Defence Research and Development Canada | Recherche et développement pour la défense Canada

DRDC | RDDC
technologysciencetechnologie

2016-10-17

DRDC-RDDC-2016-L328

Produced for: Col Darrell Russel, LCol Ronald Bell. Canadian Army Land Warfare Centre (CALWC), Kingston, Ontario

Scientific Letter

Emerging and disruptive technologies impact assessment workshop

Results from 2015

Background

Early identification of emerging and potentially disruptive technologies (EDT) directly informs capability development cycles by enabling Defence organizations to assess potential threats and opportunities that such technologies could have on current and planned operational capabilities.

In 2014, Defence Research and Development Canada (DRDC), in collaboration with the Canadian Army Land Warfare Centre (CALWC), developed a methodology to assess the impact of emerging technologies on Canadian Army capabilities. The methodology and tools used to assess the impact of emerging technologies have been presented in [1] and results obtained in 2014 have been published in [2].

Emerging and disruptive technology impact assessment workshops are held annually for new technology areas. The same methodology and tools have been used in 2015 when DRDC and CALWC examined the following technology areas: non-lethal weapons (NLW), quantum sciences (QS), and human performance optimization (HPO) technologies.

This Scientific Letter presents an overview of the results for the 2015 edition of the impact assessment workshop held at CALWC in December 2015. Detailed outlook briefs from subject matter experts on the three topics can be found as attachments under Annexes A, B, and C.

Statement of results

Overview

The emerging technology areas reviewed during the workshop were very different in nature and maturity. Despite the fact that NLWs have been around for a while and can be considered as a mature technology area, technologies such as directed energy weapons and high energy lasers are emerging as new trends in this area. The multiple application areas of quantum sciences

are very broad and include sensing, computing, imaging and navigation. Finally, human performance optimization technologies are also very broad and include both non-invasive and invasive means to optimize human performance.

Overall, as shown in Figures 1 and 2, human performance optimization technologies and quantum sciences applications have been assessed by participants as having the highest potential impact on Army operational functions out to 2040 (H3). Quantum sciences have been rated with the highest impact, 5.4 on a scale from 0 (no impact) to 7 (highest impact). Quantum sciences applications have the potential to bring game-changing capabilities to the SENSE function. Capabilities highly impacted by quantum sciences include:

- ground sensor network;
- airborne and strategic sensor network;
- CBRN defence;
- explosives hazard avoidance; and
- command and control network.

Human performance optimization technologies have been assessed with high potential impact across a wide range of operational functions (SHIELD, ACT, SENSE, SUSTAIN). Health Services System is the capability area that will be the most impacted by developments in human performance optimization technologies (5.95). Other capabilities impacted by human performance optimization developments include:

- planning and decision support systems;
- intelligence systems;
- information operations;
- protection from fires; and
- CBRN defence.

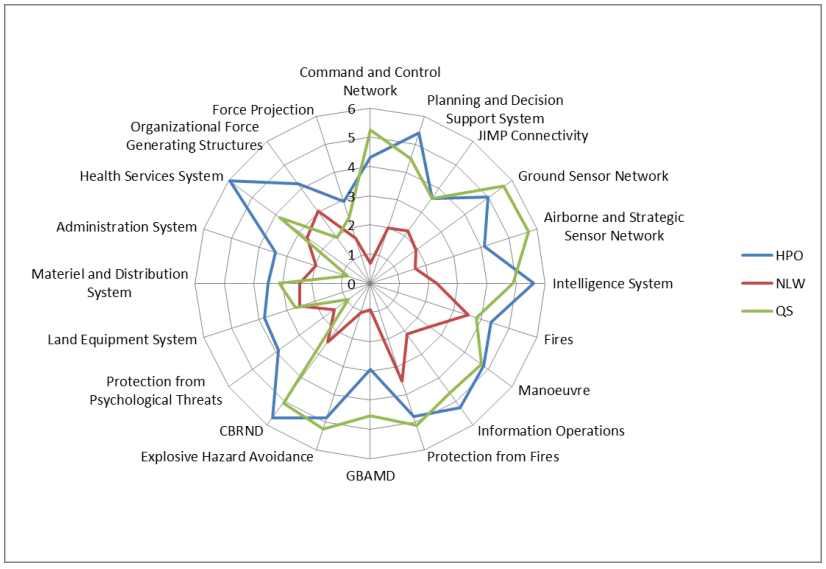


Figure 1: *Overview of potential impact on Army capabilities (H3).*

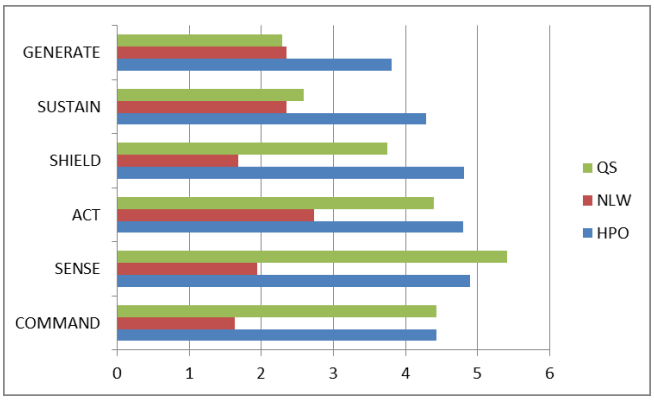


Figure 2: *Overview of potential impact on Army operational functions (H3).*

The following sections provide details about each of the three technology areas assessed.

Non-lethal weapons (NLW)

According to the US Department of Defense, NLWs are explicitly designed and primarily employed to incapacitate people or materiel, while minimizing fatalities, permanent injury to people, and undesired damage to property and the environment [3].

NLWs can generate incapacitating effects by denial, deterrence, degradation, disabling, disruption, etc. NLWs can be categorized by their application:

1. Antipersonnel non-lethal weapons (designed to incapacitate an individual)

2. Area-control non-lethal weapons (designed for crowd control, or area access denial)

3. Anti-vehicle non-lethal weapons (designed to stop a vehicle without inflicting lethal damage to its occupants)

A recent scientometric study [4] conducted by the National Research Council (NRC) for DRDC in support to the EDT impact assessment workshop has shown that usage of NLWs is more common in the Law Enforcement community than in the military. Moreover, the types of technologies the military tends to use are different from the ones used by Law Enforcement. As shown in Figure 3, hailers, high power microwave devices and directed energy weapons seem to be used almost exclusively by the military whereas rubber projectiles and tasers are mostly used by Law Enforcement organizations.

Military vs. Law Enforcement, Correlation with Technology Subjects (%)		
Technology (n)	**Military (369)**	**Law enforcement (388)**
Hailers (21)	61.9	
IED disabling (13)	61.5	7.7
Electronics - Jamming (51)	58.8	11.8
Directed energy weapons (87)	56.3	4.6
Vessel stopping (48)	56.3	6.3
Unmanned vehicles - NL Payload (41)	56.1	7.3
Active denial systems (64)	53.1	1.6
High-power microwave devices (104)	52.9	4.8
Barriers (14)	50.0	7.1
Vehicle stopping (16)	50.0	6.3
Launchers (21)	47.6	33.3
Underwater (24)	45.8	4.2
Anti-swimmer (14)	42.9	
Acoustic weapons (51)	41.2	3.9
Millimeter wave (39)	41.0	2.6
Electromagnetic weapons (49)	40.8	10.2
Portable or handheld (22)	36.4	27.3
Laser dazzlers (47)	36.2	8.5
Behavioural/crowd modeling and simulation (115)	33.9	10.4
Modeling and simulation (195)	31.8	14.4
Gyrotrons (10)	30.0	
Obscurants (18)	27.8	16.7
Chemical/calmative (101)	27.7	30.7
Flashlights and LEDs (12)	25.0	33.3
Plasmas (12)	25.0	8.3
Projectiles (83)	24.1	24.1
Wireless (14)	21.4	
Rubber projectiles (34)	17.6	50.0
Blunt impact devices (52)	15.4	46.2
Pepper spray/tear gas (90)	14.4	43.3
Bean bags (11)	9.1	72.7
Liquid jets/Water cannon (14)	7.1	42.9
Electric, conducted energy (195)	6.7	67.2
Tasers (376)	5.3	61.4
Flash / bang grenades (14)		28.6

Figure 3: *Usage of NLW technologies in military and law enforcement communities.*

During the workshop, non-lethal weapons were not perceived as providing potential solutions to any of the Army Hard Problems (see Annex D). It was mentioned that they might indeed negatively impact some of them, by increasing soldier burden and requirements for more power and energy.

From a legal perspective, one of the reasons why NLWs have been assessed with medium impact on Army capabilities is due to the fact that according to the current Law, the Canadian Army is allowed to use NLWs only in expeditionary theatres and for crowd control and escalation (or de-escalation) of force (EOF) situations only. Moreover, the Canadian Army already use effective means such as flares, warning shots, vision impairment devices, etc. for EOF situations in expeditionary theatres of operations. For various reasons, there is also strong social, cultural, and institutional resistance against the integration of NLWs in the military.

It is also important to consider the evolution of the Future Operational Environment (FOE). Many online videos can easily be found showing how to use 3D-printers to build your own directed energy weapon. There could be a growing requirement to increase soldier and equipment protection against these potential threats in the FOE.

As shown in Figure 4, overall, NLWs were assessed as having medium impact on Army capabilities. Capability areas such as Fires (3.53), Protection from Fires (3.52), Organizational Force Generating Structures (3.05), and Health Services System (2.68) were the most impacted areas.

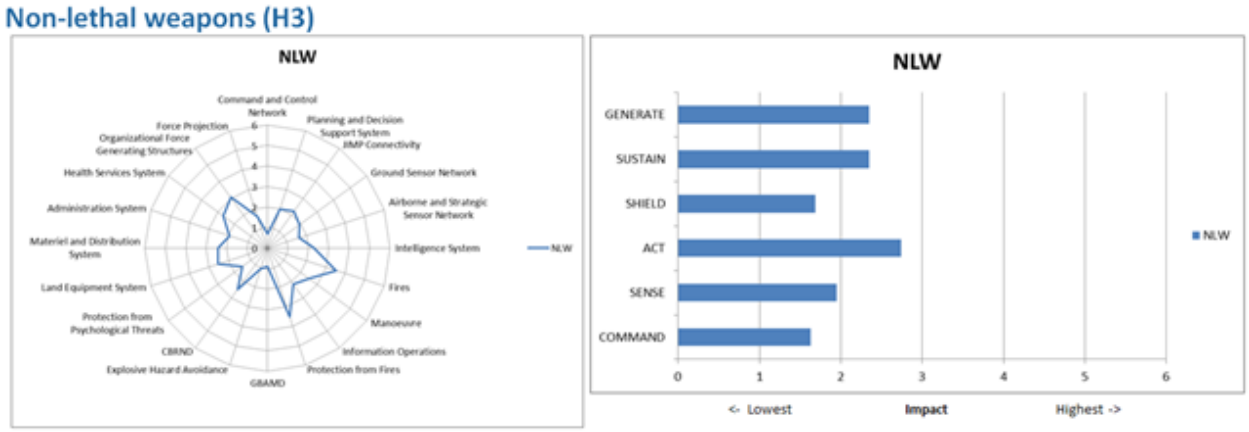


Figure 4: *Overview of potential impact for non-lethal weapons (H3).*

Quantum sciences (QS)

As pointed out at the workshop by DRDC's subject matter expert, quantum mechanics and special relativity are the foundation of all the laws of the universe, including quantum field theory and beyond, and is a permanent source of disruptive technologies. The UK launched a National Quantum Technologies Programme in 2014 [5] and the European Union is considering injecting €10B over ten years in quantum initiatives and infrastructures in Europe [6]. Other countries in the world have implemented similar programs.

Key applications of quantum technologies include non-line-of-sight and secured imaging, improved radar and lidar, more accurate positioning, navigation and timing systems, and enhanced explosives detection. Much of the work is still lab-based, with real systems in some cases still years away.

From a military perspective, the technologies of interest include quantum enhanced imaging, quantum clocks, cold-atom inertial sensors and photoacoustic spectroscopy based on quantum cascade lasers.[1] Given the results from the workshop, and the serious investments being made by Allies in quantum technologies, it is recommended that DND/CAF increases capability development focusing initially on inertial sensing, quantum (atomic) clocks, and quantum radar.

As shown in Figure 5, overall, quantum sciences were assessed as having high impact on specific Army capabilities. Capability areas such as Ground Sensor Network (5.65), Airborne and Strategic Sensor Network (5.70), CBRN defence (5.06), Explosive Hazard Avoidance (5.23), and Command and Control Network (5.23) were the most impacted areas.

[1] For more details see NRC's study on quantum sensing [7].

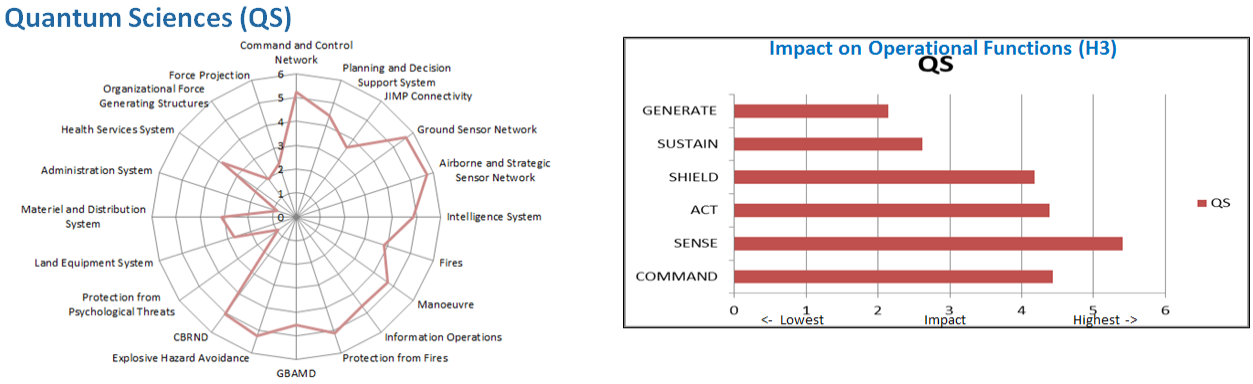


Figure 5: *Overview of potential impact for quantum sciences (H3).*

Human performance optimization (HPO)

Human performance can be optimized through several means. As shown in Figure 6, those means can be either invasive or non-invasive to the human body. Human performance optimization is an intervention introduced onto or into the body designed to improve performance, appearance, or capability besides what is necessary to achieve, sustain or restore health. Major subdomains include physiological means, computational means, cognitive means, automation, robotics and telepresence. Research is being supported by various drivers such as sports performance, biohacking, and corporate security.

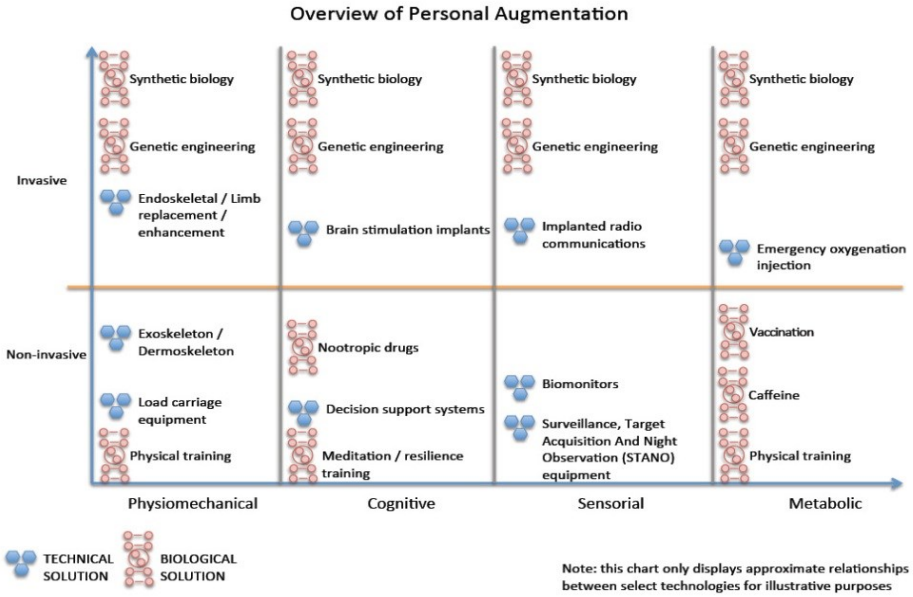


Figure 6: *Invasive and non-invasive means to human performance optimization.*

Key applications of human performance optimization include increased soldier endurance (both physical and cognitive), health monitoring through implanted or worn sensors, injuries monitoring, and new medical counter-measures. It is expected that invasive means to human performance optimization will face more resistance to their adoption given the ethical dilemmas

and policy issues they will create. For more details see recent NRC studies on Human Optimization that were produced to support the workshop [8–9].

As shown in Figure 7, overall, human performance optimization means were assessed as having high impact on several Army capabilities. Capability areas such as Health Services System (5.95), CBRN defence (5.7), Intelligence Systems (5.60), Information Operations (5.25), and Ground Sensor Network (5.00) were the most impacted areas.

It was noted at the workshop that the Canadian Army should start discussions to assess ethical dilemmas and policy implications of human performance optimization means and engage with primary stakeholders such as the Surgeon-General, the Judge-Advocate General, and ADM(Pol). It was also noted that for adversaries, ethical and policy barriers might not be an issue in implementing human performance optimization capabilities and that it is likely that such "optimized adversaries" will be part of the FOE and could potentially generate new threats and opportunities. It is recommended that DND/CAF continue to monitor progress in this area and sponsor studies to investigate ethical dilemmas and policy issues that will impact the possible adoption of such capabilities by the future Forces.

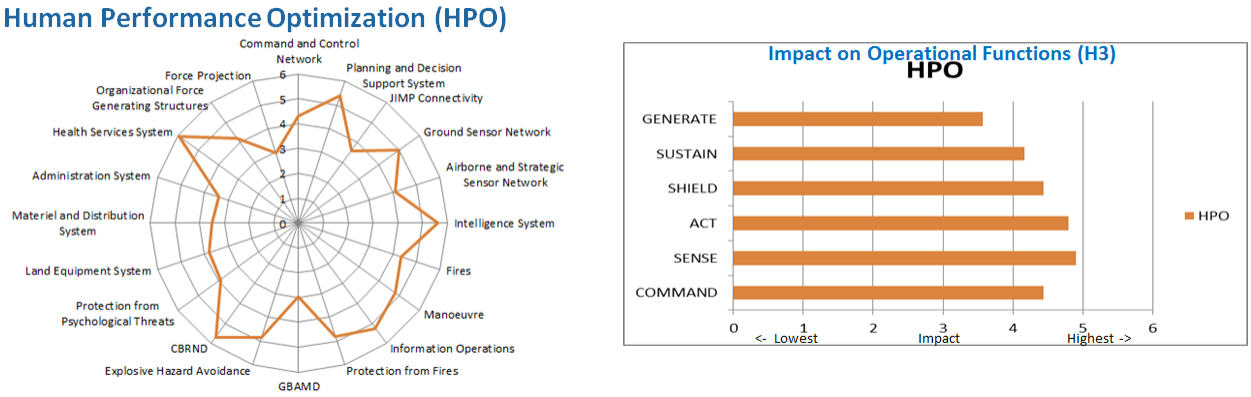


Figure 7: *Overview of potential impact for human performance optimization technologies (H3).*

Discussion of results

As already observed, two of the emerging technology areas considered at the workshop have been assessed with high impact across several Army functions. Looking at the results from the last EDT impact assessment workshop through the perspective of the Canadian Army Hard Problems, how could the three emerging technology areas provide potential solutions?[2] Table 1 shows which technology areas could bring solutions to Army Hard Problems. Human performance optimization technologies will likely deliver innovative solutions for several of the Hard Problems.

[2] See Annex D for the list and description of Canadian Army Hard Problems.

Table 1: *Potential contributions of emerging technologies to army hard problems.*

ARMY Hard Problem	Non-Lethal Weapons	Quantum Sciences	Human Performance Optimization
Power and Energy			
Vehicle Engineering		✓	✓
Soldier Burden			✓
Soldier Resilience			✓
Soldier Protection	✓	✓	✓
Cognitive Overload			✓
The Network		✓	
Manoeuvre Over Distance			✓
Explosive Hazard Avoidance	✓	✓	✓
Managed Readiness			✓
TOTAL	2/10	4/10	8/10

Conclusion

Assessing the potential impact of emerging technologies is essential to inform capability development and planning of S&T programs. EDT impact assessment workshops have been designed by DRDC in collaboration with CALWC to challenge both current and future Army capabilities and to identify potential opportunities and threats to inform the Army of Tomorrow and the Future Army capability development.

Results from the workshop strongly support and highlight the need to include quantum technologies in the Defence S&T program to shape this emerging technology area and maximize its integration with operational capabilities as the technology matures and delivers new applications. Overall, findings have shown that human performance optimization and quantum technologies will likely contribute to high impact and potentially game-changing new capabilities for future military forces.

Prepared by: Dr. Alain Auger (Lead S&T Outlook, Office of the Chief Scientist, ADM(S&T)).

References

[1] Auger, A. *Emerging and Disruptive Technologies Impact Assessment.* NATO Paper. STO-EN-IST-135 Educational Papers. DRDC-RRDC-2015-N015. 2015.

[2] Auger, A. *Impact Assessment of Emerging Technologies: Results and Lessons Learned from the Canadian Army.* DRDC – Corporate Office. DRDC-RDDC-2015-R205. October 2015.

[3] Department of Defense Directive. *Policy for Non-Lethal Weapons*. U.S. Department of Defense. No. 3000.3. 9 July 1996.

[4] Brady, B. and McLaughlin, T. *Non-lethal Weapons: A Scientometric and Market Study*, NRC-KM. DRDC-RDDC 2015-C341. November 2015.

[5] *A roadmap for quantum technologies in the UK.* Innovate UK. 2014.

[6] *Quantum Manifesto: A New Era of Technology.* European Union. May 2016.

[7] Culhane, M. *Quantum Sensing: A Scientometric Study*. NRC-KM. DRDC-RDDC-2016-C053. November 2015.

[8] Wiseman, E. *Scientometric Study on Human Optimization*. NRC-KM. DRDC-RDDC-2015-C235. October 2015.

[9] Wiseman, E. *Human Optimization Research: International Activity*. NRC-KM. DRDC-RDDC-2016-C080. March 2016.

Attachments

Annex A: Corriveau, D., Pudo, D., Bourget, D., and Wong, F.C. *Non-lethal weapons outlook brief,* 2015

Annex B: Balaji, B., *Quantum sciences outlook brief,* 2015

Annex C: Michaud-Shields, M. and Niall, K., *Human performance optimization outlook brief,* 2015

Annex D: Canadian Army Hard Problems (2015)

Annex A Non-lethal weapons outlook brief

Defence Research and Development Canada | Recherche et développement pour la défense Canada

Non-Lethal Weapons

Dr. Daniel Corriveau, Dr. Dominik Pudo, Daniel Bourget and Dr. F.C. Wong

Outlook Brief

Emerging Technology Impact Assessment Workshop

Nov. 30 – Dec 4, 2015

DRDC | RDDC

Canada

Outline

- What is the technology or technology area?
- Barriers and Tipping Points (STEEP+LD Method)
- Potential Defence and Security Implications/Applications as Related to the Army
- Strengths, Weaknesses, Opportunities, Threats (SWOT) Analysis
- Key Players & World Leaders
- Related Policies (Canadian & foreign), Doctrine, TTPs
- S&T Trends/Future Directions for the technology
- Level of Agreement in the Scientific Community
- Own assessment against Army Hard Problem
- References

What is the Technology

- *Overview of the technology*
  - *Non-Lethal Weapons (NLWs) are explicitly designed and primarily employed so as to incapacitate personnel or materiel, while minimizing fatalities, permanent injury to personnel, and undesired damage to property and the environment.* [1]
    - *The word "Incapacitate" should be understood broadly: Deny, Deter, Degrade, Disable, Stop*
  - *NLWs can be distinguished by three applications:*

1. *Antipersonnel non-lethal weapons (designed to incapacitate an individual)*
2. *Area-control non-lethal weapons (designed for crowd control, or area access denial)*
3. *Anti-vehicle non-lethal weapons (designed to stop a vehicle without inflating lethal damage to its occupants)*

[1] Department of Defense Directive. (1996, 9 Jul.). *Policy for Non-Lethal Weapons*. No. 3000.3.

What is the Technology

- *Overview of the technology*
  - *Sub-domain, Time to maturity/Rate of growth*

Sub-Domain	Current TRL	TRL 2020	TRL 2025	TRL 2030
Kinetic: • Weapon/projectile design • Underwater environment	• 9 • 4-7 for some maritime uses	• 9 • 5-7 for some maritime uses	• 9 • 6-8 for some maritime uses	• 9 • 7-8 for some maritime uses
Chemical: • Methods of dispersing	• 9 for tear gas • 4-6 for other types	• 9 for tear gas • 5-7 for other types	• 9 for tear gas • 6-7 for other types	• 9 for tear gas • 7-8 for other types
Anti-mobility: • Little "new" technology	• 9 for barriers, caltrops, nets • 6-7 for lubricants and foams	• 9 for barriers, caltrops, nets • 7-8 for lubricants and foams	• 9 for barriers, caltrops, nets • 8-9 for lubricants and foams	• 9 for barriers, caltrops, nets • 9 for lubricants and foams

What is the Technology

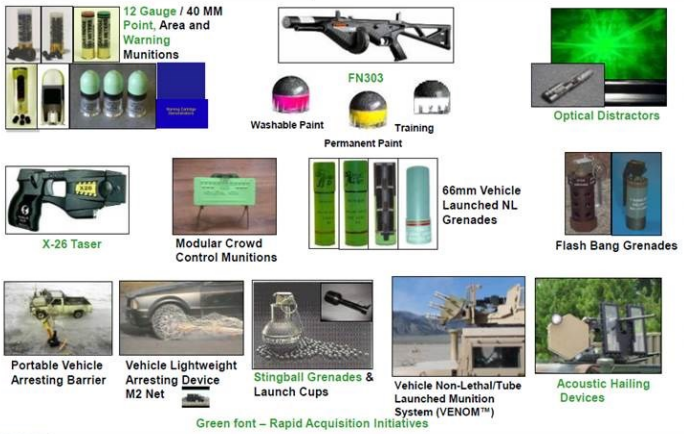
Sub-Domain	Current TRL	TRL 2020	TRL 2025	TRL 2030
Acoustic: • Component technologies • Microwave or ultrasonic pulses to generate high noise levels	• 9 for loud hailers, flash-bangs • 6-7 for maritime • 3-4 for acoustic pressure, microwave or ultrasonic technologies	• 9 for loud hailers, flash-bangs • 6-7 for maritime • 3-4 for acoustic pressure, microwave or ultrasonic technologies	• 9 for loud hailers, flash-bangs • 6-7 for maritime • 4-5 for acoustic pressure, microwave or ultrasonic technologies	• 9 for loud hailers, flash-bangs • 6-7 for maritime • 5-6 for acoustic pressure, microwave or ultrasonic technologies
Electric shock: • Some alternate types (e.g., piezo) and methods of delivery	• 9 for EIDs (wired)	• 9 for EIDs (wired)	• 9 for EIDs (wired)	• 9 for EIDs (wired)
Optical disruption: • Improvements based on laser type • Improved scalability	• 9 for most environments • 6-7 for maritime and some technologies (e.g., LED	• 9 for most environments • 7-8 for maritime and some technologies (e.g., LED	• 9 for most environments • 8-9 for maritime and some technologies (e.g., LED	• 9 for most environments • 9 for maritime and some technologies (e.g., LED dazzlers)

What is the Technology

Sub-Domain	Current TRL	TRL 2020	TRL 2025	TRL 2030
Directed energy: • Theoretical and physical basis • Millimeter wave: • High power microwave (continuous/pulse)	• 7-9 Active Denial (Raytheon) • 4-6: All others	• 7-9 Active Denial (Raytheon) • 5-7: All others	• 8-9 Active Denial (Raytheon) • 6-8: All others	• 9 Active Denial (Raytheon) • 7-9: All others

What is the Technology

Technologies fielded by the US DoD (2015)



What is the Technology

Law Enforcement Vs. Military: Tech Emphases

Publications which reference military usage also tend to describe certain applications (e.g., vehicle or vessel stopping) as well as higher tech.

Law enforcement applications correlate more closely with older, higher TRL technology – and TASERs.

Military vs. Law Enforcement, Correlation with Technology Subjects (%)

Technology (n)	Military (369)		Law enforcement (388)	
Hailers (21)	●	61.9		
IED disabling (13)	●	61.5	•	7.7
Electronics - Jamming (51)	●	58.8	•	11.8
Directed energy weapons (87)	●	56.3	•	4.6
Vessel stopping (48)	●	56.3	•	6.3
Unmanned vehicles - NL Payload (41)	●	56.1	•	7.3
Active denial systems (64)	●	53.1	·	1.6
High-power microwave devices (104)	●	52.9	•	4.8
Barriers (14)	●	50.0	•	7.1
Vehicle stopping (16)	●	50.0	•	6.3
Launchers (21)	●	47.6	●	33.3
Underwater (24)	●	45.8	•	4.2
Anti-swimmer (14)	●	42.9		
Acoustic weapons (51)	●	41.2	·	3.9
Millimeter wave (39)	●	41.0	·	2.6
Electromagnetic weapons (49)	●	40.8	•	10.2
Portable or handheld (22)	●	36.4	●	27.3
Laser dazzlers (47)	●	36.2	•	8.5
Behavioural/crowd modeling and simulation (115)	●	33.9	•	10.4
Modeling and simulation (195)	●	31.8	•	14.4
Gyrotrons (10)	●	30.0		
Obscurants (18)	●	27.8	•	16.7
Chemical/calmative (101)	●	27.7	●	30.7
Flashlights and LEDs (12)	●	25.0	●	33.3
Plasmas (12)	●	25.0	•	8.3
Projectiles (83)	●	24.1	●	24.1
Wireless (14)	●	21.4		
Rubber projectiles (34)	•	17.6	●	50.0
Blunt impact devices (52)	•	15.4	●	46.2
Pepper spray/tear gas (90)	•	14.4	●	43.3
Bean bags (11)	•	9.1	●	72.7
Liquid jets/Water cannon (14)	•	7.1	●	42.9
Electric, conducted energy (195)	•	6.7	●	67.2
Tasers (376)	·	5.3	●	61.4
Flash / bang grenades (14)			●	28.6

What is the Technology

- *Drivers:*

The main drivers for adoption of such weapons stem from the new and complex challenges faced by warfighters, police, and others as they carry out their missions around the world. These drivers include:

- *Combat environments that are increasingly asymmetric, i.e., they include non-traditional combatants (terrorists, guerrillas) and methods.*
- *Specific missions, including disaster relief and humanitarian efforts, peacekeeping, and crowd control.*
- *Warfare in urban environments, at close quarters and even inside buildings.*
- *The need to deal with a mixture of combatants and non-combatants – and the need to gain the trust, confidence, and cooperation of the latter.*
- *The need to limit collateral damage.*
- *A need for response that can escalate from non-lethal to lethal (shouting and then shooting).*
- *Increased social media attention*
- *Ethical use of non-lethal weapons*

Barriers and Tipping Points (STEEP +LD Method)

Dimension	Barriers	Tipping Points
Social (ethical, moral, etc.)	Cultural issues and myths, such as those that characterize some of the newer technologies as "Star Wars" weapons or death-rays Fear of misuse and abuse of the technology by the authorities toward torture	Past: Increasing media coverage, familiarization of the general public with lasers due to telecom, and medical industries. Future: social acceptance of DEWs and realistic expectations. Unfortunate events: Ferguson / Chicago
Technological	issues related to range and accuracy, scalability/calibration, line of sight, beam formation, sensitivity to moisture, safety of use versus target characteristics Kinetic, acoustic and directed energy methods can be fatal at close range, but are ineffective if striking distance is too far away	Past: Laser diode and fibre evolution due to telecom industry, emergence of laser welding and material processing. Future: New high power laser systems at novel wavelengths, ancillary technology evolution
Economical	Expense and long timelines of development and approval: 1997-2009 no new weapons and only 4 fielded items Compared to the overall expenditures on weapons and munitions, the budget for NLWs is rather scanty	As the technology gets adopted for civilian application, economies of scale will be realized Past / future: DEW have very low cost-per-shot (cents) as opposed to kinetic weapons

Barriers and Tipping Points (STEEP +LD Method)

Dimension	Barriers	Tipping Points
Environmental	Minimal	
Political	No national strategy for NLWs, no access to Allied information, minimal national expertise, no work whatsoever on high powered microwave systems	Past: Awareness of Allied laser systems effectiveness and development Future: Exchange agreements, national strategy, expanded R&D scope

Barriers and Tipping Points (STEEP +LD Method)

Dimension	Barriers	Tipping Points
Legal	Human effects evidence can be scanty and not peer reviewed. Proof of "unnecessary suffering" can be difficult without in depth human effects research. While the consensus is that the Law of Armed Conflict does apply to non-lethal weapons, some types and uses fall into an indeterminate area. Chemical incapacitants such as pepper spray, for instance, may legally be used for law enforcement and crowd control, but not as an instrument of conventional warfare. The use of other drugs, such as calmatives or other incapacitants, is likely prohibited by the Convention on Chemical Weapons and other disarmament instruments.	As new NLWs get introduced to the market, there is a significant effort usually deployed to evaluate the associated risk. Jurisprudence to establish legal boundaries for each new technology
Defence	Preference of the military for tried and true lethal methods seriously obstruct the fielding of all NLWs. Few operational guidelines exist that apply to operational use of NLWs. Integration of NLWs in the weapons spectrum, and the perception that their use may produce unrealistic expectations and may complicate outcomes.	Development of a doctrine on the use of NLWs. Past: Traditional use of Flash-Bang devices to startle opponents. Introduction and use of the Laser Warning Technology in Afghanistan to assess possible threat intent. Future: Army mission shifts towards some type of law enforcement role will promote adoption and use of NLW Operations in future complex urban environments

Potential Defence and Security Implications/Applications as Related to the Army

- Implications: Revision of doctrine to allow for non-lethal engagements
  - Revision of Rules of Engagement so as to add nonlethal components
  - Revision of scaled responses to threat beyond the traditional "warning shot"
  - Redefinition of threat neutralization (kept at a range, incapacitated)
  - Introduction of the concept of temporary neutralization (over a limited time frame)
  - Permission to engage civilians and combatants equally with non-lethal means

- Applications: Scenarios under limited or complex RoEs
  - Operations with hidden/dispersed combatants in a civilian population
  - Operations with limited RoEs due to political implications
  - Operations in complex urban environments
  - Operations where the survival of the target is paramount (capturing of High Value Targets)
  - Asset and critical infrastructure protection

Potential Defence and Security Implications/Applications as Related to the Army

Critical asset protection

Objective: Protect critical infrastructure from hostile crowds (civilians + enemy combatants)

Issues with lethal response:

- Escalation of violence
- Excessive amount of targets
- Political and media ramifications
- May not establish a safety perimeter

Non-lethal allows for area access denial with no causalities

Target-in-crowd neutralization

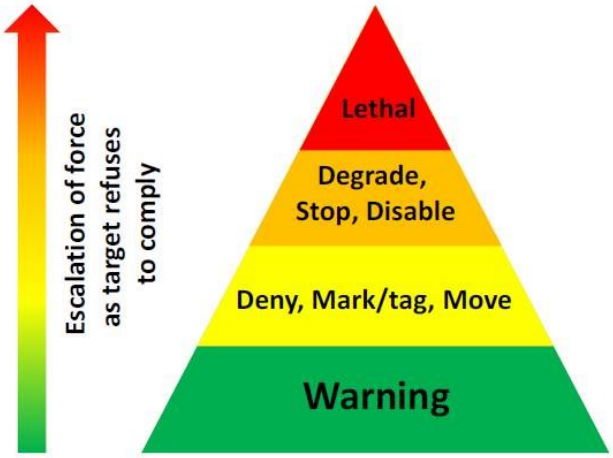
Purpose: Neutralize confirmed hostile targets hidden in a civilian crowd

Issues with lethal response:

- Cannot engage a target without clear view / ID
- Cannot temporarily incapacity a group

Non-lethal allows to temporarily incapacitate a group containing a hostile crowd

Potential Defence and Security Implications/Applications as Related to the Army



Escalation of force concept related to NATO NLW requirements

Potential Defence and Security Implications/Applications as Related to the Army

Action	Target	Location	Requirement
Warning	Individuals, including vehicle operators	NA	Desired effective range: 0-600 m Desired duration of effects: minutes
Tag/mark	Individuals, vehicles	Open or confined area	Desired effective range: 0-300 m (0-600 m for vehicles) Desired duration of effects: 2 days
Move	Individuals	Out an open area, out a confined area/within building	Desired effective range:0-100 m (0-20 m in buildings) Desired duration of effects: 60 min
Deny	Individuals, vehicles	Open area, confined area	Desired effective range: 0-300 m (0-600 m for vehicles) Desired duration of effects: 2 hrs
Degrade/Stop/Disable	Individuals	Open area, confined area and in buildings	Desired effective range: 0-300 m (0-100 m in open area) Desired duration of effects: 60 min
Degrade/Stop/Disable	Vehicles	Open area and confined area	Desired effective range: 0-600 m Desired duration of effects: 60 min

Strengths, Weaknesses, Opportunities, Threats (SWOT) Analysis

Example: Overall SWOT for DEWs

Strengths

- Range
- Speed of delivery
- Volume of fire
- Duration of effect
- Precision engagement
- Controlled effects (scalable effects)
- Electronic magazine
- Logistics

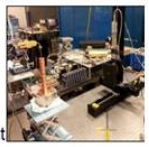
Weaknesses

- Size and weight
- Source technology
- Power requirements
- Ruggedization
- High cost
- Specialized training requirements

Opportunity

- World's Directed Energy lead
- Game changer
- Addresses multiple missions/applications

Programmatic Threats



- Misperceptions
- Initial prototype costs
- Limited leverage
- New battlefield effects
- Bomb damage assessment
- Legal, treaty, and policy
- Kinetic vs non-kinetic weapon comparisons

Non-Lethal capabilities assist operating forces in minimizing civilian casualties and collateral damage

Strengths, Weaknesses, Opportunities, Threats (SWOT) Analysis

Shipboard Lasers SWOT

Strengths

- Robust and commercially available tech
- Rapid maturation, declining costs of basic tech
- Cost-effective (ca. $1/per shot)
- Substantial USG-funded R&D effort (US$26.9 M for FY2016)
- Graduated responses and ability to address diverse threats (counter-materiel and counter-personnel)
- Fast engagement times

Weaknesses

- Size, weight
- Weather conditions, and atmospheric absorption, scattering, turbulence
- Requires line of sight
- Thermal management issues for some types (e.g., slab)
- Effectiveness against hardened targets
- Systems engineering and integration into current ship designs

Opportunities

- Atmospheric propagation in various environments
- Ruggedization
- Combining compactness with high power efficiency
- Combination with other weapons systems
- Bioeffects
- Modeling and simulation

Threats

- Rapid development/implementation by other nations (Iran, China, Russia)
- Safety issues when misused
- R&D focus is more on combat weapons
- R&D funding constraints, lack of quick results
- Public misperceptions

Strengths, Weaknesses, Opportunities, Threats (SWOT) Analysis

Active Denial MMW SWOT

Strengths

- Extensive safety and effectiveness research (11,800 exposures)
- Effective at long ranges, up to 1,000m
- Narrow band = relatively interference free
- Legal, treaty and arms control compliant, per USG
- Substantial USG funding as part of DEW R&D

Use by both military and law enforcement/corrections

Weaknesses

- Size, weight, logistics of transport
- Cost of procurement
- Thermal management
- Start-up (instant on) and cycle times
- Integration with existing platforms, vehicles
- Scalability: specific range requirements
- Damage to ordnance?
- Rain fade and propagation issues

Opportunities

- Smaller, lighter, lower cost systems and components, e.g., antennas, integrated circuits, man-portable
- Bioeffects: effective spot sizes, study of multiple beam effects
- Longer range systems and shoot-on-the-move
- Integration with existing platforms
- Development of autonomous solid state MMW sources (95-GHZ and 220-GHz, GaN
- Thermal management systems

Threats

- Public misperceptions
- Cost of R&D
- Cost of procurement
- Procedural and cultural issues associated with NLWs: complexity of integration with other options, training requirements , cultural biases
- Development by other nations (China, Russia), use to reinforce maritime claims

Strengths, Weaknesses, Opportunities, Threats (SWOT) Analysis

Kinetic NLWs SWOT

Strengths

- Low cost
- Compact
- Low SWAP (size weight and power)
- Legally accepted
- Mature
- Ruggedized
- Established TTP
- All-weather

Weaknesses

- Unintended injuries
- Limited adaptability to target
- Shot placement and dispersion
- Impact location on target
- Ricochet
- Easily defeatable by readily available sports gear

Opportunities

- Visco-elastic materials
- Meta-materials
- Synergy with other technologies (projectile+malodorant)
- Smart launcher
- Programmable projectiles
- Crowd psycho-social pre-conditioning

Threats

- Public perception
- Unintended lethality or permanent injury
- Legal ramification
- Perceived versus real TRL (reduced funding)

Key Players & World Leaders

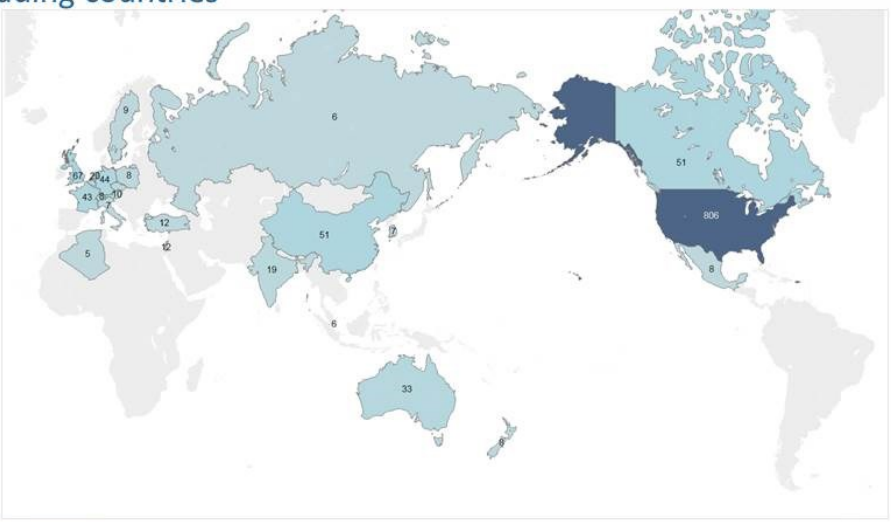
- Leading countries

Country (Total)	Top Technology Subject Groups	Top Applications Subject Groups
United States (806)	Tasers (277); Conducted energy (163); Modeling and simulation (112); Behavioural/crowd modeling & simulation (68); HPM (58); DEW (57)	Law enforcement (266); Military (223); Crowd/riot control (72); Terrorism (53); Counterinsurgency (29)
United Kingdom (67)	Chemical/calmative (14); Tasers (13); Modeling and simulation (8); Pepper spray/Tear gas (8)	Law enforcement (28); Military (14); Crowd/riot control (11); Maritime (4); Vehicle stopping (3)
Canada (51)	Tasers (23); Modeling and simulation (9); Behavioural/crowd modeling & simulation (8); Conducted energy (8); DEW (3)	Law enforcement (24); Crowd/riot control (9); Military (7); Terrorism (4); Maritime/Underwater (2 each)
China (51)	Modeling and simulation (24); Behavioural/crowd modeling and simulation (12); Active denial and Laser dazzlers (6 each); MMW and Projectiles (5 each)	Crowd/riot control (14); Military (5); Targeting (4); Decision support (2)
Germany (44)	Tasers (14); Conducted energy (11); Modeling and simulation (6); Behavioural/crowd modeling and simulation (6); HPM, Projectiles ,and Targeting (4 each)	Law enforcement (8); Military (6); Crowd/riot control (5); IED disabling, Vehicle/Vessel stopping (3 each)
France (43)	Modeling and simulation (11); Tasers (9); Blunt impact (7); Behavioural/crowd modeling and simulation, Projectiles, and Rubber projectiles (6 each)	Law enforcement and Military (10 each); Maritime (8); Terrorism (6); Vessel stopping (5); Crowd/riot control (4)
Australia (33)	Tasers (12); Blunt impact (5); Conducted energy (4); HPM (3)	Law enforcement (11); Military (7); Crowd/riot control (2)
Netherlands (20)	Modeling and simulation (5); Behavioural/crowd modeling and simulation, Blunt impact, Laser dazzlers, Rubber projectiles (3 each)	Military (6); Crowd/riot control (5); Law enforcement (4); Terrorism (2)

21

Key Players & World Leaders

- Leading countries



Key Players & World Leaders

- Research Organizations/Universities
  - University of Minnesota, MN, USA (29)
    - Tasers (26); CEWs (17); Law enforcement (15)
  - Penn State University, PA, USA (19)
    - Law enforcement (12); Terrorism (7); CEWs (3)
  - University of California, San Diego, CA, USA (15)
    - Law enforcement, CEWs (12 each); Tasers (7)
  - Fraunhofer ICT, Germany (6)
    - Acoustic weapons (3); Vehicle/Vessel stopping (2 each)
  - Omega Research Foundation, UK (5)
    - Chemical/calmative (3); CEWs, Pepper spray/tear gas (1 each)
  - Chinese Acad Sciences, Changchun (4)
    - Laser dazzlers (4); Solid state (2)

Key Players & World Leaders

- Leading companies
  - Taser International
    - Tasers (39); CEWs (11); Projectiles (10)
  - Raytheon
    - DEWs (7); Millimeter wave, Targeting (6 each); Projectiles (5); HPMs (4)
  - Rheinmetall
    - Projectiles (12); Flares (5); Pepper spray/tear gas (4)
- Patents and their owners
  - Taser International, Raytheon, Rheinmetall

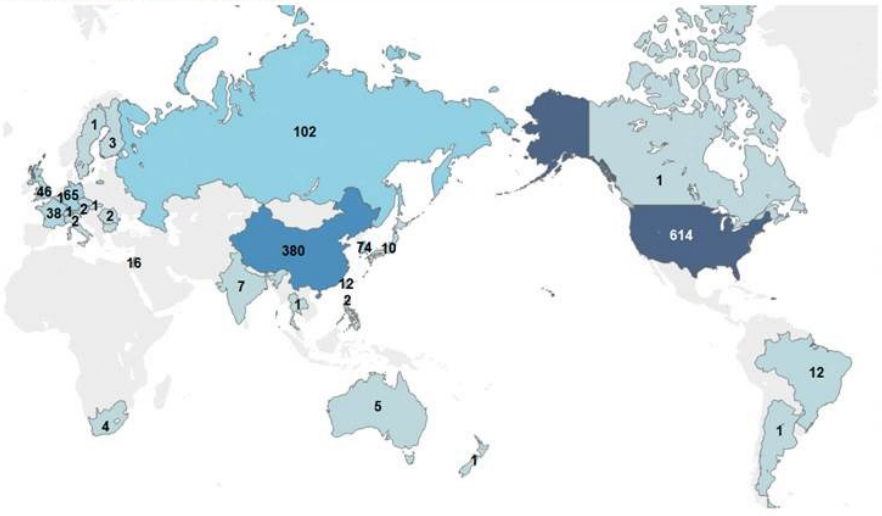
Key Players & World Leaders

- Patents and their owners

Country (Total)	Top Technology Subject Groups	Top Applications Subject Groups
United States (614)	Projectiles; (256) Pepper spray (88); Marking or paintball (71) ; Portable or handheld (68); Launchers (67)	Military (85); Law enforcement (79); Maritime (36); Targeting (35); Crowd or riot control (27); Vehicle stopping (15)
China (380)	Projectiles; (77) Pepper spray (72); Laser dazzlers (56) ; Portable or handheld (45); Blunt impact devices (38)	Crowd or riot control (136); Law enforcement (134); Military (42) ; Terrorism (34); Maritime (25); Homeland security (20)
Russian Federation (102)	Pepper spray (27); Projectiles (26); Flares (23); Conducted electrical weapons (10), Rubber projectiles (7)	Terrorism (11); Military (8); Maritime (6); Law enforcement, Aviation security (5 each)
South Korea (74)	Pepper spray (53); Projectiles (11); Launchers (7) ; Portable or handheld; Water cannon (6 each))	Maritime (7); Anti-piracy (6); Military, Law enforcement (3 each); Terrorism (2)
Germany (65)	Projectile s(25); Pepper spray (24); Flares (15); Launchers (5); Wireless (4)	Military (10); Maritime, Law enforcement (4 each); Anti-piracy, Targeting, Aviation security (3 each)
United Kingdom (46)	Projectiles (13); Barriers (12); Portable or handheld (6); Pepper spray (4)	Military, Maritime (6 each); Aviation security, Crowd or riot control (4 each); Law enforcement, Anti-piracy (2 each)
France (38)	Projectiles (30); Flares (11); Pepper spray, Launchers (9 each); Obscurants (6)	Maritime (4); Military (3); Crowd or riot control, Law enforcement, Anti-piracy (2 each)
Israel (16)	Projectiles (7); Flares (3); Launchers, Wireless;, HPM (2 each)	Targeting (2); Maritime, Law enforcement, Aviation security, Decision support (1 each)

Key Players & World Leaders

- Patents and their owners



Key Players & World Leaders

- Known Associations/Working groups (national & international)
  - USAF Research Laboratory, San Antonio, TX
  - National Institute of Justice, Washington, DC
  - Naval Postgraduate School, Monterey, CA
  - ARDEC, Picatinny Arsenal, NJ
  - European NLWs working group
  - NATO SAS 094
  - NATO Stanrec 4744
- Known Canadian R&D Efforts (e.g. source of info: NSERC database)
  - DRDC (Valcartier, CORA)
  - University of Toronto, ON
  - Justice Institute of BC, New Westminster, BC
  - Carleton University, Ottawa, ON
- GoC/DRDC SMEs
  - Daniel Bourget, Dominik Pudo, Daniel Corriveau, Peter Dobias, Donna Woods, …

Related Policies (Canadian & foreign), Doctrine / TTPs

Policies	Country	Doctrine, TTPs
NATO policy on nonlethal weapons		
DoD Directive 3000.3E, DoD Executive Agent for Non-Lethal Weapons	U.S.A.	
Home Office Code of Practice on the Police Use of Firearms and Less Lethal Weapons	U.K.	
National Minimum Guidelines for Incident Management, Conflict Resolution and the Use of Force	Australia	
National Use of Force Framework Guidelines for the Use Conducted Energy Weapons National Defence Act	Canada	Crowd Confrontation Operation Doctrine

S&T Trends/Future Directions

- Strong emphasis on directed energy (laser and HPMs)
- Incremental improvements and/or combined effects for older or prototype technologies, such as TASERS, active denial, HPMs, sound and light
- Form/functional improvements: range, weight, size, duration, repeatability, precision, power density, integration with conventional ordnance
- New or difficult environments such as maritime applications or indoors
- Delivery systems such as UAVs
- The use of modeling and simulation
- And as always -- human effects, reduced RSI

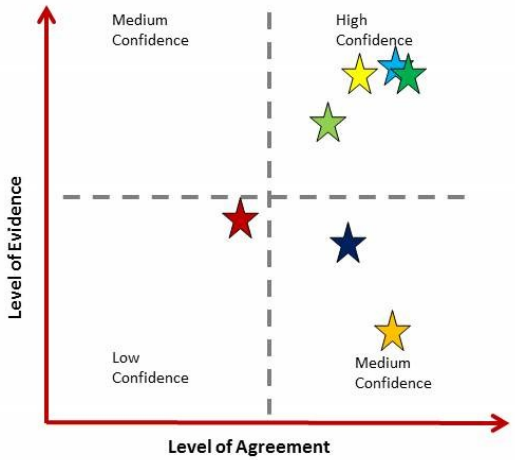
S&T Trends/Future Directions

Small Business Innovation Research (SBIR) Program

- Compact, lightweight, high performing, cost, range, duration
- Precision and performance
- Multi-frequency
- Thermal management
- Maritime environments as well as land-based
- Solid state electronics
- Other components: gyrotrons, steerable antennas
- Integration with launchers, ordnance
- Human effects

Level of Agreement in the Scientific Community

- Kinetic
- Chemical
- Anti-mobility
- Acoustic
- Electric shock
- Optical disruption
- Active denial



Impact Assessment against Army Hard Problems

	Army Hard Problem	Impact 0-5 (0 = lowest, 5 = highest)	Comments
1.	Soldier Burden	N/A	Land Operations 2021 – Adaptive Dispersed Operations states that the ACT functionality integrates manoeuvre, firepower ... to create a desired effect .. through synchronized application ... of available capabilities, both lethal and non-lethal (p. 12). The CONOPS to guide commanders and soldiers under what circumstances they are to use NLW rather than LW still requires development and refinement. It is DRDC opinion that defining when and how to use NLWs should be placed on the Army hard problem list because the FSE may require the Army to operate differently using new NLW tools in order to achieve a desired end state.
2.	Soldier Resiliency	N/A	
3.	Soldier Protection	N/A	
4.	Cognitive Overload	N/A	
5.	Vehicle Engineering	N/A	
6.	Manoeuvre over Distance	N/A	
7.	Explosive Hazard Avoidance	N/A	
8.	The Network	N/A	
9.	Managed Readiness	N/A	
10.	Power and Energy	N/A	

References

- *Brady, B., McLaughlin, T. "*Non-Lethal Weapons: A Scientometric and Market Study" DRDC Contract Report, November 20, 2015.
- Bourget, D. "FSAR WBE 1.1.5: Concept of operations on non-lethal effectors *FY 14/15 (U)" DRDC Scientific Letter, June 2015.*
- Department of Defense Directive. (1996, 9 Jul.). *Policy for Non-Lethal Weapons*. No. 3000.3.
- Brady, B. "Nonconventional Weapons Literature Survey" CISTI STIA Project #2010, October 2010.
- NATO SAS-035, "Non-Lethal Weapons Effectiveness Assessment: The Final Study Report of NATO SAS-035", RTO-TR-035, Oct 2004.
- NATO SAS-060, "Non-Lethal Weapons Effectiveness Assessment Development and Verification Study", RTO-TR-SAS-060, Oct. 2009
- NATO SAS-094, "NATO Non-Lethal Weapons Case Study Synthesis", NLW Analysis Working Group Report, STO-TR-SAS-094, 2015

Annex B Quantum sciences outlook brief

Defence Research and Development Canada | Recherche et développement pour la défense Canada

$$\frac{-\hbar^2}{2m}\nabla^2\Psi + U(x,y,z)\Psi(x,y,z) = E\Psi(x,y,z)$$

Quantum S&T 2.0

(Computing, Communication, Sensing and Materials)

Dr. Bhashyam Balaji

Outlook Brief

Emerging and Disruptive Technology Impact Assessment Workshop

Nov. 30 – Dec 4, 2015

DRDC | RDDC

Canada

Outline

- What is the underpinning science?
- What is the technology or technology area?
- Barriers and Tipping Points (STEEP+LD Method)
- Potential Defence and Security Implications/Applications as Related to the Army
- Strengths, Weaknesses, Opportunities, Threats (SWOT) Analysis
- Key Players & World Leaders
- Related Policies (Canadian & foreign), Doctrine, TTPs
- S&T Trends/Future Directions for the technology
- Level of Agreement in the Scientific Community
- Own assessment against Army Hard Problems
- References

What is the Underpinning Science

"Quantum mechanics is the operating system that other physical theories run on as application software." (Scott Aaronson)


- Quantum mechanics and special relativity are the foundation of all the laws of the universe, including quantum field theory and beyond (e.g., string theory), so a **permanent source of disruptive technologies**
- Consequently, the subject is vast: general principles are universally valid, but details and consequences markedly different
- Detailed understanding of the consequences far from known: quantum chemistry, biology
- While the core formalism was worked out in the 1920s, and fundamental to chemistry, detailed understanding of the consequences barely known
- Bottom Line: **Quantum mechanics is not intuitive, but is undoubtedly correct**.




What is the Underpinning Science

- Initial consequences, Quantum S&T 1.0 the basis of the Information Age (nuclear, solid-state electronics, lasers, digital cameras)
- If it is so old, what is new?
  - Emphasis changed from explaining nature as we see it to harnessing the quantum possibilities, e.g., inspired by quantum computing promise
  - Recent Nobel Prizes on new practical consequences of quantum mechanics: 1997 (laser atom cooling), 2001 (Bose-Einstein condensate) , Graphene (2010), optical clocks (2012)

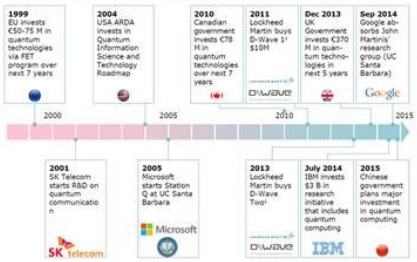


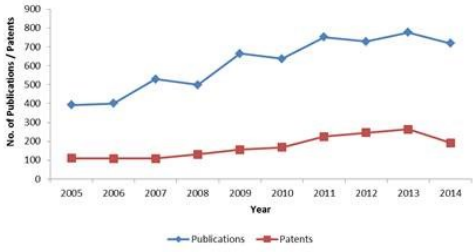







What is the Underpinning Science





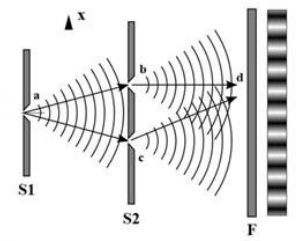
"Quantum S&T 2.0" (UK Quantum Technology Landscape 2014)

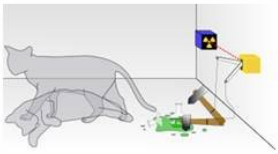
"Our vision is that quantum technologies will become game changing differentiators for UK defence and security over a 5-30 year time scale. …an extra 270 million pounds will be made available for the development of quantum technologies over the next five years."

GoC (2015): $100M Quantum S&T investment over 7 years (UBC, Sherbrooke)

What is the Underpinning Science

- QM in a nutshell:
  1) (Hazmat Spectroscopy, Lidar): Energy Quantized
  2) (Optical sensors) Wave-Particle Duality
  3) (Quantum computer) Quantum Superposition
  4) Quantum Illumination Radar) Entanglement ("spooky action at a distance")
  5) (Quantum cryptography) Disturbance-free measurement is impossible





QUANTUM COMPUTING

What is the Technology: Quantum Computing

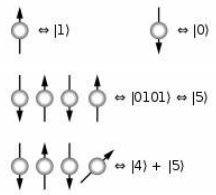
- Classical computation with bits, quantum computation with qubits
- Quantum parallelism/superposition enables much faster computations with a universal quantum computer than universal classical computer (Turing)

-Shor's Algorithm: exponentially faster breaking of current encryption algorithms

-Grover's Algorithm: Search algorithm quadratic speedup

-Quantum Simulation: Much faster approaches to design of quantum materials, medicine

- Non-universal quantum computers could also be useful, e.g., D-Wave 1000+ qubit QC used for software validation (Lockheed Martin, F-35), Search/AI/ML/Big Data (Google), nuclear physics (Los Alamos), Harvard (protein folding)



qubits can be in a superposition of all the classically allowed states

What is the Technology: Quantum Computing

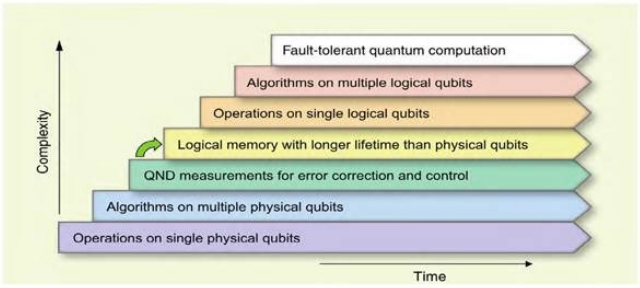


Fig. 1. Seven stages in the development of quantum information processing. Each advancement requires mastery of the preceding stages, but each also represents a continuing task that must be perfected in parallel with the others. Superconducting qubits are the only solid-state implementation at the third stage, and they now aim at reaching the fourth stage (green arrow). In the domain of atomic physics and quantum optics, the third stage had been previously attained by trapped ions and by Rydberg atoms. No implementation has yet reached the fourth stage, where a logical qubit can be stored, via error correction, for a time substantially longer than the decoherence time of its physical qubit components.

Courtesy: Institute of Quantum Computing, Waterloo

What is the Technology: Quantum Computing

- *Overview of the technology*
- Quantum parallelism/superposition enables much faster computations with a universal quantum computer than (universal) classical computer

Sub-Domain	Current TRL	TRL 2020	TRL 2025	TRL 2030
Quantum Annealing	9 (1000+ qubits)			
Universal Quantum Computer		O(100)qubits?		O(1000)qubits?

- *Drivers: Cryptography, Quantum Simulation, Software validation, Search, Big Data, Machine Learning, AI*

Barriers and Tipping Points (STEEP +LD Method)

Dimension	Barriers	Tipping Points
Social (ethical, moral, etc.)	High expectations (quality, time) for revolutionary products	-Breakthroughs: disruptive technologies for multiple qubits
Technological	-No obvious frontrunner technology -Scalability, algorithms, low temperature	-Breakthroughs: Scalable architecture -New algorithms -Room temperature operation
Economical	- Lack of industrial buy-in/job opportunity - Lack of mature products - Limited application space	- Low production costs, market success, mainstream multi-use (civilian/health/security/military) - Effectively and efficiently, coordinated efforts
Environmental		
Political	- Insufficient info sharing (among some allies) - Limited coordinated strategy - Local experts contribute to/leave for effort outside Canada	-Another country first to deploy QC (cf nuclear weapons)
Legal	-Privacy	
Defence	- Portability	

Potential Defence and Security Implications/Applications as Related to the Army: Quantum Computing

"It's tough to make predictions, especially about the future." Yogi Berra
"I think there is a world market for maybe five computers."
Thomas Watson, president of IBM, 1943
"There is no reason anyone would want a computer in their home."
Ken Olsen, founder of Digital Equipment Corporation, 1977
"Apple is already dead." *Nathan Myhrvold, former Microsoft CTO, 1997*

- US Army Research Lab supports an extensive program on quantum S&T, including quantum computing, as does AFRL, NSA, NASA, Google, Lockheed Martin
- Quantum computing means currently encrypted data could be decrypted in the future
- NSA: recent recommendation is quantum-secure communication solutions
- Utility of discovering new quantum materials via quantum simulation
- Will not replace classical computer; only for niche applications
- Biggest, undeniable gain: *technologies pursued in attempting to build a quantum computer will be useful for other areas, such as quantum sensing*

Strengths, Weaknesses, Opportunities, Threats (SWOT) Analysis

Strengths
- World-leading capability in Canada
- S&T extremely challenging, and attract best and brightest; tap that talent
- Great scientific (theoretical and experimental) interest
- Quantum information theory fundamental

Weaknesses
- Provides improved solution to a limited class of problems
- Major investment needed on multiple approaches
- Lack of experience in strategic approach
- Lack of translational capability

Opportunities
- Internationally recognized expertise within Canadian academia
- International approach, Five eyes.
- Strongly connected with other areas of applied quantum S&T, including quantum communication, quantum sensing and quantum materials

Threats
- Adversaries/Competitors investing heavily
- Poses serious threat to current cryptography,
- Even some "failed" quantum computer technology can lead to step change in quantum sensing and material technologies
- Sovereign risk, lose Canadian standing

S&T Trends/Future Directions: Quantum Computing

- QC hardware and architecture
- The search for the disruptive hardware technology (analogous to transistors for classical computers) will continue
- It is unclear when a dramatic breakthrough will happen
- Larger class of important problems solved more efficiently: Machine Learning, Optimization
- Standards: qubits, correlation, coherence time
- Exploitation of non-universal QC to solve certain problems

QUANTUM COMMUNICATION

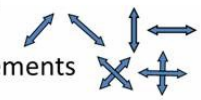
What is the Technology: Quantum Communication

"Without quantum-safe encryption, everything that has been transmitted, or will ever be transmitted, over a network is vulnerable to eavesdropping and public disclosure."

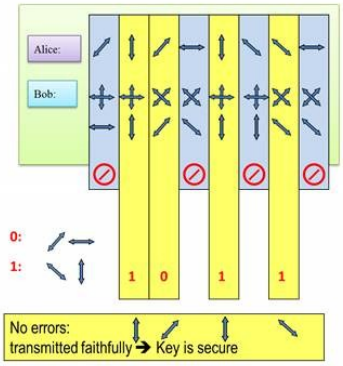
- Two type of cryptography (essential but not the entirety of security):
  - Symmetric key cryptography: same key used for encryption and decryption
  - Public Key Cryptography: one key for encrypting, other for decrypting (also for digital signatures)
- Quantum-safe crypto: safe from quantum computer attacks (Code-Based Crypto, Lattice-Based Crypto, Hash-Based Crypto, Multivariate Crypto, Quantum Key Distribution (QKD))
- Most public key cryptography are based on algorithms vulnerable to quantum attacks (RSA, ECC, Diffie-Hellman, DSA)---Shor's algorithm
- Quantum Key Distribution (QKD) security from quantum physics

What is the Technology: Quantum Communication

Quantum Part:
Create random key:
➔random signals
➔random measurements



Public discussion over faithful classical channel: distinguish **deterministic** from **random processes**



QKD Security from QM: An Eavesdropper will not know which polarization Alice choose, she can only perform measurements with errors, that will be detected.

Alternative Application: Quantum Fence?

What is the Technology: Quantum Communication

- Serious threat even without QC: practical crypto implementation

"The key is, somewhat ironically, Diffie-Hellman key exchange, an algorithm that **we and many others have advocated as a defense** against mass surveillance. Diffie-Hellman is a cornerstone of modern cryptography used for VPNs, HTTPS websites, email, and many other protocols. Our paper shows that, **through a confluence of number theory and bad implementation choices, many real-world users of Diffie-Hellman are likely vulnerable to state-level attackers. …** Since a **handful of primes are so widely reused**, the payoff, in terms of connections they could decrypt, would be enormous. **Breaking a single, common 1024-bit prime would allow NSA to passively decrypt connections to two-thirds of VPNs and a quarter of all SSH servers globally. Breaking a second 1024-bit prime would allow passive eavesdropping on connections to nearly 20% of the top million HTTPS websites. In other words, a one-time investment in massive computation would make it possible to eavesdrop on trillions of encrypted connections.**" (Best Paper: ACM CCS 2015)

- Security from known mathematical hardness is unproven (weakness known to others?), unlike security from quantum physics
- "Quantum hacking" fixed simply (e.g., protect detector)

What is the Technology: Quantum Communication

- *Overview of the technology*
  - *Provide a quantum-safe communication solution guaranteed by the laws of quantum physics (particularly the no-cloning theorem, and the fact that measurement disturbs the state of a quantum system, i.e., "untappable")*

Sub-Domain	Current TRL	TRL 2020	TRL 2025	TRL 2030
Optical Fibre QKD	9			
Free Space and Space-Based QKD	4	5-7	6-8	7-9
Point-to-Point Quantum Internet	3-6	4-8	6-9	7-9
Quantum Internet	2-3	2-5	3-7	5-9

  - *Drivers: Quantum computer, Quantum-safe cryptography*

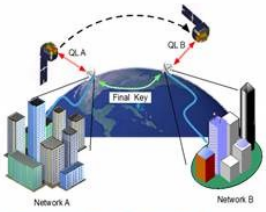
Canadian Leadership: Institute of Quantum Computing, Waterloo and Space-Based QKD---Leverage this!

Barriers and Tipping Points (STEEP +LD Method)

Dimension	Barriers	Tipping Points
Social (ethical, moral, etc.)	Eavesdropping/Privacy/Security	Quantum internet
Technological	Point to point, limited bandwidth Denial of service.	Quantum repeaters, Quantum memory
Economical	Limited interest from business	Existence of QC New code breaking algorithms
Environmental		
Political	Security vs Privacy	Major cybersecurity breaches
Legal	Privacy	Wide industry adoption
Defence	Identify Critical applications (when is 100% security required?)	Sufficient Bandwidth Free space Space based QKD

Potential Defence and Security Implications/Applications as Related to the Army: Quantum Communication

- Quantum-safe communication based on QKD
- Provably secure communication within base
- Longer distance secure communication via fiber



- Space-based QKD : Satellite bridges the large gap between ground based quantum networks
- Secure cloud communication
- Air-to-ground communication/data link
- Quantum internet

Strengths, Weaknesses, Opportunities, Threats (SWOT) Analysis

Strengths
- Canadian expertise in QKD (especially space-based QKD)
- Security based on quantum physics far more robust than currently perceived mathematical hardness (that can change with time/classified)
- Currently deployable

Weaknesses
- Assumes universal quantum computer with enough entangled qubits possible soon
- Fraction of information with longevity under threat from quantum computer small
- Weakest link often not crypto

Opportunities
- Technology applicable to other quantum S&T areas, particularly quantum sensing
- Build on Canadian world-leading expertise (e.g., space-based QKD, QEYSSAT)
- Quantum-safe crypto inevitable in future

Threats
- Heavy investment in this technology worldwide
- Expect more quantum-safe encryption, including asymmetric threats, with a major impact on COMINT
- Lose Canadian leadership in the area

S&T Trends/Future Directions: Quantum Communication

- Blended solution of quantum-safe cryptography (mathematical assumptions and QKD)
- Increase use of point-to-point quantum encryption uptake
- Standardization and Regulation
- Hand-held QKD
- "No trusted relay" quantum network
- Space-based QKD
- Quantum Internet

QUANTUM SENSING

What is the Technology: Quantum Sensing

- Classical Sensor performance limit (Standard Quantum Limit): $1/N^{1/2}$
- Ultimate (Quantum) sensor performance limit (**Heisenberg Limit**): 1/N
- Reason for quantum gain: Quantum Entanglement, Squeezed States,…
- Classification of Active Quantum Sensors

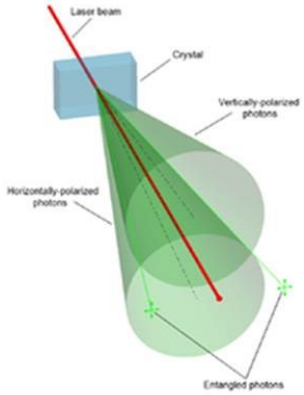
Type 0: Classical Transmitter and Receiver

Type 1: Classical Transmitter and Quantum Receiver

Type 2: Quantum Transmitter and Classical Receiver

Type 3: Quantum Transmitter and Quantum Receiver (Quantum Radar/Lidar)

- Position, Navigation and Timing Sensing: inertial navigation system (no GPS)
- Quantum Clocks: Microwave and Optical Clocks

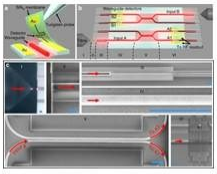


What is the Technology: Quantum Sensing

- Massive gains in sensitivity possible even with **far-from-optimal quantum-enhanced sensing**, e.g., single photon imaging

"LIDAR signal-acquisition time must be long enough to **collect the 100 to 1000 photons per pixel (ppp)** … a framework that recovers accurate reflectivity and 3D images simultaneously using on the **order of 1 detected ppp averaged over the scene**."

- Rethink active and passive optical imaging sensors (covert range finding, lidar, IR, multi-spectral and hyperspectral sensors) including standoff chemical detection
- Similar gains definitely possible in microwave regime as well: quantum-enhanced radar (microwave quantum optics) and quantum ESM---superconducting qubits, Rydberg atoms, etc used in QC



What is the Technology: Quantum Sensing

- Ultra-stable atomic clocks in smaller form factors, e.g., Chip-Scale Atomic Clock (Microsemi/Symmetricon)

-Highly accurate timing without GPS

-Simultaneous IED jamming and friendly comms

- Gravimetry: cold atom sensor for measuring gravity and gravity gradients (AOSense)

-studies of Earth's gravitational potential

-identifying special nuclear materials

-void detection

What is the Technology: Quantum Sensing

- *Overview of the technology (based on unclass)*
  - *Active and passive quantum sensors for sensing electric, magnetic, gravitational fields, inertial (position, navigation and timing) sensing that are closer to the HL, a considerable improvement over existing sensors, but with further room for improvement*

Sub-Domain	Current TRL	TRL 2020	TRL 2025	TRL 2030
Quantum -Enhanced (QE) Lidar/Radar	1-3	3-5	4-7	7-9
QE Hyperspectral/Multispectral Imaging	3	4-6	5-8	8-9
Quantum Navigation	2-5	4-7	6-9	7-9
Quantum-Enhanced ESM for EW	2 ?	2-5?	5-7?	7-9?
Further QE Magnetometry	3-4	4-5	5-7	7-9
Beyond Quantum Cascade Laser Chemical Sensing	2-4	3-6	5-8	7-9

  - *Drivers: Sensing in challenging environnments, GPS-denied environment navigation*

Barriers and Tipping Points (STEEP +LD Method)

Dimension	Barriers	Tipping Points
Social (ethical, moral, etc.)	False positives Increased sensitivity and risk assessment.	Real increased threats. Eg chemical attack on large city. Water supply security.
Technological	Ruggedization Productization Data handling and false positives.	Manufacturability reliability.
Economical	Economy of scale	
Environmental	Robustness, calibration.	Agreed standards
Political		
Legal	Privacy, false positives.	
Defence	Wide application space. Power, portability, reliability. Information overload	Integrated data handling. Reduced Cost. Reduced power consumption

Potential Defence and Security Implications/Applications as Related to the Army: Quantum Sensing

- Increased sensitivity of active and passive implies considerably improved situational awareness from larger standoff distances:

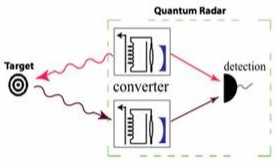
-Higher Probability of detection

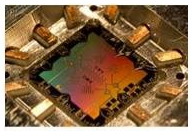
-Better parameter estimation

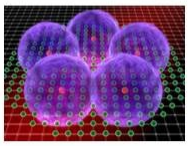
-Improved tracking

-Improved multi-sensor fusion

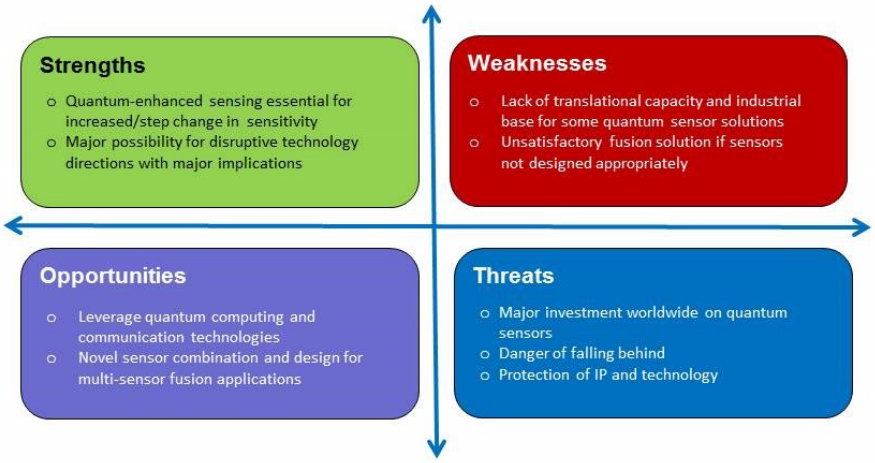
- Quantify performance bounds based on the laws of quantum mechanics, as opposed to currently available technology







Strengths, Weaknesses, Opportunities, Threats (SWOT) Analysis



S&T Trends/Future Directions: Quantum Sensing

- Ultra-Cold Atom S&T as base technology for future directions, particularly quantum inertial sensors/navigators (PNT)
- Atomic clock technology for multi-platform fusion
- Step-change in sensitivity/accuracy, or alternative modalities
- Improved sub-optimal quantum lidars/radars and multi-spectral sensors
- Gravity Mapping/Imaging
- Electromagnetic sensors (Rydberg atoms)
- Remote chemical sensing based on femtosecond lasers
- Fibre Bragg Gratings for temperature and pressure
- Inertial sensing

QUANTUM MATERIALS

What is the Technology: Quantum Materials

- Case Study: Graphene (Carbon-form)
- Why the great interest?

-Record thermal conductivity

-Highest current density at room temperature (million times that of copper!)

-Strongest Material: hundred times stronger than steel!

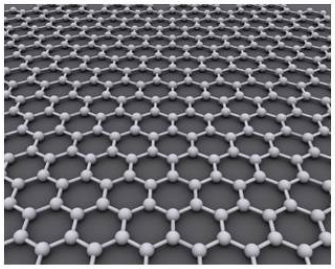
-Highly flexible mechanically

-Least permeable material

-The best transparent conductive film

-Thinnest material

Europe Invests €1 Billion to Become "Graphene Valley" :Oct 2013



What is the Technology: Quantum Materials

- *Overview of the technology*
  - *Two-dimensional materials, such as graphene, that show remarkable properties*

Sub-Domain	Current TRL	TRL 2020	TRL 2025	TRL 2030
Battery	4-7	6-8	7-9	8-9
Supercapacitors	3-5	4-7	5-8	6-9
Flexible Electronics	3-5	4-7	5-9	7-9

  - *Drivers: High technology, Consumer electronics, Energy efficiency, Battery, Solar cells, Biosensors, Flexible electronics, Clean technology,…*

"Aluminum, discovered in minute quantities in a lab in the eighteen-twenties, was hailed as a wonder substance, with qualities never before seen in a metal: it was lightweight, shiny, resistant to rust, and highly conductive. The killer app was the airplane, which didn't even exist when they were going all gung ho and gaga over this stuff."

Potential Defence and Security Implications/Applications as Related to the Army: Quantum Materials

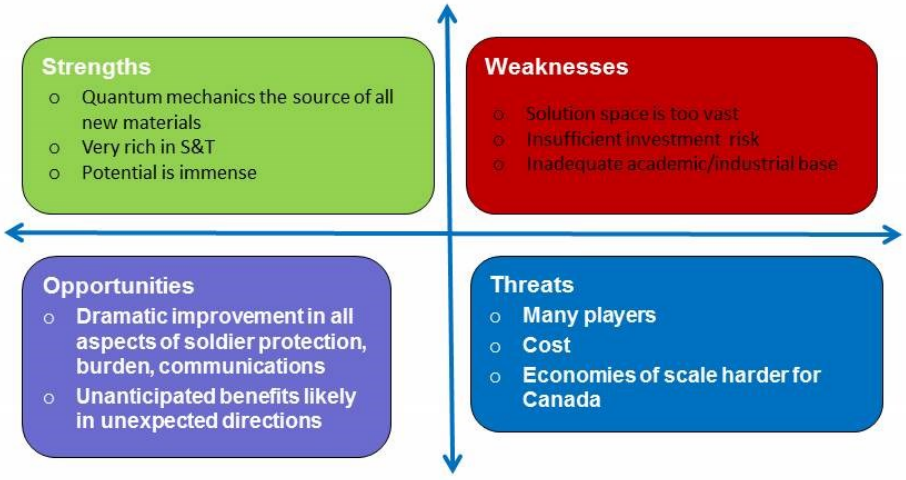
- Graphene only of the many possible 2D quantum materials: Silicene, Stanene, Borophene, Germanene, Phosphorene
- Quantum/Nano technology will play a major role in strong materials
- However, it is unlikely to be a standalone solution, but more part of a blended solution
- Power and Energy: "Quantum 2.0" for highly efficient photovoltaics
- Ingenuity and collaboration could lead to "killer app"

"As people start to branch out, they are discovering new materials that have these wonderful properties," says Coleman. "The most exciting 2D material is probably one that hasn't been made yet."

Barriers and Tipping Points (STEEP +LD Method)

Dimension	Barriers	Tipping Points
Social (ethical, moral, etc.)	High expectation	Tangible "killer apps"
Technological	Scalability	Industrial buy in.
Economical	Economies of scale	
Environmental	Limited source materials	
Political	Investment in translation	Rapid advances elsewhere
Legal	Patent landscape very crowded.	
Defence	Cost, portability, reliability.	

Strengths, Weaknesses, Opportunities, Threats (SWOT) Analysis



S&T Trends/Future Directions: Quantum Materials

- Major world-wide effort in two-dimensional materials
- Commercial sector will drive most of the innovation
- More novel applications of technology, some will undoubtedly feed into improved quantum sensors

``Samsung holds the greatest number of patents in graphene. A Korean university, which works with Samsung, is in first place among academic institutions. Two Chinese universities hold the second and third slots. In fourth place is Rice University, which has filed thirty-three patents in the past two years.``

KEY PLAYERS (Quantum Sensing)

Key Players & World Leaders: Quantum Sensing

- Important Caveat: Unclassified literature, English (e.g., Russia)
- Leading countries:

US, China, Germany, France, Japan, UK, Italy, Canada

- Research Organizations/Universities
- Canadian Organizations:

-Waterloo
-Toronto
-Calgary
-NRC
-U of Ottawa

Academic		Commercial		Government/RTO	
Chinese Academy of Sciences	(206)	NTT Corp., Japan	(55)	NIST, USA	(302)
MIT, USA	(186)	Thales, France	(54)	CNRS, France	(243)
University of Tokyo, Japan	(118)	Toshiba Corp, Japan	(27)	CNR, Italy	(128)
University of Colorado, USA	(115)	Micro Photon Devices, Italy	(24)	Max Planck Inst, Germany	(116)
Calif. Inst. of Technology, USA	(107)	Raytheon, USA	(24)	Japan Science and Tech. Agency	(105)
Northwestern University, USA	(98)	Hewlett-Packard, USA	(22)	Nat. Inst. of Info. and Com. Tech., Japan	(73)
University of Maryland, USA	(90)	IBM, USA	(22)	Nat. Inst. of Metrological Res., Italy	(61)
Harvard University, USA	(81)	Symmetricom, USA	(18)	Fraunhofer Institute, Germany	(54)
Stanford University, USA	(70)	Pranalytica, Inc., USA	(14)	Nat. Metrology Inst. of Germany	(51)
University of Hanover, Germany	(66)	Princeton Lightwave, USA	(14)	Nat. Inst. of Adv. Indust. Sci & Tech., Japan	(46)

Key Players & World Leaders

- Leading defence companies:

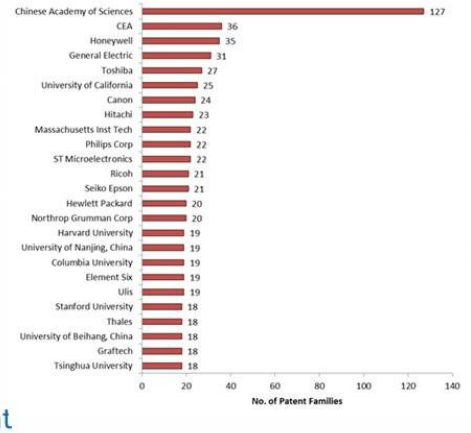
-Thales, France
-Raytheon US
-Symmetricon/Microsemi
-AOSense

- Leading Military Labs:

US ARL, NRL, AFRL, SNWSC, China

- Patents and their owners:

Chinese institutes with a significant number of patents



Key Players & World Leaders: GoC/DRDC SMEs

- DRDC Atlantic : Magnetometry, acoustic sensing
- DRDC Ottawa: active and passive microwave sensing, signal processing, multi-sensor data fusion
- DRDC Suffield : chemical sensing, GPR, nuclear
- DRDC Valcartier: lidar, hyperspectral, IR, information fusion
- NRC: Quantum photonics for sensing, fibre Bragg grating, femtosecond/attosecond, nanomaterials, nanotechnologies, atomic clocks

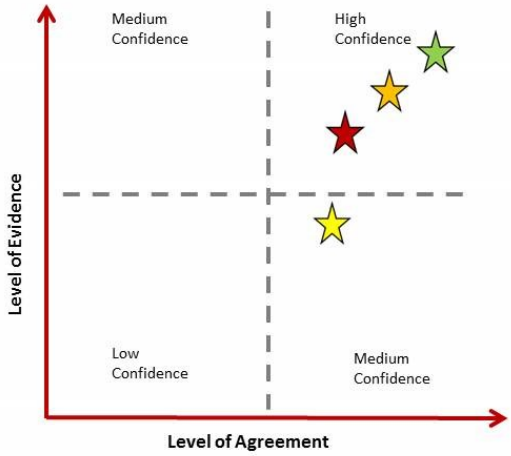
Related Policies (Canadian & foreign), Doctrine / TTPs

Policies	Country	Doctrine, TTPs

Many nation-states definitely have strong interest in quantum technologies
NSA: move to quantum-safe cryptography
Israel: strong quantum S&T group (IMOD)---used operationally
UK: strong activity on quantum S&T in recent times

Level of Agreement in the Scientific Community

- Quantum Computing
- Quantum Communication
- Quantum Sensing
- Quantum Materials



Final Remarks

- Translating fundamental science is **multi-disciplinary and very hard**, and *all stakeholders (Army, DRDC, academia/GDs, industry) must be involved as often as possible (see UK report)*
- However, **pace of disruption now much faster** than before---globalization, no complacency
- Disruptive advances **not just a matter of big budgets**---small talented, highly motivated teams can accomplish much more (Stanley 2005, Saab's "super-stealth" sub, Grippen vs F-35 data fusion)
- Quantum science (and much of technology) is unclassified and dual-use---**can't afford to fall behind**

References

- *Quantum Sensing: A Scientometric Study, NRC Nov 2015*
- *UK Quantum Technology Landscape 2014*
- *Quantum Safe Cryptography and Security June 2015, European Telecommunication Standards Institute*
- *A Roadmap for quantum technologies in the UK, Oct 2015*
- *National Strategy for quantum technologies, UK, Oct 2015*

Impact Assessment against Army Hard Problems

	Army Hard Problem	Impact 0-5 (0 = lowest, 5 = highest)	Comments
1.	Soldier Burden	3	-Reduction in electronic weight burden -Autonomy aides valuable (better with quantum sensors/materials)
2.	Soldier Resiliency	3	Improved strength/weight ratio
3.	Soldier Protection	3-4	Improved strength/weight ratio.
4.	Cognitive Overload	4	- Improved sensors will improve situational awareness - Bigger gains if combined with multi-sensor fusion algorithms
5.	Vehicle Engineering	3-4	- Current and new materials will play an important role in vehicle engineering (HF, exisiting technologies), Automomous vehicles, quantum materials for improved vehicle body
6.	Manoeuvre over Distance	3-4	-Improve operations in complex environments
7.	Explosive Hazard Avoidance	4-5	-Increased precision in existing and new quantum sensors - Leverage DRDC-V and DRDC-S expertise in existing technologies
8.	The Network	4	-Quantum secure communications for ultimate security
9.	Managed Readiness	3	-Quantum S&T a very important part of technology watch
10.	Power and Energy	3-4	-Quantum S&T a key part towards US Army Net Zero (energy, water, waste) installations

Annex C Human performance optimization outlook brief

Defence Research and Development Canada | Recherche et développement pour la défense Canada

Human Performance Optimization

Keith Niall & Max Michaud-Shields

Outlook Brief
Emerging Technology Impact Assessment Workshop
Nov. 30 – Dec 4, 2015

DRDC | RDDC

Canada

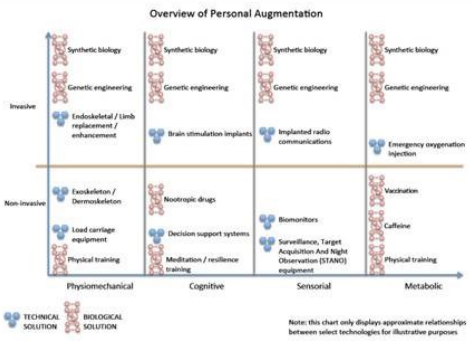
- With thanks to Erica Wiseman of NRC
- Incorporating some marked 2014 material from EDT presentation by Michel DuCharme and Len Goodman

Outline

- What is the technology? (This year and last year)
- Why Human Performance Optimization (HPO) ?
- Metagroups / Topics of interest / Specific domains
- Barriers and Tipping Points
- Potential Defence & Security Implications/Applications related to the Army
- The Big Picture
- Strengths, Weaknesses, Opportunities, Threats (SWOT) Analysis
- Key Players & Leaders
- Canadian universities / collaborations / international collaboration
- S&T Trends/Future Directions
- Assessment against Army Hard Problems

What is the Technology ?

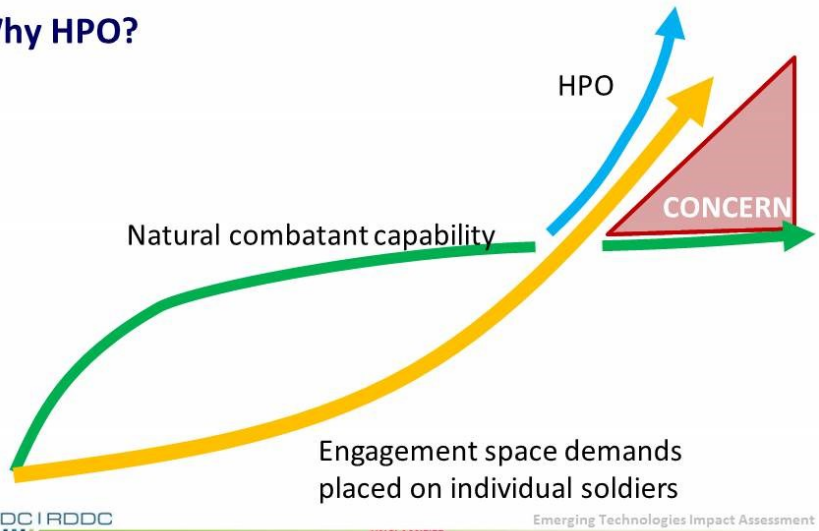
- *Overview of the technology*
  - *Human Performance Optimization is an intervention introduced onto or into the body designed to improve performance, appearance, or capability besides what is necessary to achieve, sustain or restore health (cf. Juengst, 1998)*
  - *Major subdomains: Physiological, ethical, computation and cognition, automation / robotics and telepresence*
  - *Drivers: Sports performance, Biohacking, corporate security, or big data*
    Military pressures: Dispersed ops, networks, battlefield robotics and automation, threat forces embracing disruptive tech



Definition & Introduction (DuCharme & Goodman, 2014)

- Human Performance Modification (HPM) are technologies that enhance or degrade human performance and are intrinsic to, or interact with/worn/carried on the body.
- HPM involves several categories of science and technology (materials, medicine, genetics, cellular biology, nanotechnology, social and cognitive sciences) that when integrated, may enhance or degrade the performance, health and protection of the human in the battlefield.
- HPM is the subject of active research in all regions of the world and is not limited to developed countries.
- The potential for crossover applications is high.

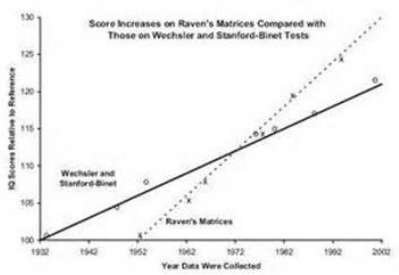
Why HPO?



Huge improvement is possible, and happening anyways

Intelligence as measured by IQ (intelligence quotient)

- Flynn Effect is happening already, has since 1930s
- Largest effect of IQ change in literature
- Lots of conflicting theories (Will it continue ?)
- Progressively smarter



Metagroups (Canadian publications, last 10 years)

Metagroup	No. of Publications	Scope Notes
Ethics	235	Topics relate to the ethical issues regarding human optimization. Some topics expand our conceptual range to tools of human optimization that have only been promised as of yet.
Physiological Issues	228	Topics relate to performance enhancements through physiological changes to the body, through activities, drugs, physiological monitoring or modifications of human tissue
Computational/ Cognitive Issues	205	Topics relate to cognitive enhancement as a computational issue, through technological support. These include, but are not limited to, computational aids to cognition such as enhanced mapping and location tools, logic engines, computation by social networking, and sensory enhancement.
Automation/ Robotics	153	Topics relate to the use of robots, devices and teleoperation to enhance human capabilities. These enable human operators to sense and act at indefinite distances. Such systems are often, but not necessarily zoomorphic or anthropomorphic. The goal may be to control many systems at once, as in a swarm.

Topics of Interest

Computational/Cognitive Issues	Physiological Issues	Automation/Robotics	Ethical issues
• Ubiquitous pervasive computing (ubicomp) • Low-power computing • Augmented reality • Neuromorphic computing • Position, navigation, and timing • Enhanced vision • Visualization of large information databases • Exobyte computing • Cultural Aids/ Automated machine translation	• Sleep-wake cycle • Circadian adjustment • Ergogenic aids • Countermeasure chemical, biological, radiological and toxic industrial material (TIM) agents • Gait efficiency and energy • Load carriage and soldiers • Load assistance • Exoskeleton and human • Human Behavior Patterns • Self-Decontamination Aids • Physiological enhancement/adaptation for extreme environments • Physical avatars • Brain/neuronal computer interface (BNCI) approaches for human optimization	• Robotics and telepresence • Telepresence and latency • Telepresence and remote • Effectors and telerobotics • Live virtual constructive and simulation • Wearable/Implanted Intelligent Sensors • Smart Armor • Smart Personal Intelligent Assistant (SIRI-like agent) • On-board facial recognition • On-board microclimate management • Wound sensing • Antimicrobial nanofibers for clothing	• Cultural lexicon • Serious gaming and training • Trust and autonomous systems • Autonomous systems and responsibility • Autonomous systems and Privacy • Social acceptance and legal considerations for human optimization

NRC·CNRC

Sub-Domain: Physiology

Physiology	Current TRL	TRL 2020	TRL 2025	TRL 2030
Exoskeletons and dermoskeletons	7	8	9	9
Energy harvesting	6	8	9	9
Genetic Engineering	2	3	4	5
Endurance modifiers	1	3	5	7

DuCharme & Goodman (2014) on body functions
Enhanced senses and protection

- **Barriers:**
  - Reliability of the technology in harsh environments is limited. Our understanding at the molecular level of the complex interaction, integration and interpretation of the various sense signals is poor. Development of new material meeting all requirements (protection level, weight, bulkiness, stiffness, breathability) for the protection of soldiers is slow.
  - Very high performance materials that are billed to be game changers often suffer from 1 or more properties that make their use in soldier systems impractical (e.g. degraded performance after getting wet, abrasion resistance, resistance to rough handling).
  - Effective integration requires extensive research which in turn can only be affordable and timely given sufficient supply of the base material to support multiple investigations and allow industry to take on board the challenges of manufacturability at an industrial scale.
- **Opportunities:** Leveraging the S&T effort from the health industry in the development of hearing and visual aids.

Sub-Domain: Computation and Cognition

Computation and cognition	Current TRL	TRL 2020	TRL 2025	TRL 2030
Mass data visualization	4	6	7	9
Decision support systems	4	6	7	9
Cognitive enhancement drugs	2	3	4	6
Brain computer implants	1	2	3	4

DuCharme & Goodman (2014) on Brain functions & interfaces

Augmented cognition and reality (AR)

- **Definition:** Technologies that can increase or complement cognitive functions such as alertness, attention, learning, memory, judgement and sense-making.
- **Examples:**
  - Computer system detecting anxiety from speech and facial expression.
  - Predisposition indicators: enzyme expression and genetic markers in blood that can detect predisposition to anxiety disorders and mental health; iris patterns are indicative of anxiety.
  - Neuronal and genetic manipulation can lead to therapy for stress resistance, anxiety and PTSD.
  - Modification of behavior with drugs: enhance trust with oxytocin.
  - Sound-induced affective state changes
  - Emotional self-regulation training techniques to reduce anxiety, stress and improve the decision making process.
  - Use of social media and social engineering to deceive, alter trust and change behavior.
- **Barriers:**
  - Robust scientific evidence is sometimes missing and the underlying physiological mechanisms not well understood. Better understanding at the neural level will be the tipping point for the development of effective technologies. Better understanding of the risk factors for cognitive decline and neurodegeneration are required to improve its management.
  - Long term side effect of the technologies on general health, quality of life, judgement/decision making and psychotic behaviour are not known.
  - Interdisciplinary approach is essential for exploiting the potential of the technology.
  - Power (doubling every 5 years) and information processing demands (doubling every 2 years) unsustainable for AR.
- **Opportunities:** Many neuro-pharmaceuticals also combat fatigue. This technology can work in synergy with Intelligent Adaptive Interfaces (IAIs) to increase cognitive capacities.

Sub-Domain: Robotics and telepresence

Robotics and telepresence	Current TRL	TRL 2020	TRL 2025	TRL 2030
Complete remote bio-monitoring	4	6	7	9
Sensory enhancement, substitution	2	3	5	6
Implanted communications	1	1	3	5
Augmented Reality interfaces	4	6	9	9

DuCharme & Goodman (2014) on Social functions
Social media, computing and engineering

- **Definition**: Social network and social technologies used to gather information and change individual and social intelligence, behavior and decision-making.
- **Examples**:
  - Crowd sourcing to solve complex problem or locate an offender
  - Social media intervention to accelerate behavior change in a community, change collective intelligence, opinion and behavior.
  - Use Apps to monitor individual behavior; use of network to monitor crowd or population behavior
  - Use of Twitter for early warning of danger
  - Use of social media to conduct an influence operation
  - Collective intelligence and cognition can be harnessed using decision support and computing (conventional and social) system to solve problems beyond our current individual capacity.
- **Barriers**: Ethical issues and regulation could limit the use of some technologies.
- **Opportunities**: Can build from the experience of other nations.

Barriers and Tipping Points (STEEP +LD Method)

Dimension	Barriers	Tipping Points
Social (ethical, moral, etc.)	Concepts of privacy, human rights, and dignity	Social and demographic forces may rapidly lead to transition to acceptability of invasive mechanisms
Technological	- Understanding of genetic and epigenetic effects - Tissue and organ rejection - Compact and light power sources - Detailed understanding of the human brain	- Genomic studies underway - Medical research underway - Marching towards singularity - Power sources lagging

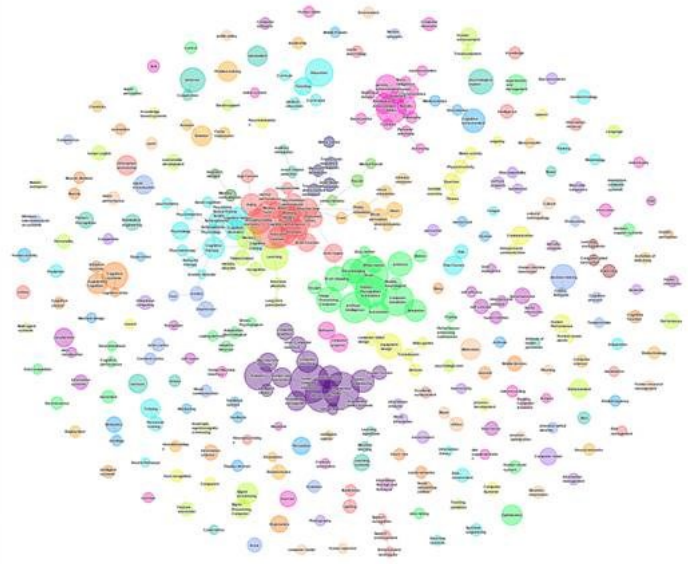
Barriers and Tipping Points (STEEP +LD Method)

Dimension	Barriers	Tipping Points
Economical	- High initial cost of entry - Investment into individual soldier could represent prohibitive costs or lead to force reductions	- Open source and additive manufacturing make some tech attainable by the individual - Widespread commercial adoption
Environmental	- High tech remains challenged by soldier demands: ruggedness, reliability…	- Nanotech and additive manufacturing may allow novel engineering
Political	- Sensitivity to perceived weaponization of individuals	- Cultural shifts associated with demographic change
Legal	- Selection or enhancement and civil rights - Explicit barriers to some forms of invasive procedures	- Response to first use in any scenario
Defence	- Warrior culture - PY costs and force structure - Support mechanisms / logistics	- Public opinion and HPO

Potential Defence and Security Implications/Applications as Related to the Army

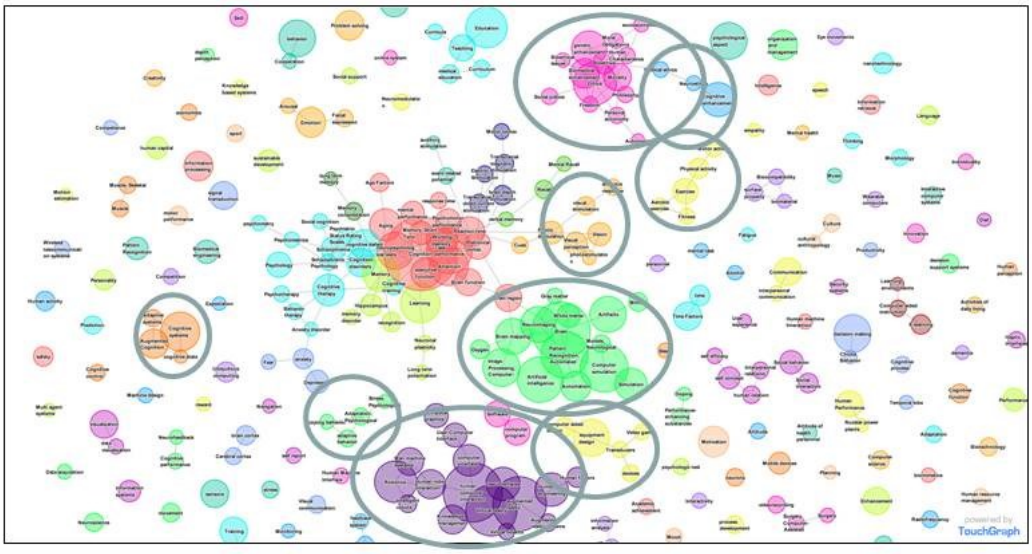
- Potential for paradigm shift in soldier capability development
- Impacts on soldier demographics and recruitment
  - Possible improvements to soldier longevity
  - Policy considerations for invasive procedures
  - Recruitment: what to do with those who are already optimized? Is optimization a voluntary or mandatory procedure?
- Security impacts in terms of asymmetric access and novel employment
- Detainee handling
- Optimized Soldier integration with Canadian society during and after service

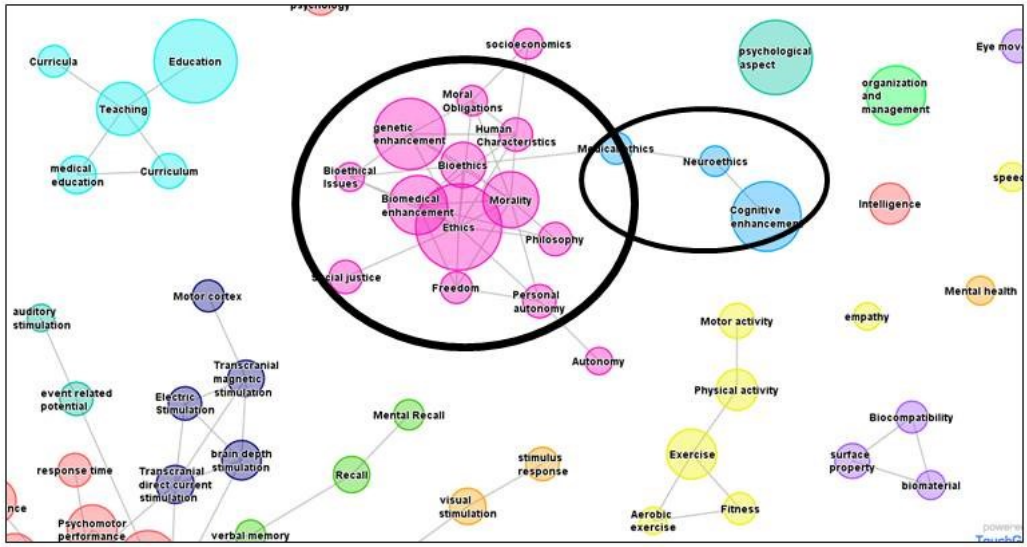
The big picture: an informal SCOPUS search *(last 10 yr.)*



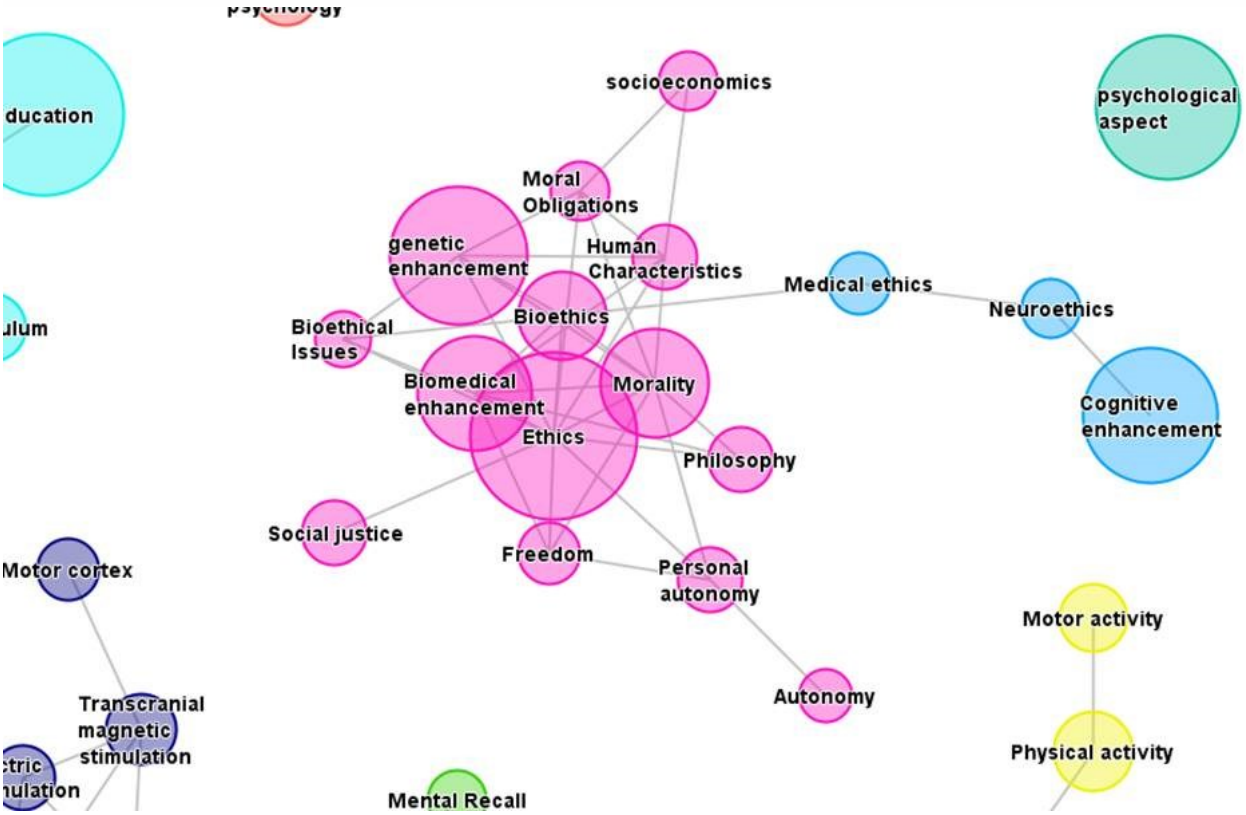
Scopus covers PubMed and Medline, IEEE Explore, Science Direct

A closer look reveals some clusters





Some connected clusters begin to look familiar

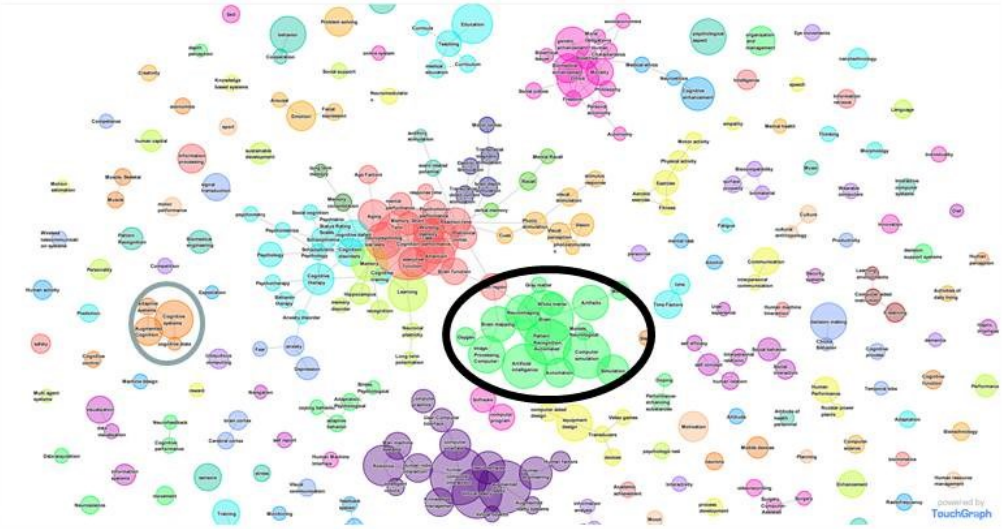


Vision: We will achieve significant advances in human optimization, in four directions:

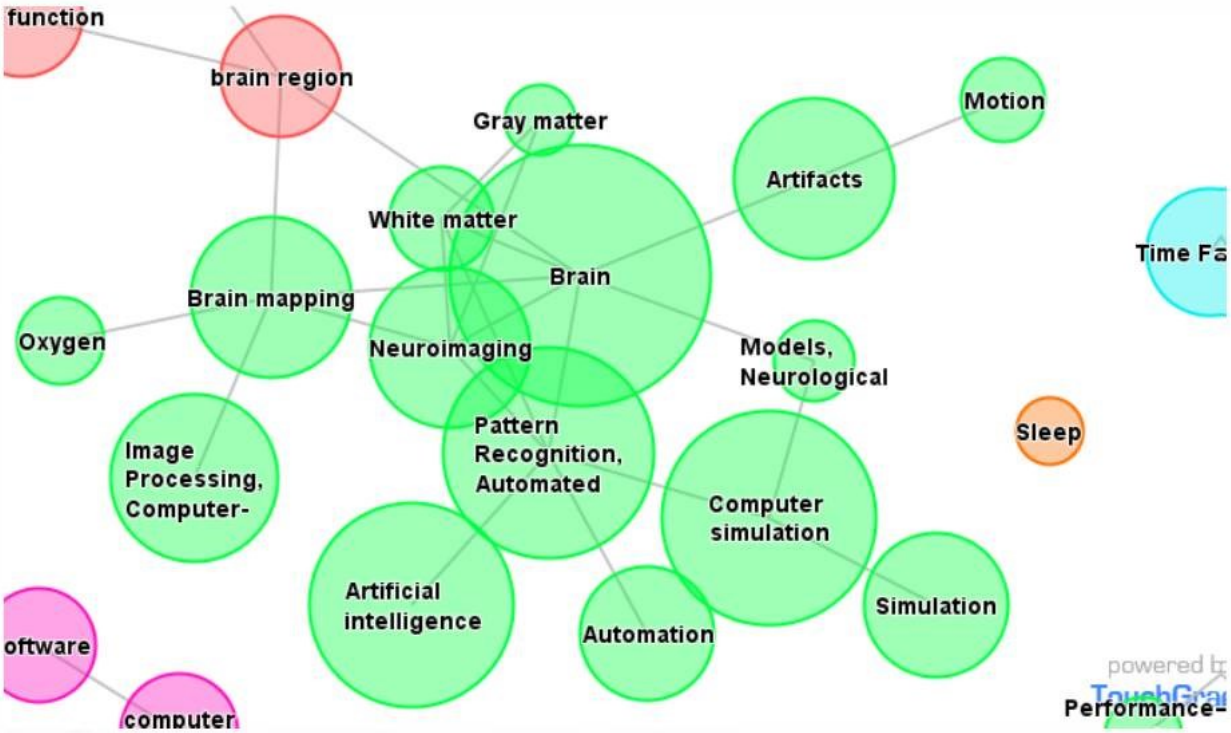
1. cognitive optimization as a computational issue;
2. performance optimization as a physiological issue;
3. human optimization as an issue of automation, robotics & telepresence;

Ethics, meaning among other things the bioethics of performance optimization and the ethics of autonomous systems.

Other interesting clusters can be seen



DRDC | RDDC Emerging Technologies Impact Assessment



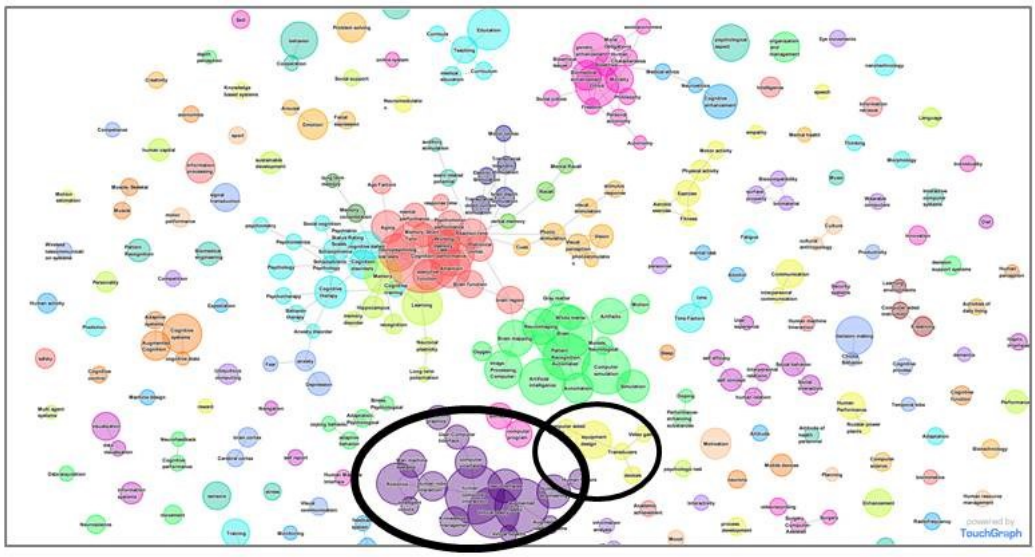
Vision: We will achieve significant advances in human optimization, in four directions:

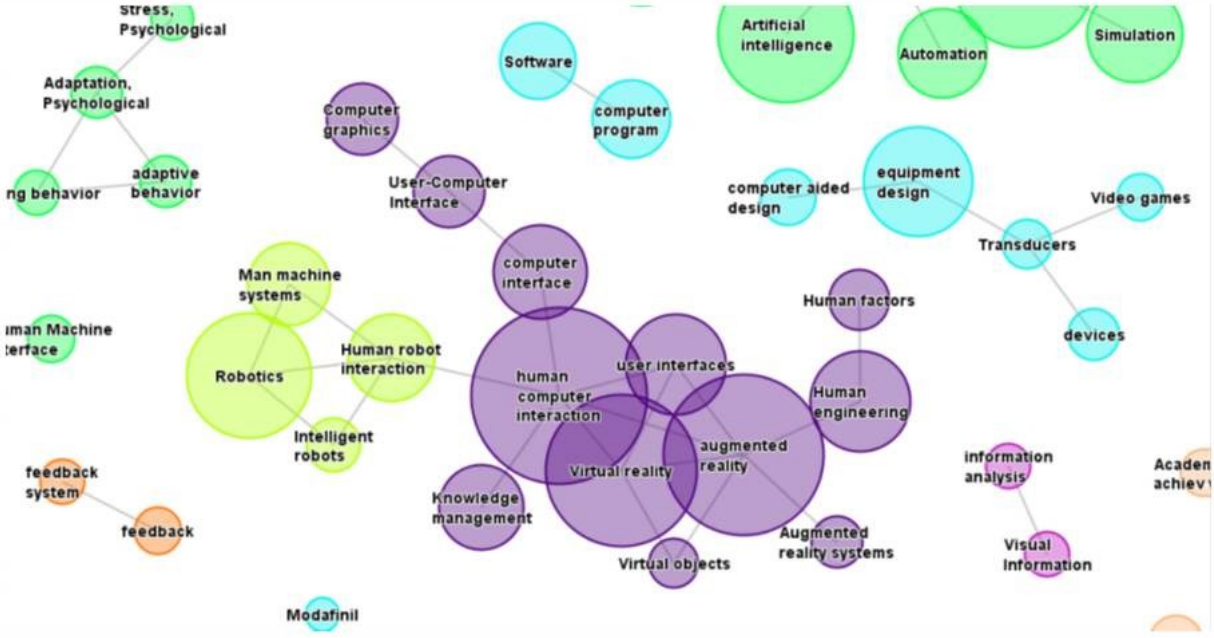
Cognitive optimization as a computational issue;

2. performance optimization as a physiological issue;

3. human optimization as an issue of automation, robotics & telepresence;

4. ethics, meaning among other things the bioethics of performance optimization and the ethics of autonomous systems.




Stress, Psychological
Adaptation, Psychological
ng behavior
adaptive behavior
Software
computer program
Computer graphics
User-Computer Interface
Artificial intelligence
Automation
Simulation
computer aided design
equipment design
Video games
Transducers
devices
computer interface
Man machine systems
iman Machine terface
Robotics
Human robot interaction
Intelligent robots
human computer interaction
user interfaces
Human factors
Human engineering
augmented reality
Virtual reality
information analysis
feedback system
feedback
Knowledge management
Augmented reality systems
Virtual objects
Visual information
Modafinil

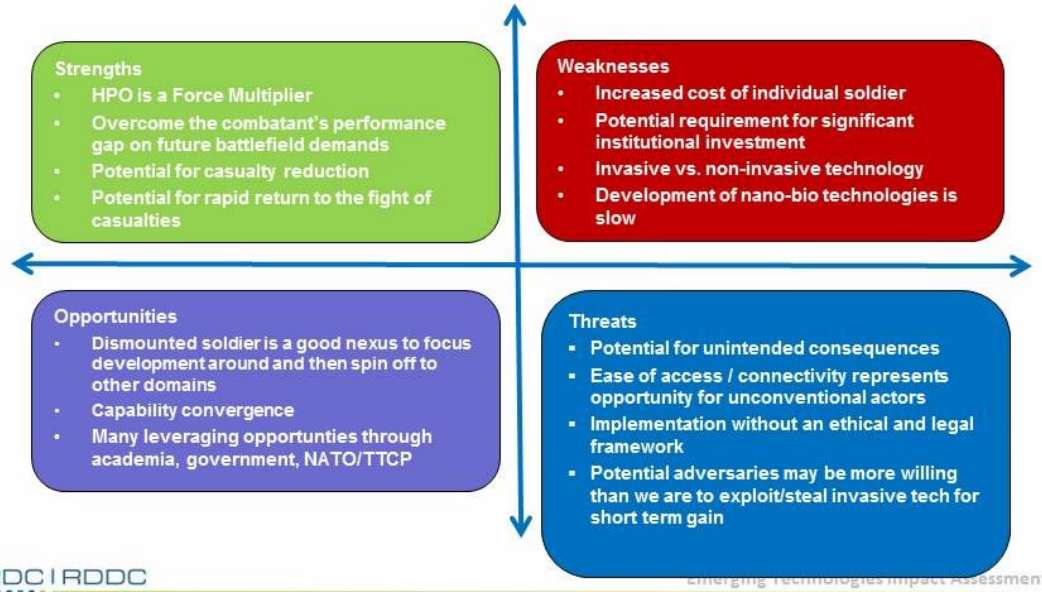
Vision: We will achieve significant advances in human optimization, in four directions:

1. cognitive optimization as a computational issue;
2. performance optimization as a physiological issue;

Human optimization as an issue of automation, robotics & telepresence;

4. ethics, meaning among other things the bioethics of performance optimization and the ethics of autonomous systems.

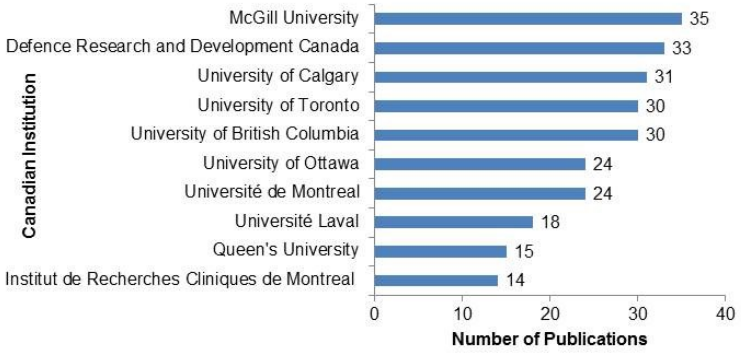
Strengths, Weaknesses, Opportunities, Threats (SWOT) Analysis



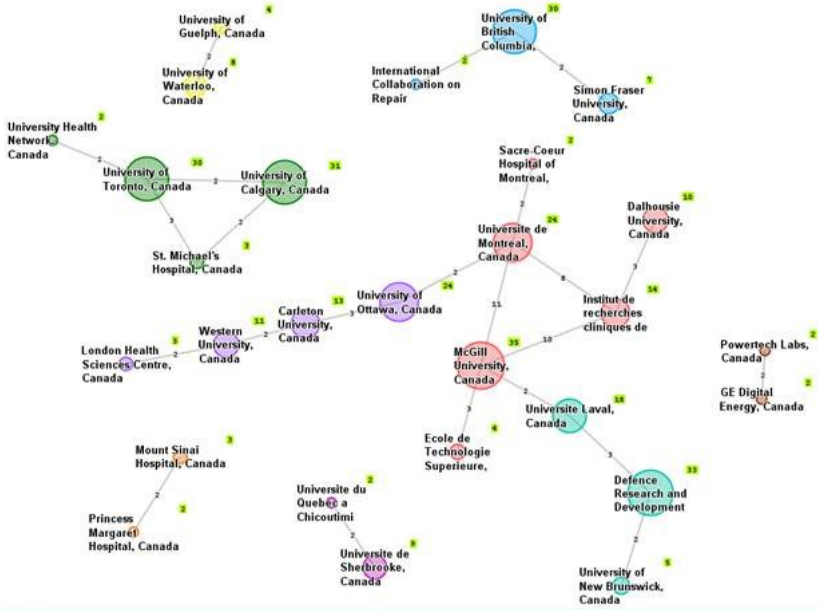
Key Players, Leaders

- Leading countries:
  US, UK, France, Russia, China, (Canada)
- Research Organizations:
  US Natick, TNO, Fraunhofer, Dstl, US AFRL, USSOCOM
- Leading companies:
  Raytheon, Siemens, Honeywell, Apple, Cyberdyne

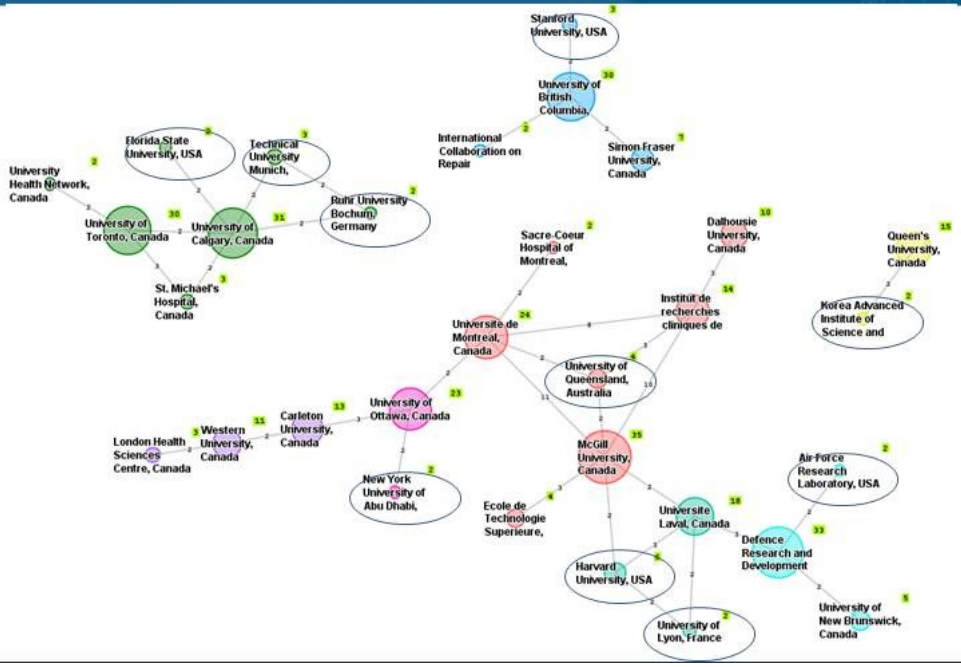
Top Canadian Affiliations



Top Canadian Collaborations



International Collaborations



S&T Trends/Future Directions

- Remote operations (automation, telepresence, robotics)
- Demonstration of metabolic advantage of exoskeletons
- Hand-held everything
- Sensory enhancement and sensory substitution
- Open source communities a major disruptive dynamic
- Combination of processes to achieve novel synergistic effects

Byword: Skillful means for the purpose of human optimization

Impact Assessment against Army Hard Problems

	Army Hard Problem	Impact	Comments
1.	Soldier Burden	****	Exoskeletons, metabolic optimization, systems integration
2.	Soldier Resiliency	***	Metabolic optimization, systems integration, lightening of cognitive burden and information processing
3.	Soldier Protection	***	Systems integration, improved situational awareness, novel senses
4.	Cognitive Overload	****	Tailored data visualization, novel interfaces, augmented reality, decision support systems
5.	Vehicle Engineering	*	Soldier system integration for vehicle interface (controls, data, power)
6.	Manoeuvre over Distance	***	Exoskeletons, load carriage assistance, wayfinding
7.	Explosive Hazard Avoidance	**	Novel senses, augmented reality, improved man-machine interfaces, social mind
8.	The Network	***	Visualization, novel interfaces
9.	Managed Readiness	***	Injury reduction, improved training efficiency
10.	Power and Energy		Converged systems, integration of protection and power, low-power computing

Human Performance Optimization

1. HPO will be here very soon.
2. Dreaming about science fiction is not research.
3. HPO comes in four flavors.
4. There are many HPO means to any goal.
5. HPO may look scary, but early adoption will change attitudes.
6. The best HPO can be found in the universities right now.
7. We should have this first (or other people will).

Annex D Canadian Army Hard Problems (2015)

The Canadian Army and DRDC jointly maintain a list of Hard Problems for the Army. Hard Problems are enduring by nature and require innovative S&T solutions. How could specific emerging technologies address some of the Army's enduring problems? Those Hard Problems are presented in the following sections. The next EDT impact assessment workshop with the Canadian Army will investigate the use this set of Hard Problems to assess potential solutions or innovations that emerging technologies could deliver.

Hard Problem #1—Power and Energy

The vast majority of logistics support goes to the provision of energy in the form of liquid fossil fuels. With limited foreseeable increase in world supply, and rising demand and rising cost, camp, mobile and vehicle power generation is at grave risk. Reduction in demand for operations and training is essential in order to keep the logistics effort supportable and alternative sources of power and energy must be made viable so that affordable supply is not threatened.

What are the S&T solutions to sustainable (reduction of petroleum use by 5% per year) and economical (no increase in cost) supplies of power and energy in support of Canada's Army?

Hard Problem #2—Vehicle Engineering

Land combat vehicle design—based on purpose—must strike a balance between mobility, firepower, protection, digitization and human factors. These design considerations must also contend with the needs of affordability, sustainability, future upgrades (increases in weight and capability), maintainability, deployability, commonality, standardization, tactical adaptability after deployment, training in all environments, autonomy and resilience to network attack.

What are the S&T solutions to significantly increased performance (25% better availability rates for operations and training) with no increase in overall cost to maintaining and sustaining the fleet?

Hard Problem #3—Soldier Burden

Soldiers conducting dismounted operations are severely constrained in terms of range, speed and endurance by the amount of additional weight they routinely carry in the form of personal protective equipment, water & food, weapons & ammunition, electronic devices and batteries. This is a significant liability to sustained mission success.

What are the S&T solutions to assist in overcoming the limitations of soldier burden imposed by the demands of the future operating environment?

Hard Problem #4—Soldier Resilience

Soldiers are exposed to increased risk of death or injury (both physical and psychological) during operations and training. This has a serious impact on readiness and sustainability of the force, and more importantly, there is a moral obligation to provide due care and attention to the protection and welfare of soldiers.

What are the S&T solutions to promote increasing resilience in soldiers with the goal of reducing casualties by 25% in comparable operational situations, and returning casualties to health 50% faster?

Hard Problem #5—Soldier Protection

The contemporary operating environment can be volatile, unstable, complex, uncertain or ambiguous—in short, dangerous. There are fewer safe areas in the battle space, and those intending harm to soldiers have rapidly increasing capability to do so and are seemingly less constrained in how they go about it.

What are the S&T solutions to provide individual soldiers, and forces in general, with the protection necessary in the future operating environment to increase survivability rates, in the short-to-mid-term, by 50%, with no detrimental effect on performance?

Hard Problem #6—Cognitive Overload

Soldiers and commanders are sometimes overburdened by the mental demands of the contemporary operating environment. There is an increasing proliferation of information in the contemporary battle space without a commensurate increase in the available visualization & analysis tools, and the individual and team preparation, required to deal with the speed & complexity of information flows.

What are the S&T solutions—in particular, network and autonomy—to reducing the cognitive demands in the future operating environment, specifically with respect to effective decision-making and planning?

Hard Problem #7—The Network

Commanders and soldiers lack sufficient timely situational awareness to understand where their assets are, who and where the enemy is, and who and where non-combatants are, and adequate means to communicate this information to each other.

What are the S&T solutions to provide an integrated network capable of the necessary—and autonomous—data collection, analysis, management and use in support of decision-making and command & control of assets (including logistics) in the future operating environment? What are the appropriate tactical level assets for operating in the cyber domain?

Hard Problem #8—Manoeuvre over Distance

In order to fully realize the concept of Adaptive Dispersed Operations manoeuvre forces will need to continually improve their range and operating endurance—and capabilities down to lower levels—in the conduct of tactical activities. This means increased speed & mobility, self-sufficiency, access to fires (including precise and scalable fires), C4ISR resources, more responsive medical and logistical support (including autonomous systems), more capable junior leaders, and the strategic resources to deploy to the theatre in the first place.

What are the S&T solutions to help achieve dominance in more expanded battle spaces of the future operating environment (e.g. dispersion and aggregation; cyber space)?

Hard Problem #9—Explosive Hazard Avoidance

The threat posed by improvised explosive devices and mines, unexploded ordnance and booby traps containing explosives (explosive hazards) has been, and is likely to remain very high.

What are the S&T solutions to permit unhindered mounted and dismounted advance in the face of explosive hazards?

Hard Problem #10—Managed Readiness

The Army is an immensely complex organization that generates and sustains a required output of forces for employment on operations. It is extremely difficult to manage all aspects of the institutional structures in support of the managed readiness cycle. Better simulation tools are required.

What are the S&T solutions to more predictable, effective and efficient management of the force structures so that the availability rates for force outputs remains above 97% within the Lead Mounting Area framework?