Findings of the Advanced Research Workshop

As reported in previous chapters, the "Advanced Research Workshop on Explosives Detection" (the Workshop) represented an important gathering of scientists, engineers, policy-makers, and administrators working within the framework of the NATO Science for Peace and Security (SPS) Programme. The three pillars of SPS are Science, Partnership, and Security, and this workshop thoroughly embodied all three in ways that will be discussed in this chapter. However, participants also identified avenues to strengthen these pillars – especially in Partnership – and we reserve discussion of this pillar for last.

Multidisciplinary Approach

One of the findings of the workshop was the multidisciplinary and cross-cutting approach inherent in all the projects presented at the workshop. It is worth noting the range of scientific disciplines represented (physics, chemistry, biology, geoscience, computer science, mathematics, etc.), as well as many fields of engineering (electrical/electronic, mechanical, informatic, communications, robotic, etc.). In many projects, practitioners from diverse disciplines collaborated closely – foreshadowing the coming discussion of partnership.

Threat Diversity

The science and technologies described in this volume cover a necessarily wide range of application modes and environments. The explosives in the title of the workshop could represent landmines, UXO, and other explosive remnants of war (ERW) in post-conflict regions. Alternatively, they could be improvised explosive

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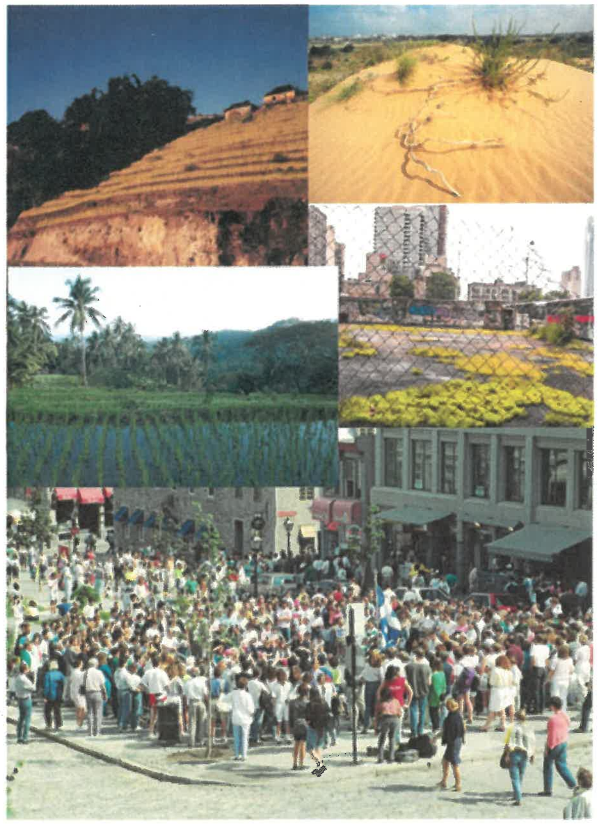

Fig. 1 Impressions of a variety of possible settings for detection of explosive devices. (All photos public domain)

devices (IEDs) deployed in active war zones, former war zones, or non-conflict areas subject to terroristic attack. Furthermore, IEDs might be stationary or moving. A stationary IED might be similar to a landmine or other ERW, while a moving IED is very different – deployed as a car bomb, in a suitcase, or as an explosive vest, shoe, or any disguising article. The possibilities are limited only by the malicious imagination of the attacker. Furthermore, in all of these modes of deployment, the environment may be different. ERW-type threats could be buried in sand- versus clay-rich soils, in dry or wet climate, on a flat plain or a mountainside, and in an open farm field or a narrow city street (see, e.g., Fig. 1) Mobile explosive threats might have different speeds and movement patterns, and be delivered by a human or vehicle, but for maximum effect will probably threaten crowded places like busy city streets, festivals, concerts, transportation terminals, etc.

Even a brief consideration of possible explosive threats suggests a minimum of about 10 environmental and operational variables, with end-members as follows (with continuous spectra between of course) (Table 1):

Table 1 End-Members of 10 possible variables for explosive threat detection

End-Member 1	End-Member 2
Stationary Explosive Device	Fast-Moving Mobile Device
Peaceful Area	Active Conflict Zone
Affluent Region	Impoverished Region
Undeveloped Setting	Urban Setting
Easy Access to Power and Communications	Remote and Isolated
Arid Climate	Wet Climate
Flat Terrain	Rugged Terrain
Granular Soils	Cohesive Clay Soils
Uniform Particle Size	Long-Graded Aggregate
Dominantly Fine	Dominantly Cobbles

The reader may immediately think of others and may realize that some of these are probably not entirely independent. However, this simply reinforces the incredible range of conditions under which detection of explosive threats must be undertaken. Figure 1 depicts just a few possible settings.

This range of variables drives the need for the range of technologies, and therefore the range of science and engineering disciplines required for a comprehensive global program of threat reduction and security enhancement. A single technology or system, or even a single set of systems, is likely to be applicable to no more than a few particular threats in rather specific combinations of settings.

Partnerships

Of course, the need for a wide variety of technologies to provide global security, and their coordinated development and deployment, will require many levels of partnership. Projects represented at the Workshop displayed excellent internal partnerships – between people of different nationalities, different levels of age, experience, and education (older PhDs working with young undergraduate students), different genders/identities (male, female, and non-binary team members) to name a few. Partnership between project teams already exists at some levels, and will be increased by the connections made at the Workshop. Several formal discussion sessions, as well as social events, provided a forum for the exchange of ideas, recognition of natural synergies, and the exchange of contact details both for continued correspondence and collaboration and for new collaborative opportunities.

Recommendations

Based on the need for multiple combinations of technologies to address the global explosive threat, Workshop participants identified and discussed several desired manifestations and opportunities for enhancing partnership. These include:

1. *Modularity*: this would allow rapid integration of sensors/systems to address specific sets of threat conditions. This will require standardization*:*
   1.1. *Standardization* of
      1.1.1. *Connectors*
      1.1.2. *Communications Protocols*
      1.1.3. *Data Formats*
2. *Centralized Data Storage*: Easy access to data generated by various project teams would allow*:*
   2.1. *Replication of Results*: This is a critical component of the Science pillar.
   2.2. *System Testing and Validation*: Comparison of the performance of new systems with existing ones can demonstrate that projects are truly enhancing the Security pillar.
   2.3. *AI Learning Data*: Artificial Intelligence/Machine Learning (AI/ML) is a fast-emerging, powerful method for rapid, high-speed target detection – and more importantly, discrimination (e.g., between threats and innocuous objects). However, development of effective intelligent systems (with necessarily very high probability of detection and low false alarm rate) requires a tremendous number of training images or datasets – probably far too many for a single research group, or even a consortium of institutions, to compile. Compilation of a global repository of shared training datasets is a great opportunity for partnership.
3. *Capacity Building*: Although great progress in demining and addressing IEDs has been realized in recent years,[1] the problem remains geographically widespread, and locally intense. There are multiple countries and territories with hundreds of IED incidents per year,[2] and hundreds of square kilometers of potentially mined land[1]. Meaningful threat reduction/security enhancement will require scale-up and distribution of the experimental, emerging, and/or new technologies. This will surely require partnership between research groups, governments, and NGOs – which can be facilitated, or simply made possible, only with NATO SPS support.

We note a final point under partnership. One aspect of enhancing security in the face of explosive threats was mentioned briefly by at least two presenters at the Workshop; they indicated that their organizations/teams certainly work on detecting explosive threats, but also on detecting and disrupting the people and networks that train and support those who would build and deploy those threats. This is an important point, and one that is not often stated explicitly: *Detecting already-*

[1]International Campaign to Ban Landmines (2018) Landmine & Cluster Munition Monitor – 2018, ICBL, Geneva.

[2]Overton, I., Dathan, J., Winter, C., Whittaker, J., Davies, R. & Kaaman, H. (2017) Improvised Explosive Device (IED) Monitor – 2017, Action on Armed Violence (AOAV), London.

deployed mines, IEDs, or moving explosive vectors is the last line of defense against catastrophic events. In this section, we imagine stopping a catastrophe by detecting an explosive device at the last line of defense (a near-miss in the language of safety and forensic engineering), and then applying a "5-Whys"[3] Root Cause Determination of the type commonly applied in product failure analysis and safety incident (or, in this case, near-miss) debriefs.[4] After detecting, responding to, and neutralizing the threat, the root cause determination could start at different points or focus on different failures; e.g., "how did this device get through previous levels of security screening?", or "why didn't the AI target identifier recognize this as an explosive device?"

However, if we start just with the situation, with no inference about the engineering- or systems-level failure, we may end-up with a very different and very broad root cause:

1. Q: Why is this explosive device here?

   A: Someone put it there.

2. Q: Why did they put it there?

   A: Because they wanted to harm or terrorize ______.

3. Q: Why did they want to harm or terrorize______?

   A: Because they believe that _____ has/have wronged them egregiously.

4. Q: Why do they believe that ____ has wronged them?

   A: Because _____ has something (resource, land, honor, security, privilege, etc.) that rightly belongs to them.

5. Q: Why do they feel that it rightly belongs to them?

   A: ________________________________.

There is a massive body of psychological, historical, religious, cultural, etc. literature providing Answer 5 for various peoples, at different places and times. We conclude that to achieve the highest and earliest-stage level of safety/security effectiveness on a global scale, we will need cooperation amongst the physical sciences and engineering, as well as political and social sciences. This requires a coordinating framework with global reach – a role that can only be filled by an international organization such as NATO SPS.

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[3]Ohno, T. (1988). Toyota Production System: Beyond Large-Scale Production, CRC Press, Boca Raton.

[4]Tuli, R. W., & Apostolakis, G. E. (1996). Incorporating Organizational Issues into Root-Cause Analysis. Process Safety and Environmental Protection, 74(1), 3–16.

Special Call for Proposals

According to the findings of this workshop, the NATO SPS Programme issued a special call for proposals in October 2019 in the field of explosives detection. The call encouraged long-term research in the hard sciences, as well as in social disciplines (such as political science, anthropology, sociology, psychology, etc.). Social science applications could be in the form of long-term studies, case studies with practical applications (i.e. sharing best practices, developing recommendations, identifying gaps), field studies, etc.

The SPS Programme addresses the following key priorities and areas in the field of Mine and Unexploded Ordnance Detection and Clearance:

(a) Development and provision of multi-sensor systems, new and advanced technologies, methodologies and best practice
(b) Ensuring end users are given sufficient relevant information and included in the decision-making process.
(c) Active and ongoing review of past projects to drive future works
(d) Fostering the integration of devices and methods from different project and technologies into other and future projects
(e) Data analysis
(f) Preparation for Actual Field Conditions
(g) Dissemination and Capacity Building

The findings of the Advanced Research Workshop have helped define the following areas of interest in a systematic way:

- **Multi-Sensor Systems**
  - Standardization of communications protocols
  - Development of modular sensors and other components
  - Integration of existing detection technologies
  - Testing and evaluation of the effectiveness of various combinations of sensors
  - Field procedures or algorithms for pin-pointing of targets
- **Data Analysis**
  - Advancement of post-processed detection systems to real-time results
  - Novel data fusion methods
  - Application of artificial intelligence/machine learning to explosive object identification
  - Compilation of test results and target signatures or images into a widely-accessible database
  - Identify common shapes or elements of IEDS to enhance detection and discrimination
  - Automation of threat detection and response

- **New or Rapidly Developing Technologies**
  - Development of drone-mountable systems
  - Adapt technologies for remote robotic operations
  - Identification of emerging technologies
  - Integrate systems using "smart" cyber-physical components
  - Elevate technology readiness level for existing but under-developed methods
  - Methods for search area or clearance area reduction
  - Enhance portability and field applicability of direct explosives detection technologies
- **Preparation for Actual Field Conditions**
  - Develop scalability for promising approaches
  - Develop or adapt promising lab/test bed technologies to realistic terrain
  - Organization of realistic field trials for promising technologies
- **Dissemination and Capacity Building**
  - Commercialization and distribution of well-developed technologies
  - Enhancement of communication between researchers and end-users
  - Exchange of equipment for synergistic co-development or integration
  - Exchange of young researchers