. *Canadian Defence Beyond 2010: The Way Ahead* and *Department of National Defence: 2003-2004 Report on Plans and Priorities*)

Canadian niche implications: DRDC sensing and advanced materials research will have a significant development and applications role to play in developing these new technologies.

Alliance/partnering potential: Possible opportunity to partner with US and other allies, as a CF S&T priority, in developing new soldier technologies.

Advisory input: Good investment opportunity to develop nano-technology and manufactured based combat equipment for CF personnel. These devices are unlikely to be developed solely by the private sector. Most useful path would be to align with labs producing materials of military interest through parallel or directly funded development.

Disruptive Impact Potential:



Each parameter has a maximum value of 10. Maximum total value is therefore 50.

Total value for this technology: 40/50

Annex 1C – Nano-Cognitive Category 1

Technology Under Consideration: INTEGRATED ACOUSTIC HELMET

Description: Tunable hearing, night vision, communications, physical and auditory protection.

Status: Near-term (1 to 5 years); Nano-IT-Cognitive integration.

Background: Work going on in US.

Opportunity: Use existing technology for disruptive land operations.

Desired outcomes for CF: Tactical awareness and cognition of "in-field" activity.

- *Enhanced hearing, hearing protection and audio-cognition*
- *Also integrate communication and night vision capabilities*

Convergence issues:

- Technology factors: Compact sound amplification/protection, Acoustic spectrum analysis, Nano-materials, Secure communication.
- Process factors: Integration of acoustic, analysis, communication and vision functionality.
- Infrastructure factors: Field support, training and adoption factors.

Define whether technology is disruptive or sustaining: Disruptive

- Business Model: Changes force awareness/recognition, response and communications, and "in-field" analysis capabilities; permits alternate response/deployment patterns.
- Performance Metrics: Land-based, acoustic sensing, acoustic and physical ear/head protection, integrated sensing/communications functionality.
- Potential incubating users and uses: JTF-2.

Technology/System factors (incremental, architectural, modular, radical): Modular – but with potential architectural changes for operations.

Maturity considerations and TRL: Components mature; TRL = 5.

Current Players: US army is developing an acoustic helmet. (Degree of sensing/communication integration and personnel protection?).

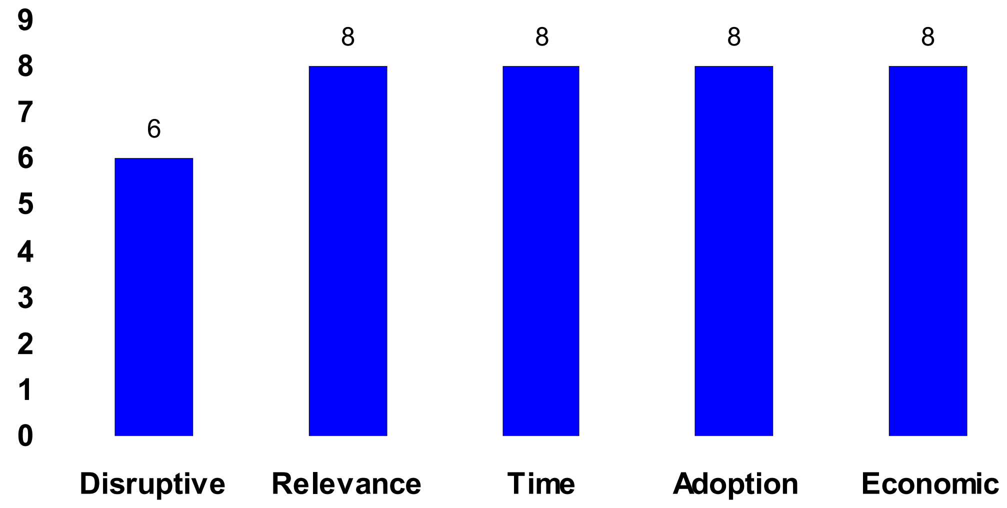
Alignment of outcomes with CF requirements: Good alignment – enhanced sensing, communication and cognition for troops.

Canadian niche implications: All technologies are within Canadian high-tech realm and research/industrial core competencies.

Alliance/partnering potential: Possible opportunity to partner with US and Britain in terms of "off-the-shelf" capability and future performance trajectories and interoperability.

Advisory input: This has the hallmarks of a disruptive "in-field" technology, not unlike night vision in the 1970s/1980s (and it incorporates night vision). It is really an integration exercise with a sound value proposition and short time horizon. Good investment opportunity.

Disruptive Impact Potential:



Each parameter has a maximum value of 10. Maximum total value is therefore 50.

Total value for this technology: **38/50**

Technology Under Consideration: MEDICAL TRAINING SIMULATION

Description: Development of a complete simulated training environment for military medical training

Status: Near-term (1 to 5 years) to Mid-term (6-10) Nano-IT-Bio-Cognitive integration.

Background: Work going on in US, both in academic as well as commercial areas. Canada has simulation expertise, especially in DRDC.

Opportunity: Develop a simulation system that can be used for combat casualty care and training with the potential to evolve into active telemedicine.

Desired outcomes for CF: Simulated and military specific medical training for the CF

Convergence issues:

- Technology factors: Nanoscale materials development; nano-sensors and actuators integration; Virtual reality software integration.
- Process factors: Integration of current and developing nano-material, nano-sensors, visual, and force devices into single platform.
- Infrastructure factors: Medical training, simulated combat casualty, co-operative training agreements.

Define whether technology is disruptive or sustaining: Disruptive

- Business Model: Potentially changes completely how military medical training carried, roles and responsibilities of medical staff, with the potential of changing medical training in general.
- Performance Metrics: Significant reduction in training budget, increased numbers of medical operationally trained personnel, improved retention of qualified personnel.
- Potential incubating users and uses: Surgeon General

Technology/System factors (incremental, architectural, modular, radical): Modular – Could lead to complete architectural change in how military medical training is performed

Maturity considerations and TRL: Components range from immature to mature; Nano= 3-5, IT= 6-8, Bio= 6-8, Cognitive=3-5.

Current Players: Dartmouth Univ. Virtual Workshop, Inc., simulations for training, Center for Wireless Information Systems – electrical signal directly to nervous system, CAVE "holodeck" room; UK private and academic research into commercial applications. Japan leads in nano-manufacturing.

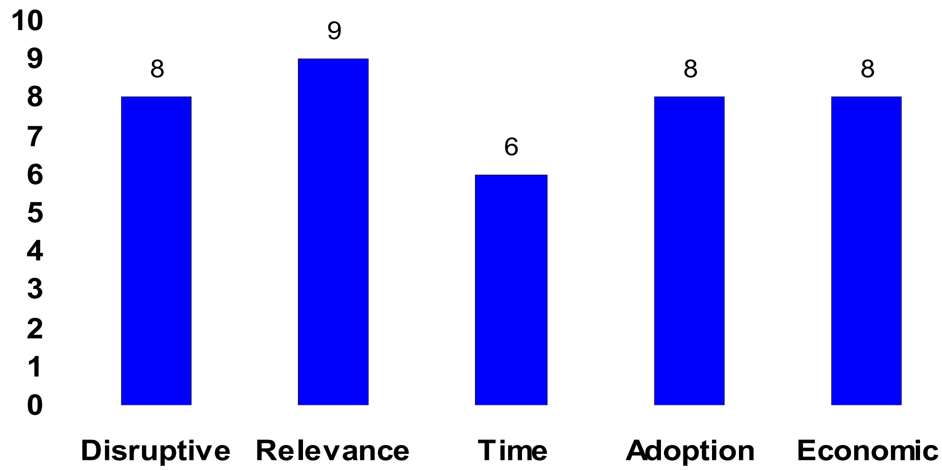
Alignment of outcomes with CF requirements: Good alignment – "A robust modelling and simulation capability will be a necessity to deal with the 2010 and beyond environment." (Recommendations for DND's S&T Approach to 2010 and Beyond, #8)

Canadian niche implications: Strong Canadian simulation expertise in aeronautical industry, strong medical research community, respected DRDC simulation capability.

Alliance/partnering potential: Opportunity to partner with US for medical and electronic R&D. Japan in manufacturing. Opportunity to become international provider of choice for simulation training.

Advisory input: Fund a new platform to integrate and exploit developing technologies. Research already underway in simulation based training to extend specifically to medical training. Probability that commercial developments can be adapted to medical school use is high, potentially further reducing costs.

Disruptive Impact Potential:



Each parameter has a maximum value of 10. Maximum total value is therefore 50.

Total value for this technology: **39/50**

Technology Under Consideration: PERSONAL INFORMATION DEVICES

Description: Through reconfigurable hardware that can be voice activated, it becomes possible to develop a handheld personal information device that can serve a multitude of functions including communications, GPS, weather/environmental monitoring, miniature radar, personal physiological monitor.

Status: Mid term (6 to 10 years) Nano IT Cognitive (possibly Bio) integration.

Background: Many academic and technology start-up companies, primarily in the United States are pursuing the concept and technologies associated with reconfigurable computers and computer hardware.

Opportunity: To develop a single, personal device that would perform the functions of three, four or more currently independent devices.

Desired outcomes for CF: **Provision** to CF personnel of a single, multi-functional personal information device that would replace a number of independent devices and that would be small enough and portable to be easily integrated into the current military kit.

Convergence issues:

- Technology factors: Reconfigurable computer hardware development is still in its early stages, but with the emergence of customized nano-materials, nano-manufacturing, many new options are evolving.
- Process factors: Integration of current and developing micro and nano- manufacturing of nano-material, nano-sensors, leading to an integrated personal information device.
- Infrastructure factors: Many IT component-manufacturing facilities could be re-configured to produce the necessary components.

Define whether technology is disruptive or sustaining: Disruptive

- Business Model: Potentially changes completely how the soldier will interact, communicate and function within their military environment. As well, it would change completely the current command and control doctrine.
- Performance Metrics: Significantly reduce the number and size of electronic based equipment required for operations. Concurrently, while providing the individual soldier with the same capability, a unit builds in multiple redundancies into communication, location, environmental monitoring etc.
- Potential incubating users and uses: Search and Rescue, Reconnaissance units, JTF.

Technology/System factors (incremental, architectural, modular, radical): Modular/Radical – Could lead to complete architectural change in military operations.

Maturity considerations and TRL: Components range from immature to mature; Nano= 3-5, IT= 3-6, Cognitive=5

Current Players: Numerous academic and technology companies are actively pursuing the development and adaptation of reconfigurable hardware to personal information devices. Leaders include Chameleon systems, Hewlett-Packard, Xilinx and UC Berkeley.

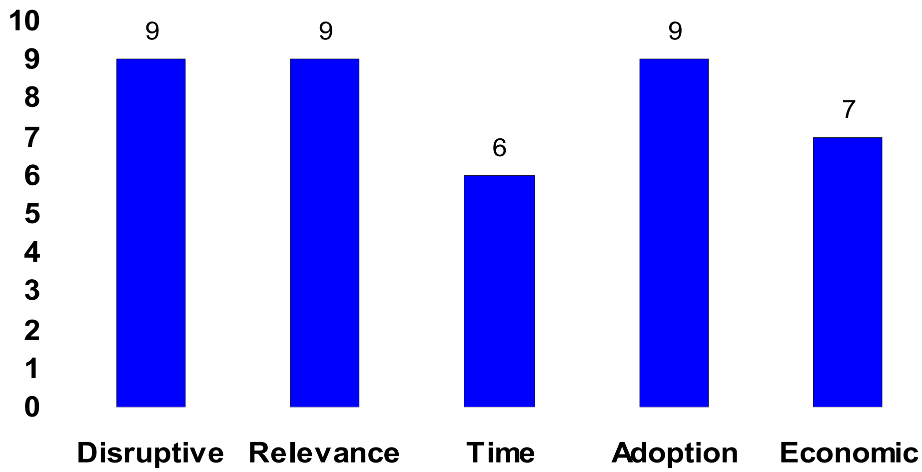
Alignment of outcomes with CF requirements: Excellent alignment – Strategy 2020, Critical Attribute of Modernization "Focus defence R&D efforts to target leading-edge technologies, while capitalizing on Canadian technological know-how to build and extend CF distinctive competencies such as telecommunications and sensing."

Canadian niche implications: Canada is a world leader in communications technologies.

Alliance/partnering potential: Opportunity to partner with US lead universities and companies, especially for manufacturing and integration of components required for Personal Information Device.

Advisory input: Funding research in reconfigurable hardware and working towards developing technology demonstrators.

Disruptive Impact Potential:



Total value for this technology: **40/50**

Technology Under Consideration: VISUAL-VERBAL LANGUAGE DEVELOPMENT

Description: Integration of verbal and visual means of communication to overcome ever increasing information overload

Status: Near-term (3 to 6 years); IT-Cognitive-Bio integration.

Background: New research initiatives proposed by leading US researcher that would integrate traditional text with visual characters, charts and icons to improve ability to assimilate, analyze and present large amounts of data or information.

Opportunity: By better understanding how the human mind accepts and learns new information or copes with large volumes of information, this technology provides a opportunity to counter the complexity associated with the information revolution.

Desired outcomes for CF: With the CF facing constant demands and restrictions on a limited number of personnel, the introduction of a new visual-verbal language could increase the quality and amount of information that is made available and required by the CF.

Convergence issues:

- Technology factors: Current IT status and development ideal for the creation and display of a new visual-verbal language. Work on understanding the human cognitive processes must continue
- Process factors: Multidisciplinary research teams must be brought together to develop the common language
- Infrastructure factors: Requires the collaboration and cooperation between military end-users of the information, the language developers and subject matter expertise.

Define whether technology is disruptive or sustaining: Disruptive

- Business Model: Development of a visual-verbal language that will substitute the traditional verbal or graphic reporting methods is a radical change in presenting information
- Performance Metrics: Increases in the total amount of information that can be processed and disseminated. Probably a significant reduction in the volume of paper and reports required to produce the required information
- Potential incubating users and uses: Intelligence community

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Technology/System factors (incremental, architectural, modular, radical): Radical– A complete change in the traditional methods of reporting and presenting information

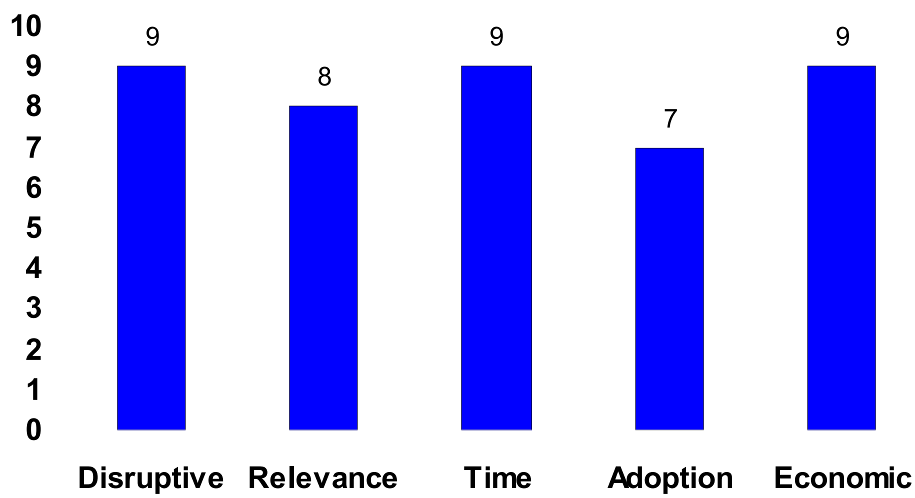
Maturity considerations and TRL: Components mature; TRL = 4

Current Players: Concept is being developed by Robert E. Horn, visiting professor at Stanford University. Project is sufficiently radical and novel, that there is a minimum following at the present time.

Alignment of outcomes with CF requirements: Excellent alignment – CF has noted in their Capability Gaps 2002-2012 that a significant gap that has been created by the "information revolution" and that there.
Canadian niche implications: All technologies are within Canadian high-tech realm and academic research core competencies. A successful implementation would place Canada in a unique world leading position.
Alliance/partnering potential: With the potential sources of information arising from many areas, collaboration and participation with Allies, in particular the United States, will ensure interoperability and seamless exchange of information.

Advisory input: The total investment in this research area is significantly less than many others as much of the IT technology is already present. Successful introduction of this concept is primarily an investment in human time and requires a committed desire to try something new.

Disruptive Impact Potential:



Each parameter has a maximum value of 10. Maximum total value is therefore 50.

Total value for this technology: 42/50

Annex 2A – Nano-Biotechnology Category 2

Technology Under Consideration: IMPLANTED COMMUNICATIONS TECHNOLOGY

Description: Implanted microphones and transceivers.

Status: Long-term (20+ years).

Background: Work going on in shrinking components (Emkay Innovative Products)

Opportunity: Implanted communications devices have mobility, stealth advantages.

Desired outcomes for CF: Decreased weight and increased functionality of communications platform. Invisible connections for all personnel.

Comments: Direct human interface technology is nascent, likely will not be widely deployed except in medical cases (vision/hearing loss). Considerable research and testing needed, and resistance to implants may be insurmountable.

Technology Under Consideration: EMBEDDED PRECISION EVENT TIMERS

Description: Incorporate MEMS and nanoscale devices devices to trigger biological or chemical events in internal (Human)or external (mechanical or chemical) systems.

Status: Long-Term (20+ years).

Background: Work going on in consumer model rockets

Opportunity: Automate timed delivery of drugs internally, mechanical or chemical processes.

Desired outcomes for CF: Permits precise control of mechanical or chemical events, possibility of removing humans from process. Permits automated drug delivery to personnel on scheduled basis (i.e., performance enhancers).

Comments: Direct human interface technology is nascent, likely will not be widely deployed except in medical cases (vision/hearing loss). Considerable research and testing needed, and resistance to implants may be insurmountable. Precise nanoscale triggered devices have weapons potential.

Technology Under Consideration: PIEZO-ELECTRIC POWERED DEVICES

Description: Nanoscale devices powered using pizoelectronics to transfer power from human body energy (pressing a switch, walking).

Status: Long-term (20+ years).

Background: Work going on in US, Germany on battery free devices, atomic force microscopes, communications systems, consumer applications (sneakers that light up while person is walking).

Opportunity: Ultraminiaturized devices such as hearing aids, microcantilever arrays for projection displays.

Desired outcomes for CF: Smaller lighter devices (orders of magnitude) for deployed forces, unmanned deployments.

Comments: Currently only applicable in very low power applications. Investigation in P2P device communication is focused on commercial applications, evolution may be translated to military use.

Technology Under Consideration: NANO-SCALPEL

Description: Incorporate nano-level materials, sensors and actuators on nanometallic surgical intruments

Status: Long-Term (20+ years).

Background: Work going on in US on MEMs level.

Opportunity: Integrate new materials into existing technology, add sensor and actuator technology not possible before.

Desired outcomes for CF: Precise and accurate surgery. Surgeon gets more and better data during procedures.

Comments: Technology will likely realize a certain amount of benefit from the application of MEMs and before the application of nano-scale engineering is sought.

Technology Under Consideration: PERSONALIZED DISPLAYS

Description: Small, inexpensive projection and display systems contained in a helmet or goggles.

Status: Medium-term (10+ years).

Background: Work going on in US, (NOMAD display) EU, Japan on MEMs level display technology

Opportunity: Integrate new materials into established technology, add sensors and actuator technology not possible before.

Desired outcomes for CF: Precise displays with interpreted content (supported by embedded computing).

Comments: Current technology prohibitively large/expensive for widespread deployment. Technology will likely realize a certain amount of benefit from the application of MEMs and similar technologies before the application of nano-scale engineering is imperative. Considerable technology transfer opportunities

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Technology Under Consideration: RF (RADIO FREQUENCY) MEMS

Description: Low power solution which integrates communications – switches, inductors, resonators and filters – into a wireless transceiver chip.

Status: Medium-term (6 years).

Background: Work going on in Germany, US, EU, Japan on MEMs level transceiver chips

Opportunity: Communication system on a chip to improve radar, explosives (smart artillery shells), missile guidance systems. Smaller and ultralight chips may be embedded in uniforms or personnel.

Desired outcomes for CF: Small, light wireless communications, eventually embedded in personnel.

Comments: Current tech prohibitively large or too expensive for widespread deployment. Current research expects factory production of chips in the 3-5 year time frame, after which they can be incorporated into military devices. Personnel embedded devices may face insurmountable resistance.

Technology Under Consideration: WEATHER MONITORING, MANIPULATION

Description: MEMs sensors, transceivers, transmitters, actuators, delivery devices..

Status: Long-Term (20+ years).

Background: Work going on in NASA

Opportunity: First monitoring and predicting weather at events, then effecting localized or weather pattern changes via substance delivery.

Desired outcomes for CF: Monitoring weather conditions accurately, imposing conditions for field advantages.

Comments: Direct human interface technology is nascent, likely will not be widely deployed except in medical cases (vision/hearing loss). Considerable research and testing needed, and resistance to implants may be insurmountable. Weather manipulation is a weapon.

Annex 2B – Nano-Information Technology Category 2

Technology Under Consideration: COMMANDER'S ASSOCIATE

Description: Stressful combat decision-making process could be alleviated via the Commander's Associate by 2008. This AI tool assimilates incoming data, and aids the commander in drawing conclusions. Alternatives would be reviewed before a final decision on course of action is made.

Status: Mid-term (5 to 10 years); Nano-IT-Cognitive integration.

Background: Research is under way (US DARPA, UK MOD DTC) to assist/augment human decision-making during various mission scenarios. Chaotic operational environment will require improved decision-making process.

Opportunity: Rapid, secure, command and control will be extended to the tactical operations level during SAR, humanitarian assistance, PKO, sovereignty enforcement, and joint combat operations. More efficient decision making by opposing forces could leave CF personnel at disadvantage during operations.

Desired outcomes for CF: Efficiency in and speed of decision-making by CF personnel "in-field" will increase. Currently a research focus for both DARPA and DRDC; fits with DND/CF emphasis on compatible equipment with allies, using open architecture platforms, and improved ties with industry as a CF S&T priority.

Comments: For faster, more secure communications and enhanced decision making during CF operations, AI software, portable-wearable wireless hardware, infrastructure for communications transmission and receipt needs to be affordably manufactured and integrated. These devices will be useful for private sector companies with geographically distant business operations.

Technology Under Consideration: NANO-COMPUTERS

Description: Nano-scale computing devices.

Status: Mid-term (5 to 10 years); Nano-IT integration

Background: Research is being conducted at US and Israeli universities, DARPA, and corporate labs (BigBangwidth, Genencor, Dow Chemical, Affymetrix, Nanotero, IBM).

Opportunity: Improved encryption and decryption capabilities; and enhanced scenario simulations. Such technology could improve training programs, encryption-decryption, and sensor networks. These devices will be disruptive because enhanced, wearable computers will allow CF personnel to have small, faster, lighter sensors and communications devices. Early incubating users could include JTF-2, intelligence units, and CBW detection units.

Desired outcomes for CF: Nano-computers will help develop virtual reality mission scenario simulations, coordinate battlefield sensor networks, UAV fleets, and the encryption/decryption of information and communications. Combat operations will be enhanced, at the tactical level, as training and surveillance of enemy targets are enhanced. Improved "in-field" analysis capabilities will permit alternate response/deployment patterns. Enhanced sensing, command, control, communication for CF personnel and fits with DND/CF emphasis on compatible equipment with allies, using open architecture platforms, and improved ties with industry.

Comments: Successfully manufacturing and integrating robust, stable, cost effective sensors, Artificial Intelligence software, quantum dots, storage devices, and error-free software will be future challenges.

Both BigBandwidth and CRC Broadband Applications and Demonstration Lab could contribute to a Canadian niche expertise in this area; with opportunities to partner with external university researchers and private companies. Good investment opportunity to develop nano-electronics for CF personnel. Dual use applicability to civilian industries also.

Technology Under Consideration: NEURO-PROSTHETICS

Description: Human brain-Machine interfaces utilizing fast broadband links. Clearer, more detailed communications and effective decision-making as outcomes.

Status: Long-term (10+ years); Nano-IT-Cognitive integration

Background: Research underway in US and Canadian university laboratories; also DRDC HSS and DFE research programs.

Opportunity: Tactical operations and C4ISR will be enhanced as commanders have a better grasp of how SAR, humanitarian assistance, PKO, sovereignty enforcement, and joint combat operations are progressing.

Desired outcomes for CF: Tactical awareness and cognition of “in-field” activity will be extended down to the tactical operations level. Enhanced sensing, communication, cognition for troops and fits with DND/CF emphasis on human-machine interfaces, compatible equipment with allies, using open architecture platforms, and improved ties with industry. Individuals and groups will be able to communicate more clearly across cultural, linguistic, geographic, and specialization barriers; increasing organizational effectiveness.

Comments: These technologies are not yet within Canadian high-tech research/industrial core competencies. Therefore, a domestic capacity must be developed.

There is an opportunity to partner with allied and DRDC researchers and Canadian professors, as a CF S&T priority, to develop such devices. Key challenges include: Sensors and software to interpret human brain/body signals; Computer visualization graphics; and secure communications networks. Successfully manufacturing interface components will be vital.

Technology Under Consideration: ADVANCED POWER SOURCES

Description: Stable, easily portable longer life power sources.

Status: Mid-term (5 to 10 years); Nano-Materials integration

Background: Research in Canada and the US at both corporate (Ballard Power, Plug Power, UTC Fuel Cells, Motorola, Toshiba, DARPA, PolyFuel, Neah Power, Tiax, MTI Microfuel Cells, and Jadoo Power Systems) and university laboratories.

Opportunity: Longer missions as power would be supplied by compact fuel cells (bio-diesel, ethanol, hydrogen). These power sources will vastly enhance operational time in the field for CF vehicles and personnel in-field; permitting alternate response or deployment patterns.

Desired outcomes for CF: CF personnel's devices could operate longer without refueling in SAR, humanitarian assistance, PKO, sovereignty enforcement, and joint combat operations. Without the need to idle, there will be a reduced heat signature.

Potential incubating users: JTF-2, aerial reconnaissance vehicles and submarines.
Fits with DND/CF emphasis on compatible equipment with allies, using open architecture platforms, and improved ties with industry.

Comments: Key challenges – building cost effective power source components; obtaining energy from various fuel types (ethanol, methanol); and allowing for hot-swapping or switching power sources without turning off current applications. Such power sources should be smaller in size, lighter weight, greater energy storage capacity, very durable, and allow extended energy consumption. Fuel cell technologies are already a fit with Canadian automotive and energy industry strengths. Opportunity to partner with US firms and researchers, as a CF S&T priority, in developing advanced power source capability and interoperability with allies.

Annex 2C – Nano-Cognitive Category 2

Technology Under Consideration: HUMAN COGNOME PROJECT

Description: A project to understand the structure and function of the human mind.

Status: Long-Term (10 plus years); Nano-IT-Cognitive-Bio integration.

Background: The concept was initially introduced at the first NBIC Converging Technology Workshop sponsored by the US National Science Foundation.

Opportunity: To develop an understanding of how the mind works, the relationships between thought, physiological processes and other cognitive activities.

Desired outcomes for CF: To participate in the development and leverage the research findings in the broad area of NBIC convergence, and in particular, the understanding of the human mind.

- *Enhanced human performance*
- *Establish the basis for new research and new methodologies for performing military activities.*

Comments:

a) The human cognome project is a parallel development to the human genome project. Although no dramatic or disruptive results have evolved from the genome project, the potential has yet to be exploited. Similarly for the human cognome project, the same potential exists.

b) With its long-term projection, there is no immediate benefit; therefore it is placed as a Category2 project.

c) A great deal of enabling research and technology development is required to start populating the parameters of the project.

d) While DND/DRDC would probably not be involved in the basic research, seed funding, administrative participation and collaborative research are possibilities to ensure DND/DRDC is involved from the initial stages.

e) The potential benefits would seem to suggest that Canada participates at its earliest stages.

Technology Under Consideration: BIOROBOTICS, REMOTE TACTILE SENSING AND TELEOPERATING

Description: Development of robotic tactile sensing and related remote sensing capabilities

Status: Mid Term (5-10 years); Nano-IT-Cognitive integration.

Background: As nano-, bio-, and it- technologies converge, there is an increasing interest in duplicating human sensory capability using biorobotics.

Opportunity: By developing human compatible sensory capabilities, remote assessment, telemedicine and tele-operations become a reality. The military may not always have sufficient medical personnel to cover all areas of a battlefield, or may not be able to get specific surgical expertise to certain areas. Research in biorobotics gives the opportunity for remotely assessing and even performing surgical intervention using the convergent technologies of IT and NBIC.

Desired outcomes for CF: CF personnel in a variety of operations will be able to remotely work on and repair equipment, perform simple surgical procedures etc.

- *More effective use of personnel*
- *Extends deployment capability*

Comments:

a) The ability to transmit sensory information remotely is a major benefit of the nanotechnology/cognitive integration.

b) This technology still requires sufficient academic and enabling technology development before it can be introduced as practical or as a technology demonstrator.

c) The technology still requires further improvement in sensitivity and in transmission of the sensory data.

d) Creating this capability has tremendous potential as an asymmetric warfare tool for Canadian and allied forces.

Annex 3 – Definitions and Nanotechnology Overview

Definitions

Nanotechnology – is concerned with materials and systems whose structures and components exhibit novel and significantly improved, chemical and biological properties, phenomena and processes because of their nanoscale size. Structural features in the range of about 1 to 100 nanometers determine important changes as compared to the behaviour of isolated molecules (1 nanometer) of bulk materials. For comparison, 10 nanometers are 1000 times smaller than the diameter of a human hair. [Ref. 3]

Nano-biotechnology – Nano-biotechnology applies the tools and processes of nano/micro-fabrication to build devices for studying or exploiting biosystems. Researchers also learn from biology how to create better micro-nanoscale devices. The self-assembly and repair characteristics found in biological systems are two of the ultimate goals of nano-fabrication. [Ref. 4]

Nano-information Technology – The convergence of Nanotechnology and information technology refers to the synergy arising from combining nanotechnology and information computing technology. New materials will be designed and made at the molecular level to improve information processing and to speed up connectivity.

Information or data on cognitive, biological and physiological conditions will be received, transferred and processed at much faster speeds than before.

Nano-cognitive Technology – A nano-cognitive convergence sees the development of nanoscale sensors with the potential to greatly expand or enhance human sensory capabilities.

Cognitive science in the broad definition seeks to understand the structure and function of the human mind and its relationship to the external world. The main areas of research that contribute to cognitive science include the neural sciences: human sensory perception, cognitive psychology, artificial intelligence, linguistics, philosophy and robotics.

MEMS – Microelectromechanical systems (MEMS) devices integrate physical, chemical and biological processes in micro- and millimeter-scale packages. MEMS devices are used in IT, aerospace, automotive, environment, medical and energy industry applications. (On the horizon is the development of nanomanufacturing technologies that will support tailor-made products having functionally critical nanometer-scale dimensions produced using massively parallel systems or self-assembly.) [Ref. 5]

Molecular Assembler – A general purpose device for molecular manufacturing capable of guiding chemical reactions by positioning molecules. [Ref. 6]

Nanotechnology

Worldwide, nanotechnology is in an exciting phase of its development. The first commercial applications are reaching the markets in limited areas, with a host of international and intra-national co-operative efforts pushing the boundaries of the science itself. Unique in the degree of interdisciplinary science it requires to advance, nanotechnology is also extremely broad in its potential applications. A true transformative technology, it will have implications from materials science to health care.

In government expenditures for nanotechnology R&D, Japan leads, pursuing an integrated program of university and company research, focused on nano-materials and manufacturing technology. Recent interest in Japan has focused on biology integration. The US is approaching year 4 of its National Nanotechnology Initiative, with stated goals for 2002-2003 targeting nanoscale manufacturing research, biological-chemical-radiological-explosive detection and protection, instrumentation and standards, education and training and industrial partnerships.

There is a nascent commercialization wave in the U.S., primarily in the health and pharmaceutical industries. Western Europe had an early focus on tools and techniques but has recently targeted the communications and healthcare applications of nanotechnology.

Estimated government nanotechnology R&D expenditures:
(in $ millions/year)

Country/Area	**2002**
W. Europe (EU plus Switzerland)	400
Japan	750
U.S.	604
Other (Australia, Canada, China, Korea, Taiwan, E. Europe)	520
Total	**2,274**

Government Nanotechnology Funding: An International Outlook,* M.C. Roco, Chair, WH/NSTC/Nanoscale Science, Engineering and Technology Subcommittee (NSEC), and Senior Advisor, NSF, http://www.nano.gov

Canada

From the preceding it may appear that Canada is not making nanotechnology a priority. However, the U.S. patent records show a different picture. Private industry has been focused in Canada on materials science and applications, agribusiness and on communications technologies, and has supported these efforts with considerable patent activity. In addition, citation records show that Canada's patents are in use by other researchers to the extent that it ranks 3rd, behind France and Japan, in mean patenting activity for the top 12 countries (excluding the U.S.). (Marinova and McAleer, 2002)

Annex 4 – Disruptive Technologies

Disruptive Technologies

The following is a brief primer on the nature of disruptive technologies. Clayton Christensen, of Harvard Business School, is considered the leading thinker in the area of disruptive technologies and disruptive innovation. The following text draws substantially on his work. He states in *The Innovator's Dilemma* [Ref. 2] that disruptive technologies bring to market a very different value proposition compared to sustaining technologies. Sustaining technologies foster improved product performance. Although disruptive technologies generally under-perform established products in mainstream markets, they have other features that certain fringe customers value. Christensen notes that disruptive products are usually cheaper, simpler, smaller and easier to use. They move up-market when they have sufficient functionality to unseat incumbent, sustaining technologies – which often provide more features than customers need or want.

As noted earlier, disruptive technologies are often existing technologies, used in a new fashion, that change the nature of doing business in an established industry. Fundamentally, disruptive technologies incubate in other market segments and change the performance criteria for the market [from Ref. 7].

Disruptive technologies may be architectural, modular or radical innovations – but not incremental.

Disruptive Attributes

Clayton Christensen [from Ref. 8] outlines the following attributes for a disruptive technology:

- It disrupts existing competitors, rather than leap ahead of the them with a better product in an existing market.
- It enables a larger population of less skilled or less wealthy (or well-funded) people to do something more simply and conveniently that historically could only be done by experts or wealthy people, in inconvenient centralized settings.
- It targets the trajectory of improvement that has not yet overshot what customers can absorb. It does not attempt to disrupt competitors who have not yet overshot what their customers can utilize.
- It targets a set of less demanding customers who would be delighted to have a simple product.
- It minimizes infrastructure barriers; most new technologies are plug-compatible in existing systems of use.
- It builds an outcomes or purpose brand.

He also presents the following list of questions [from Ref. 8] to test whether an innovation idea has disruptive potential:

- “Where is the application that a simpler, more convenient technology would take root before it matures enough to become relevant to our current best customers?”
- “Who might be some unsophisticated customers that would be delighted to have a crappy product?”
- “Do we think that our best customers [existing] would want the product? If so, it’s probably not a disruption.”
- “Will it strengthen our existing business model? If so, it probably is not a disruption.”

Christensen notes that “disruptive technologies almost always takes root in a very undemanding application. The established market leaders almost always try to push the disruption into an established application and, in so doing, they spend enormous amounts of money and fail.” [Ref. 9]

The term “disruptive technology” is in some ways a misnomer. Christensen indicates that “we’re really talking about a disruptive business model more than a disruptive technology per se. Usually, the technology simply is an enabler of the disruptive business model.” [Ref. 9]

Disruptive Process

The disruptive process [Ref. 7] can be characterized as follows:

- A given sustaining technology (mature) is performing well and is being improved according to customer inputs/demands (e.g., mainframe computer, early 1980s).
- The disruptive technology is developed but does not meet the performance requirements associated with the sustaining technology and its market (personal computer, early 1980s).
- Alternative markets are found or created where the price and performance metrics of the disruptive technology match the customer requirements (personal computer, early to late 1980s).
- The disruptive technology is developed to the point where it can now enter the original markets, challenge and then disrupt the incumbent, sustaining technology, based on new performance criteria such as size, etc. (late 1980s and beyond).

Note that the mainframe computer was not totally displaced. IBM has a healthy mainframe business today. However, the personal computer substantially affected the mainframe market. The dominance of the mainframe computer never returned after the disruption caused by the personal computer.

Disruptive Potential

Much of this work is based on the *potential* of a technology to become disruptive. The following text presents some considerations regarding the realization of this potential.

Tony Ulwick and John Eisenhauer note in *Overcoming the Innovator's Dilemma* [Ref. 10] that in order to realize disruptive potential, one needs to:

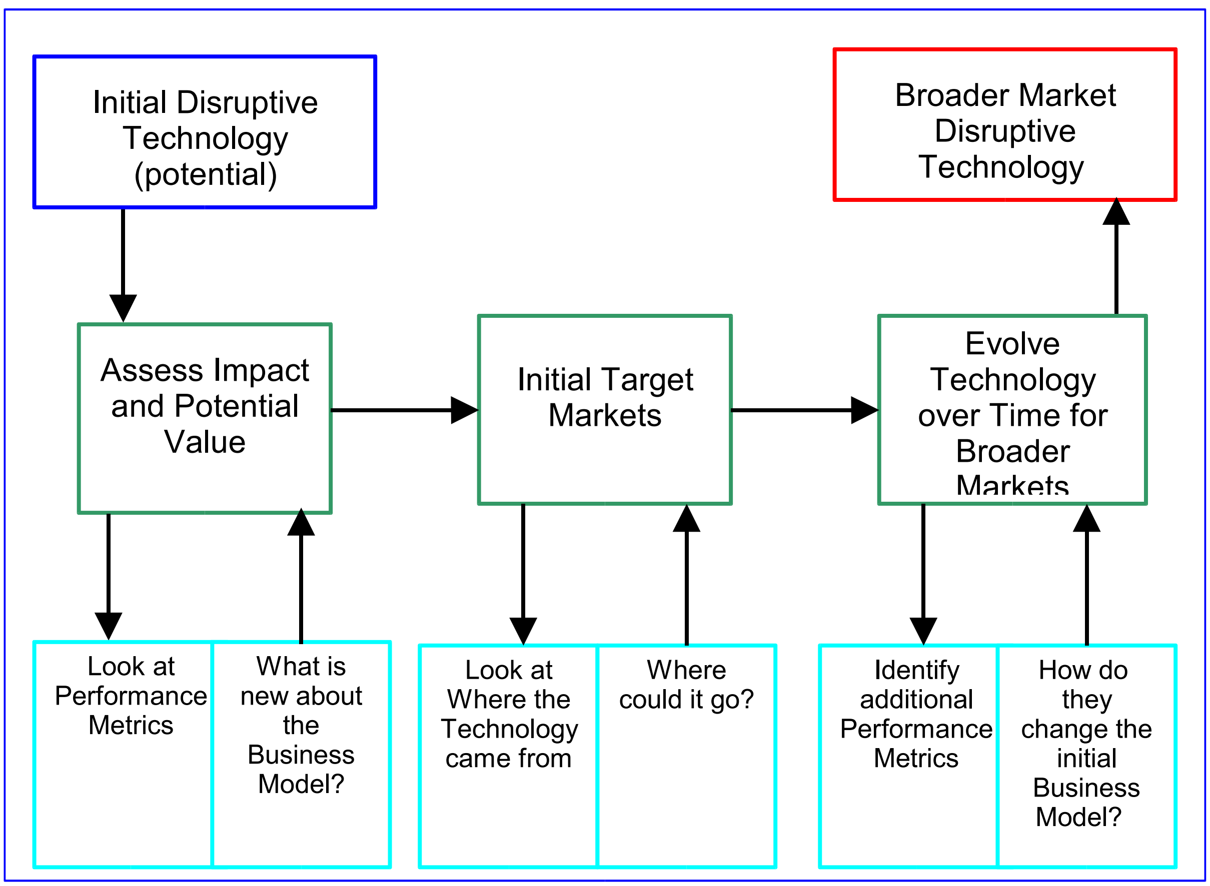
- Assess the impact and potential value of a disruptive technology;
- Identify initial target markets; and
- Evolve technology over time for broader markets.

Using Clayton Christensen's litmus test for disruptive technologies, one can assert that, at a minimum, a disruptive technology must:

- Compete on a different performance metric(s);
- Change the business model (or operational model) of an organization; and
- Incubate in fringe markets (still could be an internal market if organization is very large).

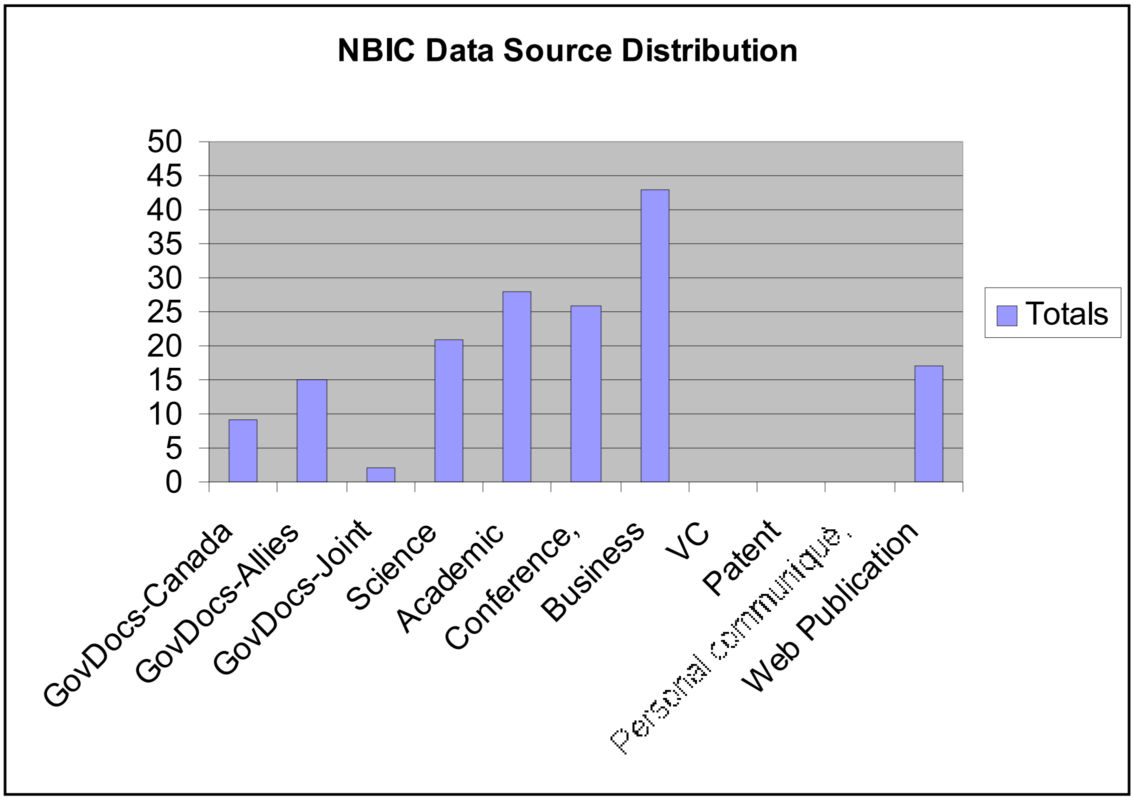
Blending the two aforementioned sets of attributes has resulted in the following Disruptive Potential map:

Figure 5

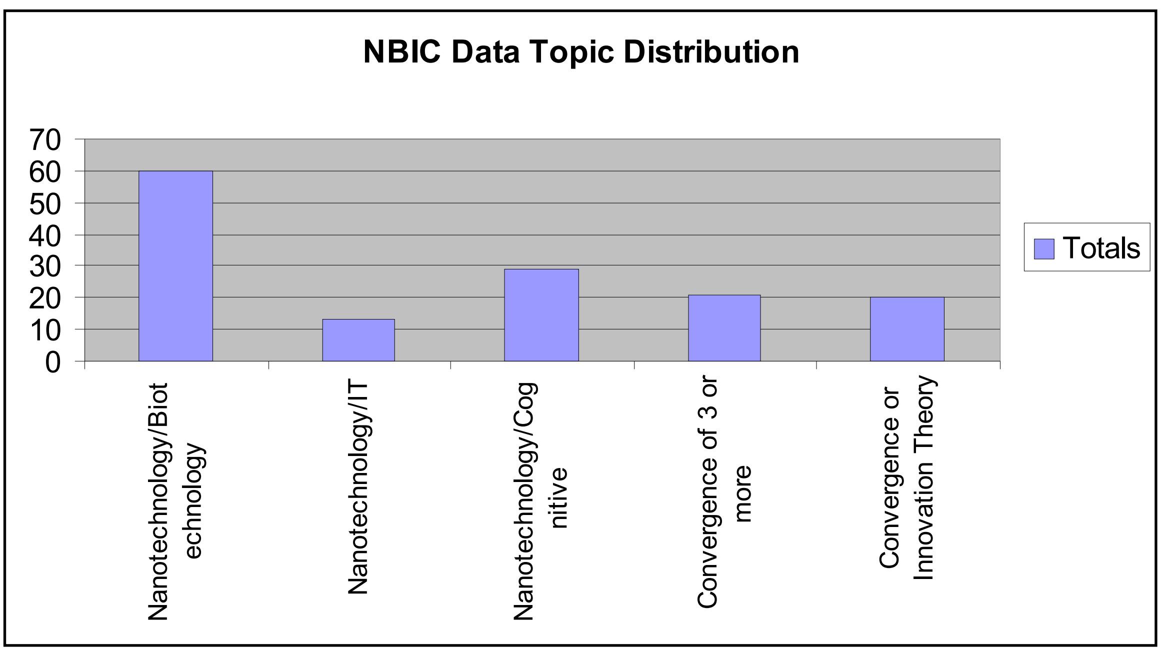


This provides a simple framework for better understanding whether or not a technology has disruptive potential – as well as how it might become a broader market (in this context, the military "market") disruption.

Annex 5 – Data Collection Sources



Annex 6 – Data Collection Distributions



Annex 7 – Relevant Sustaining Technologies

Technology Under Consideration: SELF-HEALING NANOMATERIALS

Description: Carbon (nanotube)/protein hybrid materials that repair automatically when broken

Status: Short-term (1-5 years); Nano-Bio integration

Background: Work going on in US, UK

Opportunity: Develop hybrid materials that self repair to heal breached surfaces or fabrics.

Desired outcomes for CF: Increase in equipment and uniform life and protective abilities; decrease in maintenance, repair and replacement costs.

Convergence issues:

- Technology factors: Fusion of carbon nanotubes and proteins at the nanoscale level.
- Process factors: Manufacturing and adhesion techniques.
- Infrastructure factors: Manufacturing facilities.

Define whether technology is disruptive or sustaining: Sustaining

- Business Model: Automates repair of materials and coatings used in uniforms, structures and vehicles.
- Performance Metrics: Reduces or eliminates maintenance and repair cycles
- Potential incubating users and uses: Army, navy, air force.

Technology/System factors (incremental, architectural, modular, radical): Modular – additions or replacements to surfaces, coatings for uniforms, structures, vehicles.

Maturity considerations and TRL: Some components and techniques mature; TRL = 7.

Current Players: US private and academic research into commercial applications.

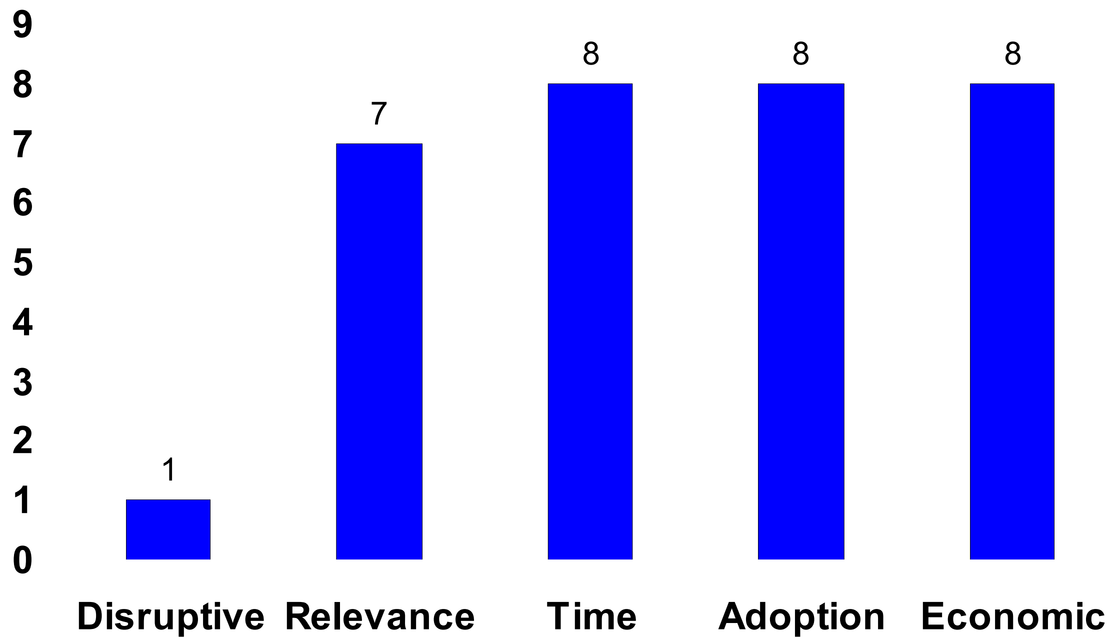
Alignment of outcomes with CF requirements: Good alignment –

Canadian niche implications: All technologies are within Canadian high-tech realm and research/industrial core competencies.

Alliance/partnering potential: Opportunity to partner with US and EU.

Advisory input: Need capability to monitor and evaluate research already underway. Note that there is a strong probability that commercial developments can be readily adapted to military use.

Disruptive Impact Potential:



Each parameter has a maximum value of 10. Maximum total value is therefore 50.

Total value for this technology: **32/50**

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14. ABSTRACT

(U) Technology Watch is a process of monitoring technologies, analyzing them, placing them in proper context and, ultimately, deciding which ones are worthy of investment. Often, this is a difficult task. Making the correct technology bets has always been a difficult problem. A Technology Watch can play a vital role to increase the probability of making decisions that have attractive outcomes.This report presents the process, and the content derived from it, for the convergence of Nanotechnology, Biotechnology, Information Technology and Cognitive Science (known as NBIC Convergence – or simply NBIC). The Technology Watch process, requisite innovation concepts, and analysis and context tools are discussed in the main section of this report. Annexes 1 and 2 provide concise analysis and context of the NBIC technologies resulting from the process. Annexes 3 and 4 present additional information on data collection. Annex 5 is a placeholder for technologies which do not meet the disruptive criteria but are nevertheless of interest (generally, sustaining technologies). The intent of this report is to provide the reader with a clearer understanding of how advances in NBIC technologies can lead to new military technologies – and why those technologies might be important to the Canadian Defence community.

(U)

15. KEYWORDS, DESCRIPTORS or IDENTIFIERS

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