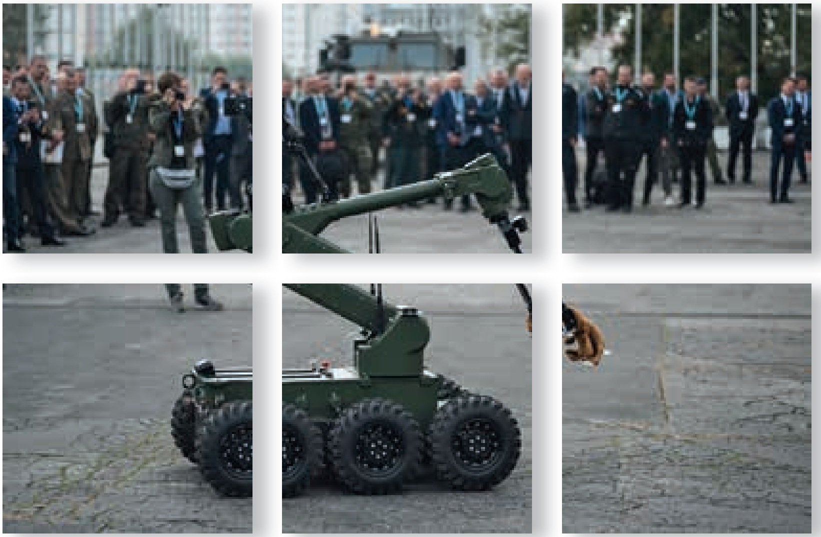
Future EOD Development in Light of the Modern Conflicts and Technological Progress

NATO EOD Demonstrations and Trials 2023
11 - 12 October 2023

A Book of Papers



NATO Centre of Excellence for Explosive Ordnance Disposal

Future EOD Development
in Light of the Modern Conflicts and Technological Progress

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The NATO Explosive Ordnance Disposal Centre of Excellence (NATO EOD COE) supports the efforts of the Alliance in the areas of training and education, information sharing, standardisation, doctrine development and concepts validation.

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A Book of Papers – *Future EOD Development in Light of the Modern Conflicts and Technological Progress* – NATO EOD Demonstrations and Trials 2023

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Preface

If future generations are to remember us more with gratitude than sorrow, we must achieve more than just the miracles of technology. We must also leave them a glimpse of the world as it was created, not just as it looked when we got through with it. - Lyndon B. Johnson - Former President of the United States of America

The words spoken out by Lyndon. B. Johnson should remind all humans that any progress made by the advancing world does not allow to harm and humiliate any living being on this planet or nature. Despite the undeniable fact, that technological progress is driven by human nature to discover the environment and explore unexplored, we shouldn't put in oblivion a fundamental tenet: technology is to save lives and defend ourselves.

EOD COE by organizing numerous NATO EOD Demonstrations and Trials (D&T) events strives to create a ground for manufacturers, end-users, scientists, and researchers not only to exchange experience but to find a common understanding of the technology's final destination.

Consequently, as science accelerates rapid technological development the D&T enterprises merge those two aspects: industry and military. In the past, the industry was dominated by military scientists who started the "arms race", notably during the Cold War. Nowadays, many of the young researchers are trying to build their own companies and sell their products globally. This has boosted significantly the competition and caused the market to be wealthy in merchandise. Each army can adjust its defensive needs and purchase the proper product effortlessly. However, some perils and traps may occur. Many of the life-saving accessories are counterfeited, without a certificate, or too brittle to be suitable for harsh military tasks.

Thus, the 7th iteration of NATO EOD Demonstrations and Trials was planned to invite reliable exhibitors with well-established positions. On the other hand, organizers dared to allow some new innovative companies to showcase their products i.e. Millson and 4Experience, to slightly crush the petrified and standardized look of the event.

In front of you there is a book of papers “Future EOD development in light of the modern conflicts and technological progress” with contributions from respected experts with their views on the latest trends and achievements from research, development and defence industry presented to a broad EOD community.

We are thrilled to announce that the goals of the event were achieved and we are already looking forward to the next iteration in 2025 for the benefit of the EOD Community of Interest (COI).

LTC Damian Piórko

NATO EOD Demonstrations and Trials 2023, Project Manager

Acknowledgement

I would like to express my sincere gratitude to you distinguished speakers, for your immense contribution to the NATO EOD Demonstrations and Trials 2023 and this publication as well.

I appreciate your willingness to sacrifice time, energy and support for this event and for sharing your insights and expertise.

May I express my sincere thanks to the previous EOD COE Director COL Robert Csaszar who started the planning process for this event. Consequently, my core team, which steadfastly and scrupulously executed the tasks was highly appreciated by the participants.

Again, many thanks to all of you for your time and effort.

COL Frantisek Mihalovic

Director, EOD COE

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Live Demonstrations Coordinator – CPT Robert Braun

Conference moderators:

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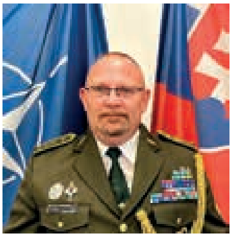
- LTC Alexander HUGYAR – Block II

Book of Papers Coordinator – Mr. Vojtech Fucek

Assisting EOD Community of Interest

Colonel František MIHALOVIČ
Director of EOD COE

Colonel František MIHALOVIČ – director of EOD COE since the 1st of September 2023, commanded the SVK National EOD and CBRN Centre for four years and was deployed to UNMEE Eritrea & Ethiopia and ISAF Afghanistan missions.



We live in challenging times when the most significant conflict since World War II is raging on the borders of the European Union and in the Middle East, Hamas terrorists are trying to destabilise the region.

As I emphasized in my speech during the Demonstration & Trials 2023, to counter terrorist threat caused by IEDs, we must constantly stimulate the technical development of procedures related to engineering technologies and constantly search for better solutions in the field of detection, neutralisation and disposal of all kinds of explosive hazards. In this day and century, it is more than necessary since EOD specialists have to deal with increasingly sophisticated IEDs, as terrorists also use modern technology to achieve their goals.

The conference we organised within D&T aimed to discuss the future development of EOD in light of modern conflicts and technological progress. Progress is still chasing this area, as well. In addition to using unmanned vehicles equipped with various sensors and cameras, artificial intelligence is also coming to the fore for the benefit of EOD specialists. Since the training of EOD specialists is highly demanding, especially financially, innovative solutions are coming in this area as well, and the main one is the use of virtual and extended reality for the training of EOD specialists. I am delighted that EOD COE has been following this progressive path in this regard and we are working together with civilian experts on the ETACS project, which is focused on the training and preparation of EOD operators using virtual reality.

Finally, I would kindly encourage readers to look for a comprehensive description of our training portfolio, focusing on learning objectives, prerequisites, conditions and other details. All useful information can be found on our website, which link is attached at the end of the article.

In conclusion, I would like to invite you for a possible contribution to our main flagship event of 2024 i.e. the 10th EOD Workshop in November. What is more, any support for the revision of NATO publications and EOD-focused terminology would be appreciated.

Last but not least, developing the ETACS project (Virtual Reality in EOD training), which is a NATO EOD training-focused undertaking, requires concise and reliable information, as a result, any cooperation with SMEs is in high demand.

More information is available on our website: https://www.eodcoe.org.

FINAL REPORT

Background

The 7th NATO EOD Demonstrations and Trials has ended. This time event was marked by the highest number of participants in its history approx. 460, which constituted 40% growth. 50 exhibitors from 17 countries occupied 64 stands, and many more were on the waiting list. Admittedly, the D&T is becoming the leading EOD/IEDD event worldwide.

In 2010 when the first iteration was brought to life, fewer believed, that the event would gain momentum to such an extent and become a desired event for exhibitors and visitors. From the beginning, the driving force to organise such a specialised event was to bring together the EOD Community of Interest (COI) and discuss the complexity of the EOD activities. 2010 was the year when the number of IEDs skyrocketed to more than 11.000 in Afghanistan. This provoked EOD COE to continue organising the D&T and become the flagship of the Centre. Since then, every second year the D&T has been organised. This process was disturbed by the pandemic, thus in 2020 the event needed to be postponed for 2021.

The extremely fast-paced technological progress demands focusing and keeping up with its development. Artificial Intelligence, distant detection by using multispectral and thermal cameras, spatial computing and the wall-to-wall presence of drones, which are slowly superseding traditional UGVs, are the imminent technological solutions to streamline tactics and procedures during and post-war times. The event organisers at the early stage of the preparation had considered these aspects and tried to pick up and invite respective companies/manufacturers before the registration opened.

The D&T23 Project Team went through numerous huddles discussing and debating the intricate process of merging the exhibition with the conference. The Team didn't pursue the idea of having the same petrified list of exhibitors as before, thus, thorough market research was performed in search of, at first glance, intriguing, but promising exhibitors. The eyes were turned to companies developing AI and XR technologies, which could significantly contribute to EOD training and combat support in the future.

The 7th iteration of the D&T was challenging for the Project Core Team since any alteration entailed budgetary strain could thwart planning and finally execution of the undertaking. Nonetheless, ever-improving cooperation with the event's venue lessor i.e. Incheba Expo Bratislava, allowed to revise the expenses causing the budget to be sufficient offering good hope for the future D&T25 organization.

Picture 1. The NATO EOD Demonstrations and Trials editions.

Static Exhibition

D&T23 delivered a platform for producers to demonstrate their best products in action. This created a unique occasion to depict the robust features of the presented equipment and attract potential clients. The experts had opportunities to check comparable equipment and exchange personal experiences from their testing in different conditions. In addition, clustered SMEs could update their knowledge about proposed disruptive technologies.

The exhibition was extended to two days to bring more opportunities for visitors and producers to tighten mutual bonds and conduct proper networking. What is more, procurement personnel/custodians had a vast opportunity to take a closer look at the industry‘s offers to their needs.

One of the event objectives was to provide a forum for equipment producers to meet with end-users to allow networking and to get direct feedback from them.

The static exhibition reflected the main idea and a leading motto of NATO EOD Demonstrations and Trials 2023.

The exhibitors presented their products based on their type:

- Detectors
- Remotely Operated Vehicles (ROVs)
- Unmanned Aerial Vehicles (UAVs)
- Devices for neutralization and disposal of hazardous materials
- Equipment for personal protection of EOD personnel
- EOD training tools including virtual reality and mixed reality

During the static exhibition, forty-six companies and other exhibitors presented valuable and high-tech equipment:

Company	Country	Web sites
3MON	SVK	https://3mon.sk/en/
4Experience Sp. z o.o.	POL	https://4experience.co/
ABP	GBR	https://www.abp-technologies.co.uk/
Alakai Defense	USA	https://www.alakaidefense.com/
Alford Technologies	GBR	https://www.explosives.net/
ATC SiPro GmbH	DEU	https://atc-sipro.de/
Brokk Security and Rescue Solutions	SWE	https://brokksrs.com/
Canadian Technology Systems	CAN	https://ctsystems.ca/
CEIA SPA	ITA	https://www.ceia.net/
Chemring Technology Solutions Ltd	GBR	https://www.chemring.com/
C-IED COE	ESP	https://www.ciedcoe.org/
Davey Bickford Defense	FRA	https://www.db-defense.com/
DeNovus GmbH	AUT	https://www.denovus.at/
DOK-ING Ltd	HRV	https://dok-ing.hr/
EOD COE	SVK	https://www.eodcoe.org/en/
Explotrain LLC	USA	https://explotrain.com/
Fenix Insight	GBR	https://www.fenix-insight.online/
GARANT Schutztechnik GmbH	DEU	https://garant-protection.com/
HCR-CTRO d.o.o.	HRV	https://www.ctro.hr/en/
HeroSight EODynamics AB	SWE	https://www.herosight.se/
ICOR Technology	CAN	https://icortechnology.com/
Inert Products LLC	USA	https://inertproducts.com/
Institut Dr. Foerster GmbH & Co. KG	DEU	https://www.foerstergroup.de/en/deu/
Intelligence-Sec	GBR	https://intelligence-sec.com/
Jakusz Sp. z o.o.	POL	https://jakusz.com/

Company	Country	Web sites
Lukasiewicz - PIAP	POL	https://piap.lukasiewicz.gov.pl/
Med-Eng	CAN	https://www.med-eng.com/
MILENG COE	DEU	https://milengcoe.org/
Milson OU	EST	https://www.milson.ee/
MS TECH Ltd.	USA	https://www.ms-technologies.com/
National Institute of Standards and Technology	USA	https://www.nist.gov/
NATO EOD COE Project ETACS	SVK	https://www.eodcoe.org/en/technology-dept/etacs/
NIC Instruments	GBR	https://nic-security.com/
NOVO DR Ltd.	ISR	https://www.novo-dr.com/
PYRA, s.r.o.	SVK	https://pyra.eu/
QinetiQ, Inc.	USA	https://www.qinetiq.com/
RMI, s.r.o.	CZE	http://www.rmi.cz/
RSI Europe	LTU	https://rsieu.com/
Scanna MSC Limited	GBR	https://www.scanna-msc.com/uk
SENSYS GmbH	DEU	https://sensysmagnetometer.com/
Teledyne	BEL	https://www.teledyneicm.com/
Telerob GmbH	DEU	https://www.avinc.com/de/ugv/innovative-losungen-fur-unbemannte-bodenfahrzeuge
Terrogence Global	ISR	https://terrogence-global.com/
University of Zilina	SVK	https://www.uniza.sk/index.php/en/
Unmanned Solutions, s.r.o.	SVK	https://unmannedground.com/
URC Systems, s.r.o	CZE	https://www.urc-systems.cz/en/
VALLON GmbH	DEU	https://www.vallon.de/en/
VCsecurity by Visiconsult	DEU	https://vc-security.net/
Vidisco LTD	ISR	https://vidisco.com/
Way Industries, a.s.	SVK	https://way.sk/

Table 1. List of the exhibitors contributing to D&T23.

There have been several innovative attempts to implement new training methods and tools to accelerate the training of EOD personnel by using artificial intelligence or virtual reality. One of them was illustrated by the NATO EOD COE dedicated to the project EOD/IEDD VR Training and XR Combat Support Kit (ETACS). EOD COE decided to set up a new booth dedicated to this project. The ETACS is a software development project for Virtual Reality goggles, combining virtual environments with explosive ordnance 3D models to provide a unique training platform for EOD operators.

Picture 2. CHOD of Slovak Forces at the ETACS project booth.

Moreover, innovative technologies were presented by the 4Experience company where visitors could merge themselves into virtual reality by using a platform emulating real body movement and mixed reality to illustrate simple solutions in how to train operatives procedurally.

Picture 3. 4Experience's VR/MR platform.

The static exhibition proved, that development in the EOD area was permanent and strongly influenced by the current armed conflicts. The equipment producers rapidly react to emerging warfare threats, therefore keeping pace with its development by seeking better solutions related to EOD operator protection, detection and disposal of all types of explosive threats.

Picture 4. Networking is a fundamental part of the exhibition.

Live Demonstrations

During the first day of the Demonstration and Trials exhibition, the companies had the opportunity to present new trends and technologies as well as their products in the field of EOD through Live Demonstrations which were an integral part of the event. The Live Demonstrations took place mainly indoors except for Jakusz Sp. z.o.o. and Łukasiewicz – PIAP companies, which performed a combined presentation of the isolation of explosives in explosion-proof container Paula without human intervention using an EOD robot right outside by the main entrance of INCHEBA pavilion. Due to the safety regulations and limited space of the Incheba Expo Centre, some technical features of EOD equipment such as disrupters or live shooting of X-ray images could not be performed. These limitations didn't vastly affect the Live Demonstrations, regardless. Due to the enormous interests of exhibitors i.e. 17 companies from 11 countries and limited time for performing the Live Demonstrations (from 11:00 – 16:00 hrs), there were 15-minute slots allocated for each company.

The presentations can be divided into the following subcategories:

Remotely Operated Vehicles (ROVs)

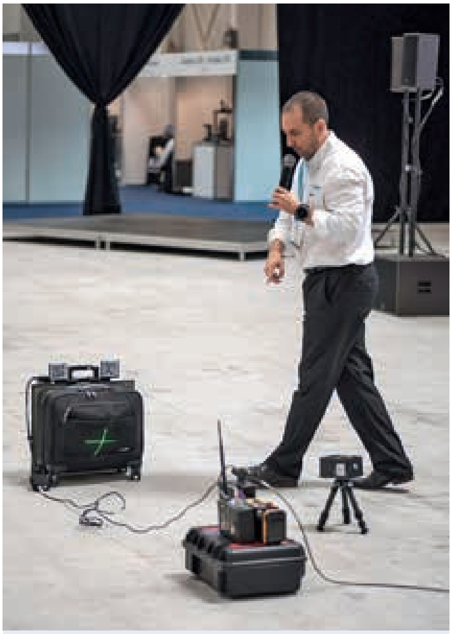
The using of ROVs during EOD operations is undoubtedly the most efficient way to perform EOD tasks and at the same time maintain EOD operator safety. Four companies i.e Łukasiewicz – PIAP, ICOR Technology, 3MON, s.r.o. and Qinetiq, Inc. presented the capabilities of their ROVs.

Picture 5. ICOR CALIBER Flex robot and Proarms 20mm Neutrex RSP demonstration.

Picture 6. QinetiQ's next-generation backpackable robot SPUR.

Detection and Identification

Another vital aspect within EOD activities, especially when facing IEDs or encountering Homemade Explosives on a scene, is the ability to detect possible threats including IED components and HME precursors. EOD operators are able, thanks to the detection and identification systems, to plan and execute their disposal procedures more precisely. Three companies introduced their X-ray imaging systems i.e. Scanna MSC Ltd., Vidisco Ltd. and Teledyne ICM.



Picture 7. Render Safe Vidisco XPAS X-Ray presentation.

Alakai Defense Systems specialises in laser and electro-optical standoff threat detection sensors for defence and security applications as well as RMI s.r.o. company with their stand-off Raman Spectrometer presented their solutions in detection methods of hazardous materials.

Picture 8. Alakai Defense presenting ARGO – Advanced Standoff Detection System.

EOD tools for operator's safety

The paramount aspect of each EOD operator during a task execution is their safety. Jakusz Sp. z.o.o. company with the collaboration of Łukasiewicz – PIAP company prepared a practical scenario showing their solution in isolation of explosives in an explosion-proof container with an EOD robot without human intervention.

Personal protective equipment for EOD operators in the form of bomb suits and their benefits were presented by two companies – GARANT Schutztechnik GmbH and Med-Eng company.

Picture 9. Isolation of Explosives in Explosion-proof Container Paula.

Picture 10. Davey Bickford Defense – fully programmable detonator.

Remote Initiation Systems

Davey Bickford Defense company presented a fully programmable detonator which was used for blasting operations and RSI Europe company introduced the RISE-1 which was a highly versatile remote initiation system.

EOD Training Solutions

Safety, consistency, flexibility and preparedness – these were the benefits of VR training which was demonstrated alongside XR technology, not only for EOD simulation, by the 4Experience Sp. z.o.o. company.

Explotrain LLC introduced their innovative FuzeX-based System of Blast Simulators and Interactive IED, UXO and Chemical Weapon Training Aids which accurately simulates the sensitivities and safeties of a variety of fuzes and ordnance through the use of a programmable circuit board inserted into inert training munition.

AI Support to EOD

Fenix Inside company presented their online cloud platform analysing millions of web-searches results every day using the latest artificial intelligence tools to cut through the noise of open-source intelligence and turn chaos into order. This unique tool offered an incredibly detailed analysis of ERW, UXO and IED worldwide.

Summary

During the Live Demonstrations, the exhibitors showed their technological innovations and products in the field of EOD and outlined how new improvements may facilitate even the most difficult tasks within EOD operations.

The visitors had a unique opportunity to meet the latest EOD tools and equipment available in the market up to now.

Company	Country	Project
Jakusz Sp. z.o.o.	Poland	Isolation of explosives in explosion-proof container Paula. Cooperation of explosion-proof container with EOD robot - isolation of explosives without human intervention.
Scanna MSC Ltd.	United Kingdom	Counter Threat Screening and Detection Solutions.
Łukasiewicz - PIAP	Poland	Heavy pyrotechnic robot PIAP IBIS Cooperation of the robot with the X-ray system.
RMI. s.r.o.	Czech Republic	Safe Stand OFF detection of difficult and dangerous samples with Raman Spectrometry.
GARANT Schutztechnik GmbH	Germany	Bombsuit.
Med-Eng	Canada	EOD Tools for Operator Safety.
ICOR Technology	Canada	ICOR CALIBER Flex robot and Proparms 20mm Neutrex RSP demonstration.
Vidisco LTD	Israel	Render Safe XPAS.
DAVEY BICKFORD DEFENSE	France	Electronic detonator.
3MON,s.r.o.	Slovakia	EOD ATRAX.
Explotrain LLC	USA	FuzeXR w/ Live Simulation.
4Experience Sp. z.o.o.	Poland	Defending the Future: From Simulation to Success.
Teledyne ICM	Belgium	The fastest way to determine the threat of an unattended package using an X-ray.
Qinetiq, Inc.	USA	Robotics.
Alakai Defense	USA	Argo , SAFR - Advanced Standoff Detection.
RSI Europe	Lithuania	RISE-1.
Fenix Inside	United Kingdom	AI in support of analysis of information on ERW, UXO, and IED worldwide.

Table 2. The list of the companies and their projects presented during the Live Demonstrations.

Conference

The edition of the conference during the D&T23 concentrated on scientific and military approaches. The convention was to present to the audience both emerging technologies and work on their research and various experiences gained by the soldiers and law enforcement on the battlefield tackling explosives.

Block I embraced the vital aspects of disruptive technologies i.e. AI, XR, stand-off detection and deep learning machines. The presentations delivered insightful pictures of the research and development projects, where these technologies will prevail in the future.

Block II revealed the threats Izrael, the USA, Mali and Ukraine were exposed to. Each of the speakers focused on diverse subject matter causing a block to be comprehensive and riveting.

Organizers of the vent regret that none of the invited speakers from Ukraine couldn't come due to their duties.

Picture 11. Ongoing conference during the Block I.

Topic	Name
Opening conference	LTC Damian Piorko
1.Block / Cutting-edge Technology for EOD	
Technologies to support EOD Training	
ETACS Project	2Lt David Slatkovsky
Stand-off detection of explosive hazards	Dr. Arnold Schoolderman
YOLO – deep learning model for UXO detection in thermal video	Mr. Milan Bajić
Modelling & Simulation for information and evaluation for decision makers connected with EODs activities on civilian and industrial environmental	Dr. Alberto De Paoli
Future technologies shaping EOD activities	
Technology possibilities for emerging bomb suits	Dr. Aris Makris
AI for EOD	Prof. John Frucci
2.Block / EO threat mitigation in a hostile environment	
Current intensive armed conflicts	
Mitigating the Threat of Terrorist Bombing Attacks	Mr. Jason Stewart, Mr. Michael Holt
Weaponized UAVs In the Ukraine Conflict	Mr. Michael Cardash
Rapid-Cycle learning for effective remedial action and dissemination of learnings	Dr. John Tull
EOD within Stability Operations and other mission	
EU TM MALI experience as J-3	LTC René Hečko
Experience EOD technician/team leader MINUSMA/Experience of staff officer MINUSMA	2Lt Ian Dhooghe
Closing remarks	COL Frantisek Mihalovic

Table 3. Agenda of the conference

Conference Block I

Following the overall theme for Block I "Cutting-edge Technology for EOD" there were formulated following block objectives:

a) To provide a platform for sharing information about the latest technologies that will or could be beneficial for the EOD Community of Interest (not only for the EOD training).
b) To inform about some aspects of Artificial Intelligence that could shape future solutions and responses from the EOD capabilities.

In line with the aforementioned goals, several guest speakers from various entities provided highly appreciated insights, perspectives, lessons, and ideas within their presentations on the following topics:

- The EOD/IEDD VR/XR Training and Combat Support Kit
- UAV applications for Military Search
- Deep Learning Model for UXO Detection in Thermal Video
- Modelling and Simulation for Information and Evaluation for decision-makers connected with EOD activities within Civilian and Industrial Environment
- EOD operator´s protection solutions in conjunction with the latest technologies and AI applications
- AI applications as a support tool for EOD

As highlighted in the collected feedback, the audience considered these block themes very inspirational for further developments of their national and alliance EOD capabilities.

Picture 12. Dr. Arnold Schoolderman, TNO, gives a presentation on Stand-off detection of explosive hazards.

Conference Block II

Following the overall topic for the conference Block II "EO threat mitigation in a hostile environment", there were formulated the following objectives:

1. Current Intensive Armed Conflicts
2. EOD within Stability Operations and Other Missions

In line with the aforementioned objectives, several guest speakers from various entities provided highly appreciated insights, perspectives, lessons, and ideas within their next inputs:

- Weaponized UAVs in the Ukraine conflict and around the globe
- Rapid-cycle learning for effective remedial action and dissemination of learnings in close connection with UKR conflict
- EU TM MALI experience from the perspective of a staff officer
- Experience EOD technician/team leader MINUSMA

Outlining the Block II, there was achieved the significant goal: *"Community of interest was informed about recent conflict zones (UKR and Mali…etc.) in connection with using new technologies and warfare methods/procedures when conducting military operations"*.

Concluding Block II, there were observed sound requirements on:

- functional Lessons Learned system,
- rapid, accurate and timely sharing of learning.

These observations are to be all-time essential to save the lives of EOD personnel and protect the civilian population in close connection e.g., conflict in Ukraine, and support to Sahel.

Last but not least, these block objectives were closely interconnected with Block I. Especially, the best practices, machine learning and emerging artificial intelligence identified by the EOD COE proved to be the drivers for considerations and further developments of the national and alliance EOD capabilities.

Picture 13. Dr. John Tull, University of Greenwich, gives a presentation on Rapid-Cycle learning for effective remedial action and dissemination of learnings.

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Benefits of Machine Learning to EOD Operators

Aris Makris, Ph.D., Jean-Philippe Dionne, Ph.D.
Med-Eng Holdings ULC, 2400 St. Laurent Blvd., Ottawa, Canada

Dr. Aris Makris is VP of Research & Development and Chief Technology Officer at Med- Eng. He holds Masters and Ph.D. degrees in Mechanical Engineering, specializing in explosions and protection against blast effects, with over 30 years of related experience. He has led numerous programs involving the design and development of advanced personal protective systems to protect against IEDs, landmines, and explosive threats. Dr. Makris and his team have also conceived and developed a number of person borne blast sensors to assist in quantifying individual blast exposure under diverse operational circumstances in order to improve medical understanding of traumatic brain injury and make improvements in procedures or equipment design. Dr. Makris has been an active member of several equipment performance standards, including the NIJ Bomb Suit standard, NATO and UN IMAS working groups, and a member of the IABTI Advisory Board.

Background

Machine Learning (ML), a field of study related to Artificial Intelligence (AI), allows for the development of algorithms that either facilitate decision-making or assist with the estimation of relevant variables. Machine Learning is built upon statistical methodologies making use of ideally large amounts of data with the aim of predicting the outcome of tests not yet conducted or scenarios not yet observed.

As Machine Learning is increasingly applied in multiple domains, it is no surprise that it will find direct and relevant applications in the field of Explosive Ordnance Disposal (EOD). Indeed, multiple EOD tasks either depend on large data sets or generate a wide array of observations that are prone to in-depth analysis. EOD specialists can take advantage of rapid developments in programming technology and stay at the forefront of new knowledge. By integrating the powerful ML methodologies, they are likely to generate significant benefits in the success rate of EOD tasks, through enhanced decision-making capabilities. The objective of this work is to highlight a few EOD tasks that are in the process of being facilitated through Machine Learning and to explore the potential for future applications.

Machine Learning in a Nutshell

Machine Learning algorithms can generally be grouped under two main umbrellas (Figure 1): supervised techniques and unsupervised techniques. In the "supervised" case, the algorithm, or "machine", "learns" by feeding it with observations, which are all associated with a so-called "label" from the start. For instance, in a study investigating how life habits influence life expectancy, data would be available from actual persons, each of them being labelled with how long they lived. The Machine Learning algorithms are then "trained" based on these labels, with the objective of predicting what label should be attributed to some other potential observation.

The focus of the current work is on "supervised" Machine Learning, as this approach is best suited to deal with EOD related challenges.

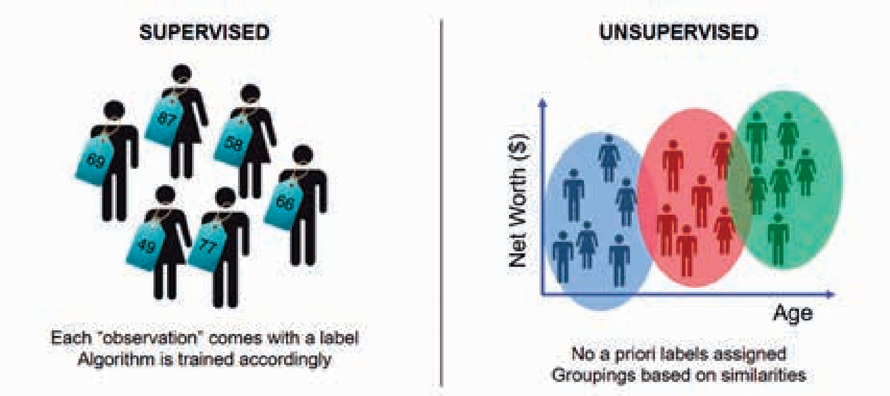

Figure 1: Illustration of Supervised Machine Learning (left), and Unsupervised Machine Learning (right)

Machine Learning algorithms can be further categorized into "classification" or "regression". Classification algorithms consist in assigning a category to a new observation, based on its characteristics or features. The number of categories is limited and each observation fits in only one. Classification algorithms are useful for decision-making tasks.

Regression algorithms on the other hand, are used to assign a numerical value to a new observation, also based on its characteristics or features. Figure 2 provides a high-level illustration of these two types of Machine Learning algorithms.

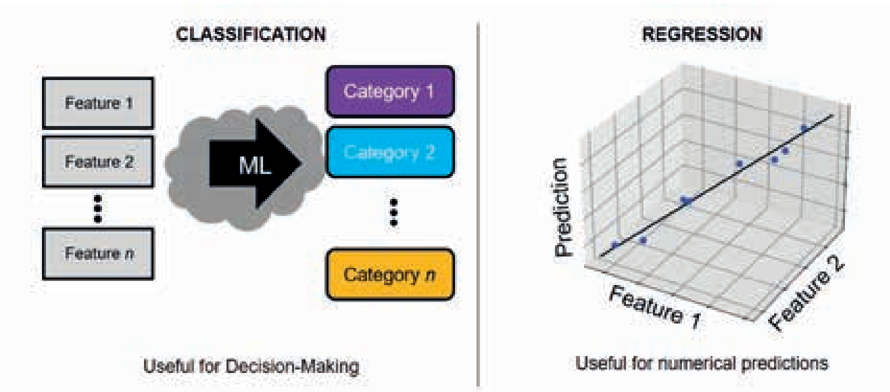

Figure 2: Illustration of a Machine Learning Classification algorithm (left), a Machine Learning Regression algorithm (right)

Finally, there exists methodologies to display the effectiveness of Machine Learning algorithms. For classification schemes, the best tool is the "confusion matrix" (Figure 3). This table compares known values that were not initially fed in the model (not part of the model training) against predictions made by the model. In Figure 3, a simple medical diagnosis scenario is shown, where each patient either has or has not a given disease (on each row), while the model predictions are expressed in the two columns. Good predictions are shown in green, while bad predictions (known as false positives or false negatives) are shown in red. From this confusion matrix, one can quantify the performance of the model using parameters such as the "precision" or "recall". For regression models, the effectiveness can instead be expressed in terms of percentage difference.

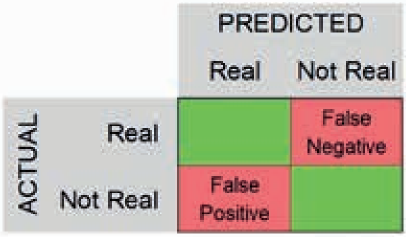

Figure 3: Illustration of "confusion matrix" in a simple scenario involving a diagnosis related to a disease

EOD-related Machine Learning – Current Successful Applications

Personal-borne blast sensors

Militaries and EOD teams worldwide recognize the requirement to capture, record, export and assess injury potential from data relating to blast events, which led to the advent of blast dosimetry. Only after data is recorded and analyzed can experts correlate event data from acute and recurring overpressure exposure to Traumatic Brain Injury (TBI), and other blast-related injuries. Blast dosimeters have been developed and fielded in military training and deployed operations over the last 15 years, first as helmet-mounted variants focusing on acceleration measurements, and eventually body-worn sensors providing overpressure data (Figure 4). This blast dosimeter concept incorporates three overpressure sensors pointing in different directions, one microphone (up to 150 dB), three "high-g" orthogonal accelerometers to capture soldier motion following the blast (up to 200 g's), and three "low-g" orthogonal accelerometers (up to 30 g's) to determine the soldiers' posture at the time of the event. However, only the pressure sensor data is discussed here.

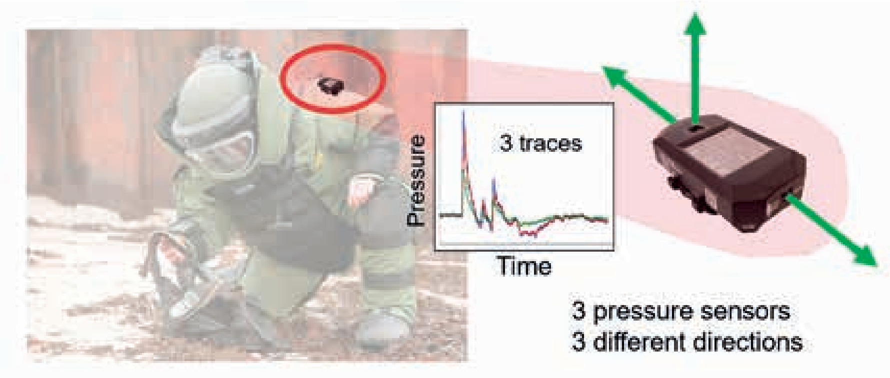

Figure 4: Person-borne blast sensor device to record and track blast overpressure exposure for individuals potentially exposed to blast (including bomb technicians).

While body-worn sensors have proven useful in quantifying the blast exposure of soldiers involved in Explosive Forced Entry (EFE) and to optimize standard operating procedures, important issues remain before such sensors can fully meet the requirements from the military medical community and for the EOD community. In particular, numerous blast events get missed (false negatives) when blast dosimeters fail to record relevant blast data. Furthermore, the devices pick up an even larger number of false positives, where dosimeters erroneously record events of no relevance to blast injury. Figure 5 illustrates typical “real blast” and “noise” signals that can be read by such blast dosimeters. Noisy “not real blast” signals can arise from multiple sources, such as x-ray signals, intense light or other electromagnetic signals.

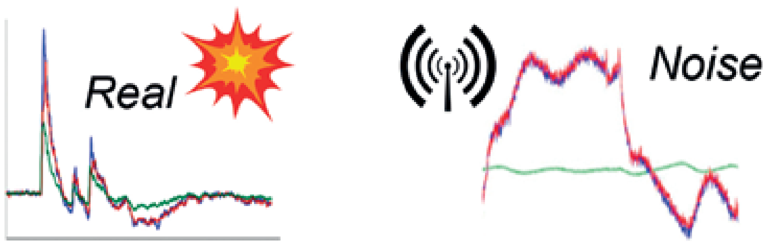

Figure 5: Illustrations of real blast (left) and noise signals (right) potentially recorded by person-borne blast dosimeters

Med-Eng engineers applied their knowledge and expertise related to Machine Learning, to an algorithm aimed at properly classifying signals from blast dosimeters as either "real blast" or "noise". This algorithm first extracts a number of relevant "features" from the blast signals, such as the peak and average pressure values, the maximum blast impulse, the positive phase duration etc. The Machine Learning algorithm is able to identify, based on these features, whether a given pressure trace corresponds to an actual blast, based on the "signatures" associated with them, compared to noisy electromagnetic signals. The effectiveness of the tool developed exceeds 98%, thereby clearly emphasizing the relevance of Machine Learning tools for such a classification task. With "noisy" signals properly identified and categorized, the analysis can then focus on the true blast signals.

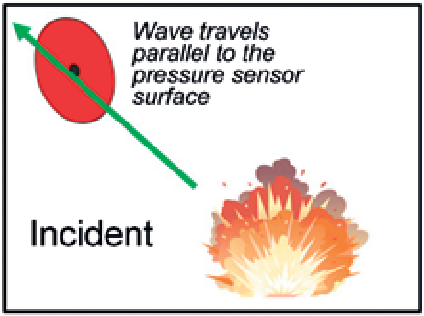

Figure 6: Concept of incident pressure: a pressure sensor measures the pressure of a blast wave moving in a direction parallel to the surface of the sensor

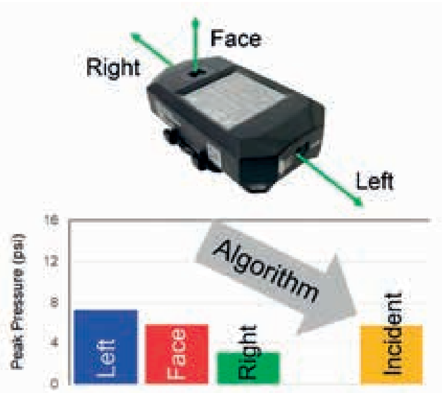

Figure 7: High-level illustration of the concept of the equivalent incident pressure Machine Learning algorithm: an equivalent incident pressure is estimated based on the data from the original three pressure traces

However, even when this "not real" data and noisy signals are extracted out, the interpretation of the blast signals is not straightforward. Indeed, in many cases, the pressure sensors from the dosimeter device are not fully or directly exposed to the blast, which can result in pressure traces and peak pressure values that are difficult to relate to the actual blast. To address this issue, Med-Eng engineers developed a Regression Machine Learning algorithm aimed at estimating the effective incident pressure that the dosimeter has been exposed to. Once again, the algorithm extracts key features from the signals, i.e., "Machine Learning", combining the data from the pressure sensors pointing in three distinct directions, to arrive at an appropriate estimate. The concept of "incident" blast is illustrated in Figure 6, while the concept of the algorithm estimating the incident pressure based on the original pressure traces is illustrated in Figure 7. The predicted incident pressure levels were on average within 17% of the actual values, which is reasonably good for this type of violent event with high variability/scatter, when tested in controlled conditions.

Moreover, it is generally not possible to estimate the directionality (provenance) of a given blast, relative to the soldier or bomb technician. Such directionality information can be useful both for training, forensics and medical applications, to relate blast injuries with better defined blast exposure. Again, a Machine Learning algorithm was developed to estimate the blast directionality, taking features of the pressure traces into account. In particular, the algorithm (or "Machine Learning") considers factors such as the time of arrival of the blast and the ratios of peak pressures between the three pressure sensors housed within the dosimeter device.

Based on these features, the algorithm then predicts the directionality in terms of horizontal orientations of the blast relative to the device, corresponding to 45° ranges, or octants. Such 45° ranges were deemed granular enough, given the inherent variability of blast and the fact that even approximate orientation data is likely to bring benefits for both forensics and medical applications.

Appropriate blast orientation determinations (within the appropriate 45° range) were obtained in 86% of the cases, and greater than 96% to be within one octant, demonstrating the validity of the approach. With additional data to be collected over time, it is expected that the Machine Learning algorithm will provide an even higher performance level.

Figure 8: High-level illustration of the concept of the blast directionality Machine Learning algorithm: the directionality of the blast is estimated based on the data from the original three pressure traces, and classified into one of the 8 octants

Finally, while not as relevant to bomb technicians, a Classification Machine Learning algorithm was also built to identify the types of weapons used by Soldiers during training and operations, as many weapons generate blast overpressure at levels that can be injurious over the long term. Again, appropriate features from the pressure signals were extracted and associated with various weapon types. The ability of the algorithm to properly identify the weapons used was in excess of 90% for the cases tested, after training the algorithm (or learning by the machine) with large amounts of data from different weapons.

Optimal Bomb Suit sizing

Med-Eng bomb suits come in 4 different sizes (Small, Medium, Large and Extra-Large for the latest generation EOD 10 Suit), to accommodate a large proportion of bomb technicians. The appropriate suit size for an individual is normally determined based on a sizing chart provided in the product specification. This sizing chart is based on the height and weight of the bomb technician. While this sizing system works reasonably well, there are some individuals with body types that deviate from the "average" and for whom as a result, the sizing table does not provide the optimal suit sizing.

With this gap in mind, Med-Eng engineers are applying a Classification Machine Learning algorithm with the aim of better predicting the appropriate bomb suit size, for a given user's body. While the existing sizing chart only took two body measurements into account (height and weight), a more advanced tool had to consider additional body characteristics (or categories/inputs) to achieve a higher performance.

To get access to such additional body characteristics without the burden of involving a body measurement expert, an existing sizing "app", developed by Safariland (Med-Eng's parent company) for the purpose of body armor sizing, was used. Through this smartphone application, two photos are taken from an individual (front and profile) while wearing close fitting clothes. From these photos as well as the height and weight of the individual entered manually, the sizing app builds a representative "avatar" (see Figure 9). From this created avatar, a wide range of body measurements can be extracted. Previous studies had demonstrated the effectiveness of this sizing tool at properly estimating that wide range of body measurements. Figure 10 illustrates examples of body measurements that can be extracted from the sizing tool.

Figure 9: Illustration of the sizing app used to assist with the development of a Classification Machine Learning tool to optimize the selection of bomb suit sizes (jacket and trouser). The sizing app takes front and profile photos, which are then turned into an Avatar, from which various body measurements can be estimated

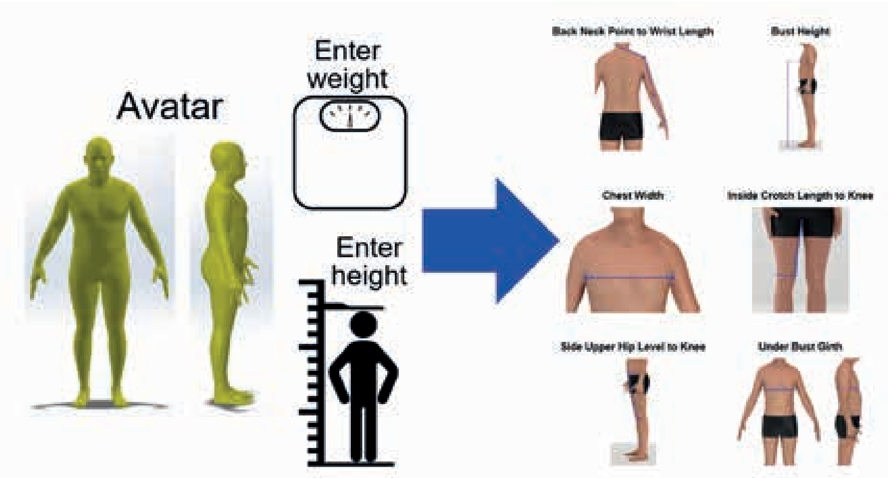

Figure 10: Examples of body dimensions that can be extracted from the sizing application, based on the avatar and the weight and height of the individual being sized

Measurements were then made of volunteers using this app, along with fit trials to determine, or classify, which suit sizes were the most appropriate for each of them. Based on these measurements and suit sizing “labels” associated to each participant (as per Figure 1), a Machine Learning algorithm was trained to arrive at a so-called “Decision Tree”, replacing the original sizing chart from the product specification based only on height and weight. Figure 11 provides a simple illustration of such a Decision Tree (the actual tree, still under development, involves more variables). Despite the limited number of participants, the Decision Tree was found to be more effective than the sizing chart, which confirms that the Machine Learning approach is very promising for determining bomb suit sizes. This study also helped determining which body measurements are the most relevant for sizing tasks.

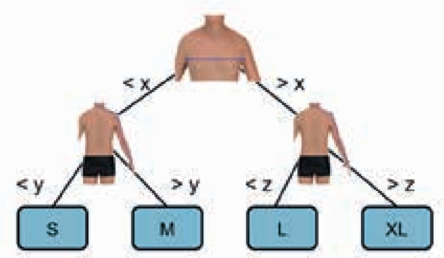

Figure 11: Example of a Decision Tree assisting with the selection of the optimal bomb suit size

Mine/Munition Detection (Image Analysis)

Machine Learning can also be applied to assist with the detection of minefield ordnance, through the analysis of aerial images. Indeed, there exist powerful image recognition tools that have been "trained" by being exposed to a large number of images with appropriate labels. In the case of mine and munition detection, images have been captured by drones flying over fields where the presence of ordnance had already been assessed through human analysis. The Machine Learning algorithm can then in turn, based on the "labels" provided by human analysis, associate the presence of ordnance with specific terrain image features.

Applied to new images never used for training and never analyzed by humans, the Machine Learning algorithms are then effective at detecting the presence and classification of threats, thereby greatly facilitating the work of EOD search and disposal teams on the ground. Figure 12 provides an example of an aerial image where the computer-generated predictions for the location of mine threats has been superimposed.

Figure 12: Example of an aerial image captured by a drone with predicted locations of mine threats, as generated by a Machine Learning algorithm

IED Circuit Recognition (Image Analysis)

Machine Learning algorithms can also be developed to analyze electronic circuits and determine whether they contain all the essential components associated with real IEDs. Such tools can be useful to EOD technicians trying to quickly assess the presence of a real threat as opposed to a hoax. Figure 13 gives an example of an actual mock device located at a Canadian airport as well as an example of a real IED circuit (reconstructed) associated with an actual terrorist device that detonated in Colombia.

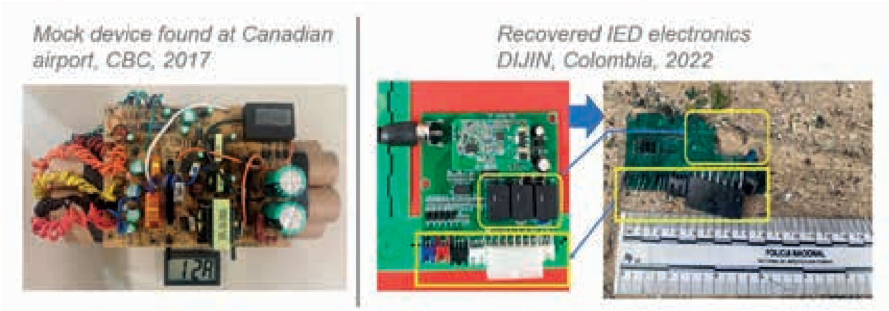

Figure 13: Example of an actual mock IED electronic circuit (left) and an actual IED circuit (right). Machine Learning algorithms are trained to properly recognize circuit components associated with true IED threats

The outcome of the Machine Learning algorithm can be for instance a Decision Tree (Figure 14) helping with the determination of the threat (IED or not) based on the presence or not of key electronic components. An actual Decision Tree would be more complicated, but Figure 14 illustrates the concept.

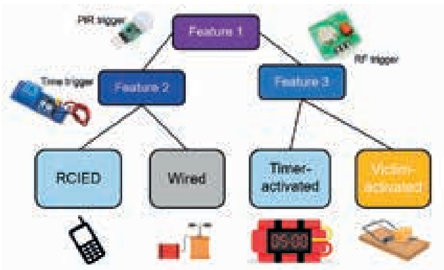

Figure 14: Illustration of a simple Decision Tree concept for the recognition of IED specific electronic components, based on the presence of specific components/features

Again, Machine Learning algorithms take advantage of the very powerful image recognition tools developed in a wide range of domains, along with a large database of IED circuitry specific images. The algorithms would have to be trained with extensive images across all categories of IED circuitry and components, in order to provide good predictions, or classifications.

One can also envision that x-ray images of luggage in airports, or unattended packages, can be analyzed through Machine Learning to be able to quickly differentiate between harmless contents in a bag/luggage/package or a high probability for an IED to be contained. X-ray images of thousands of pieces of luggage or packages found in airports would have to be inputted and properly classified to "train" the algorithm and then applied to random packages for predicting danger, instead of having overwhelmed or tired human beings trying to make an assessment, under pressure of passengers and line ups.

EOD-related Machine Learning – Potential for Future Applications

The previous section highlighted a few EOD related areas where Machine Learning algorithms have already been introduced, or are being contemplated, and, in some cases, already provide highly valuable predictions to EOD technicians and investigators. The effectiveness of these already existing tools is bound to keep increasing as the amount of data used to train the models grows.

But the range of potential Machine Learning EOD applications is much wider than the few examples illustrated above. As far as image-related algorithms are concerned, the automatic threat recognition will grow to include the analysis of x-ray images gathered from suspected IEDs, which will allow for more accurate device destruction through disruptors. Also, as bomb technicians will be increasingly equipped with a diverse set of cameras, Machine Learning algorithms will be able to "fuse" the images from regular and thermal cameras for instance, to provide enhanced reality and allow for enhanced threat recognition predictions. Indeed, thermal features of an IED and associated electronic circuitry can become "visible" to the operator, superimposed on the visible image, in a form of augmented reality.

Machine Learning algorithms will also be applicable to other types of raw data beyond images, such as sound data. Indeed, already existing voice recognition software will keep getting better to allow bomb technicians to activate tools and bomb suit functions without having to use their hands, already busy handling IEDs. Another example of potential Machine Learning application is through the interpretation of physiological monitoring data (e.g., heart and respiration rates, body temperature), by training the system measurements against technicians' actual health status. Eventually, such models could be

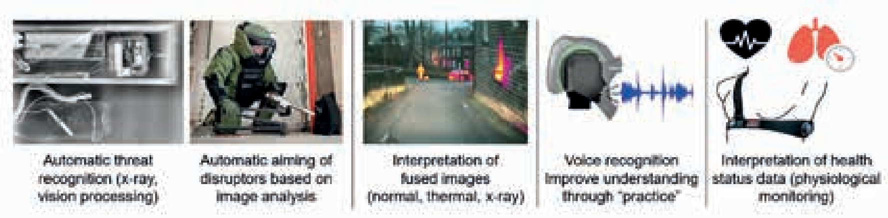

Figure 15: Example of further potential applications of Machine Learning related to EOD operations

used to detect user fatigue or stress level, that would not otherwise be readily identifiable. Figure 15 provides simple illustrations of these simple potential Machine Learning applications.

Conclusion

Machine Leaning has already impacted many aspects of EOD work, facilitating the work of the operators. The current article has highlighted a few examples related to blast dosimeters, bomb suit sizing, minefield identification through drone-generated images, and the analysis of IED circuitry. These tools have the potential to remove cognitive burden from the bomb technicians, providing them with enhanced situational awareness downrange and facilitating decision-making both for the technicians themselves, as well as at the Command Post. More specifically, enhancements in training, forensics analysis and tactical procedures are expected as a result of the introduction of Machine Learning tools.

All sources of data, including sensing, vision (sensors, detectors, ROVs, UAVs, tools) can feed into Machine Learning in the not-too-distant future, greatly expanding the potential applications of Machine Learning, if it is deemed of value, worthy of the investment in effort and resources. The challenge will remain to convey all the resulting information to the EOD operators. This information transfer could potentially take place through Heads-Up Displays within bomb suit helmets, which could convey Augmented Reality images as well as Virtual Reality.

Further down the road, advanced Machine Learning tools could allow for full autonomous response by EOD robots, further reducing the threat to bomb technicians. Although there may be concerns about this autonomous approach for the EOD application, the technical possibilities may provide some options for certain high-risk situations.

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YOLO – deep learning model for UXO detection in thermal video

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Milan jr. Bajić, a senior lecturer at Zagreb University of Applied Sciences, established and equipped a multimedia lab and procured advanced equipment such as the Hyperspectral Specim ImSpector V9 (2020) on a portable 2-meter slider with adjustable height, and thermal and visible cameras for UAV-based surveys. He contributed to educating surveyors from the Croatian Mine Action Center on the application of UAVs in non-technical surveys in 2018, and taught courses in Digital Photography, Sound Production for Bachelor's students, and Multimedia Systems and Digital Image Processing for Master's students. Milan participated in recent projects such as "STEM for a sustainable future" and "R U EU? - A game-based approach to exploring 21st-century European Identity and Values". Currently, he is pursuing Ph.D. studies at FERI, focusing on high-resolution thermal and hyperspectral imaging for detecting explosive objects.

Abstract

Deep learning has become widely utilized and extensively studied in various fields such as autonomous vehicles and face recognition. However, its application in domains like land mine (LM) clearance and explosive objects clearance, particularly in non-military contexts, is relatively uncommon. This article builds upon prior research that employed the YOLO algorithm for detecting unexploded ordnance (UXO) in thermal images and extends it to the near real-time detection of annotated explosive objects in a thermal video sequence.

This work is based on the UXOTi_NPA dataset [1], which encompasses 11 distinct explosive targets, along with an original thermal video captured from a height of 3, 5, and 7 meters with very high ground sampling distance. YOLO, known for its speed and accuracy, demonstrated the capability to detect explosive objects in over 40 frames per second (FPS), making it a viable solution for thermal videos operating at 25 FPS or 30 FPS. Currently, no automated systems are available for surface UXO detection using thermal video that can facilitate large-scale area surveys. Consequently, this research represents a significant step towards addressing this gap and paving the way for such automated solutions. Visible RGB imaging, picture, and video alike are thoroughly researched, proven by thousands of research results published on object detection, classification, recognition, and identification using various machine learning algorithms, so these are vast pools of possible solutions. Less researched because of the lack of publicly available datasets and more complex data processing are ground penetrating radar (GPR), magnetometer, and hyperspectral imaging sensors and future solutions would seek an application of deep learning algorithms for real-time detections with these sensors and their fusion for higher probabilities of detection.

Introduction

Thermal imaging captures pictures, but it relies on heat signatures instead of using visible light. In Figure 1. it is very easy to see where thermal imaging brings additional information about the position of the target that is hardly seen on visible RGB images. Everything with a temperature above absolute zero emits infrared radiation. This radiation falls in the thermal infrared region, with a 7 to 14 μm wavelength, forming a thermal image or thermogram. These images provide a detailed map of an object's surface temperature with thermal and spatial resolutions [2].

Thanks to the affordability of dual-sensor cameras, combining Thermal Infrared (TIR) and RGB, mounted on Unmanned Aerial Vehicles (UAVs), we've witnessed a surge in research across diverse applications such as regional security, structural monitoring, and environmental surveillance [3]. This trend follows years of pioneering efforts in deploying thermal imaging devices on various platforms like satellites, airplanes, helicopters, and UAVs, initially for military purposes and later expanding to civilian applications [4], [3].

Figure 1. The image shows a land mine with a green metal casing placed on green grass. The top image represents the terrain as seen in the visible spectrum, while the bottom image shows the same terrain in the thermal spectrum.

Aerial and spaceborne TIR remote sensors currently in use detect the energy emitted by the object itself. These systems don't need an external source of infrared radiation and are suitable for field use, thanks to their ability to compare an object's response with a modeled black body, eliminating the need for fixed temperature conditions [5]. However, challenges arise when the imaging device observes an object at an angle, requiring geometric corrections. One critical application of thermal imaging technology is in the detection of explosive remnants of war (ERW). These are remnants from past conflicts, such as bombs or landmines, still posing risks. Despite the historical nature of World Wars, the issue persists, with 64 countries affected by landmines [6]. Some countries have databases detailing explosive devices, but others need to develop such documents to better understand the risks of humanitarian landmine clearance.

Research in UXO detection using thermal images is limited. Notably, a prototype application using thermal imaging achieved a 78% precision in detecting the 'Butterfly Mines' [7]aerially deployed plastic anti-personnel mines are particularly challenging in terms of their detection and subsequent disposal. Detection and identification of MECs largely relies on the geophysical principles of magnetometry and electromagnetic-induction (EMI. Challenges such as environmental factors, time of day, and buried mines impact detection accuracy. Deep Learning and Convolutional Neural Networks (CNN) present promising avenues for improving reliability by bridging the gap between large datasets and the demands of working in UXO-contaminated environments [8].

In this work, the proposed is adapting and retraining the YOLO architecture, a state-of-the-art CNN, to detect UXOs from 11 different classes in highly variable thermal images also regarding detection these classes are combined in one class for this paper.

Materials and methods

The video utilized in this study was supplied by Norwegian Peoples Aid and had been employed in prior research conducted by Bajić Jr. and Potočnik [1]. Their investigation centered on the exploration of YOLOv5 as a potential detector, resulting in the creation of the publicly available UXOTi_NPA dataset. The findings were subsequently presented in a paper at the ROSUS conference in March 2023 [9], where YOLOv7, the most recent version of the one-pass object detection algorithm at that time, complemented the results. The satisfactory precision and speed demonstrated by these algorithms prompted a comparison of their inference times in this work. The evaluation involved five models of varying complexity for YOLOv5 and two pre-trained and tested models for YOLOv7. These models were trained using pre-existing models from the COCO dataset, a widely used benchmarking dataset for comparisons, as recommended in some research on this topic, where there are small datasets available. This approach not only saved time on retraining but also contributed to achieving higher precision on a customized dataset. All training and inference processes were executed on the Google Colab platform, providing the flexibility to acquire computing resources on demand. This allowed access to high computational power for a limited duration at a relatively modest cost. The results are presented in Table 1. and Table 2., here we deal with inference time, while precision is similar at 3m and 5m, those from the 7m video are a little less precise, with probability around 0.5 (50%) which can be understood because all models were trained on the dataset created from 3m height. Depict the outcomes when treating all objects as a single class, in such instances, the model is slightly smaller, facilitating faster detection. Despite this, it generally provides sufficient information to identify potential threats and pinpoint the areas that require inspection or crosscheck with other sensors.

Model	Model Size	Inference time per image (s)
YOLOv5n	1,8	0,0090
YOLOv5s	7,1	0.0091
YOLOv5m	21,1	0,013
YOLOv5l	46,4	0,0208
YOLOv5xl	86,6	0,0402
YOLOv7tiny	6,1	0,019
YOLOv7	36,8	0,0248

Table 1. Inference time of seven YOLO models

Model	Model Size	Inference time per image (s)
YOLOv8n@3m	3,0	0,0113
YOLOv8n@5m	3,0	0,0171
YOLOv8n@7m	3,0	0.0116
YOLOv8x@3m	65,6	0,0434
YOLOv8x@5m	65,6	0,0551
YOLOv8x@7m	65,6	0,0452

Table 2. Inference time of 2 YOLOv8 models on video from 3m, 5m, and 7m

Discussion

This research aimed to employ advanced Deep Learning and Convolutional Neural Network techniques for the identification of Unexploded Ordnances (UXOs) using thermal video materials. Detecting UXOs is critical for safely dealing with explosive remnants of war, and our automated approach enables aerial terrain examination, such as using Unmanned Aerial Vehicles, to pre-identify potentially hazardous areas.

A key innovation in this study is the utilization of thermal video from various altitudes for UXO detection. Thermal imaging provides crucial information about the environment and its changes, not detectable in the visible spectrum. Different materials, including UXOs, leave distinct thermal signatures, allowing accurate identification. The study compared the performance of YOLOv8, YOLOv7, and YOLOv5 on the NPA thermal video sequence. YOLOv5, a well-established architecture, outperformed YOLOv7 in terms of the trade-off between model size and detection effectiveness, primarily due to fewer false positive detections. YOLOv7 demonstrated higher processing time and resource requirements, which seemed unjustified given the results, potentially due to the small UXOTi_NPA dataset on which both models were trained. YOLOv8 again brings the spotlight on itself by getting back precision and inference time closer to YOLOv5 thus getting attention to it as promising future directions as it handles better variability in the size of objects.

This study showcases the effectiveness of combining deep Convolutional Neural Networks with thermal imaging for UXO detection in a real environment. The analysis of Table 1, detailing inference time and model complexity, led to the conclusion that YOLOv5s, although larger than YOLOv7tiny, exhibited better performance with an inference time of 0,0091 and very similar to that of YOLOv8 at an inference time of 0,0113. Figure 1. provides visual support for why thermal imaging is a superior solution for surveying large suspect areas.

Models of smaller sizes, such as YOLOv8n, YOLOv5n, YOLOv5s, and YOLOv5m, are recommended for near real-time object detection in a thermal video sequence. Their reduced inference time, less than half the sequence length, makes them suitable for deployment on edge computing devices, ensuring results during UAV flights. However, the optimistic results presented here have limitations, notably the small UXOTi_NPA dataset, created with limited objects and from a low altitude of 3m. Subsequent studies seek to broaden the dataset by integrating diverse altitudes, temporal conditions, and geographical terrains to augment the overall resilience and effectiveness of the model.

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Examination of Future Technological Advances in Explosive Ordnance Disposal Operations

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The EOD community stands at the cusp of a transformative era, with rapidly advancing technologies reshaping the landscape of capabilities and operations. This comprehensive briefing explores the key advancements and technologies that are shaping the future of EOD. A fundamental emphasis lies on innovation, paramount for ensuring the safety and effectiveness of our EOD operators in an ever-evolving threat landscape. Various forms of technology will be discussed in this briefing to include types of ground robots, Unmanned Arial Vehicles (UAVs) Unmanned Underwater Vehicles (UUV's), sensors and sensor capabilities, mapping, LIDAR, Artificial Intelligence, Machine Learning, Augmented Reality (AR) and Virtual Reality (VR). Advancements and the integration of these technologies will be examined in greater detail and how they may be incorporated into EOD operations in the future.

Robotics and Advanced Detection

In the realm of EOD, robotics is leading the charge with greater and more diverse capabilities.

Robotic platforms including wheeled, tracked to legged robots are providing more advanced cameras' sensors and tools. Ground robots also include Unmanned Arial Vehicles (UAV's) platforms that integrate with the ground vehicle.

With the development and fielding of legged robots (e.g., Boston Dynamics) it now provides an additional option to units and their operators to conduct missions. The legged robots are becoming increasing agile and fast. As the load bearing capacity becomes greater the ability to add more sensors, and detection/tool options will become normative.

UAV and Unmanned Underwater Vehicles (UUV's) can provide the Initial interrogations which will include both arial surveillance and detection combined with a plethora of other detection capabilities.

Robotic platforms being developed will include multiple technologies for surveillance, detection, mapping, identification of hazards. Having the ability to navigate under canopies in tunnels, and water will be all part of gaining a strategic advantage in a mission situation.

Paving the way for legged robots exemplified by Boston Dynamics, known for their exceptional speed, load-bearing capacity, and advanced detection capabilities. These robots, together with Unmanned Aerial Vehicles (UAVs) and Unmanned Underwater Vehicles (UUVs), can effectively deploy various types of explosives even in the most challenging environments, including under canopies, tunnels and underwater.

These technological leaps significantly enhance operator safety by reducing the proximity of human personnel to potential threats in include the:

- Detection, use of sensors to detect what type of hazard is present, chemical explosive or other.
- Software and hardware, various types of cameras, X-rays, detection equipment, air monitoring technologies use AI/ML to recognize hazards, ordnance, devices, device components.
- Longer battery life

Artificial Intelligence Hierarchy and Generative AI

Artificial Intelligence (AI) assumes a central role in the evolving EOD landscape. Machine learning, a subset of AI, leverages data and algorithms to mimic human learning, progressively refining its accuracy. Deep learning empowers the recognition of intricate patterns, while computer vision enables the extraction of meaningful information from visual inputs. These technologies not only enhance hazard detection and threat analysis but also reduce risks to EOD personnel. Generative AI applications like ChatGPT, DALL-E, and Bard are instrumental in producing high-quality text and images based on their training data, thereby enabling swifter and more precise communication and reporting.

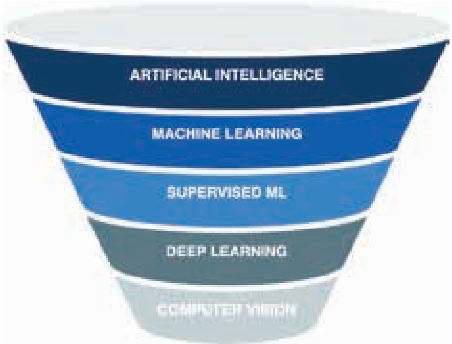

Figure 1, Demining Research Community AI Hierarchy.

Neural Networks, Interpretation, and AI/ML for Decision Support

Artificial neural networks, inspired by the human brain, play a pivotal role in interpreting data and recommending procedures while providing confidence ratings for complex threat contexts. This empowers EOD operators to make informed decisions in intricate situations. As automated detection tools continue to advance, the human element remains integral to the decision-making process. Proposed concepts, such as the EOD Command Center, harmonize various tools and information sources to recommend strategies and equipment, facilitating global intelligence sharing and enabling operators to cross-reference threats with a historical response database.

Interpret/diagnose data and recommend procedures providing confidence rating on options as complex as threat context.

- *"Am I in danger?"* What is the threat in the area?
    - Understanding if all the components for an IED are present.
    - Processing other metadata
        - Where am I?
        - What has happened here recently? (historic battlefield information)

Decision Support:

- Could it be an IED, are the components recognized as part of an IED. Explosive detection, recognition.
- Use of automated detection will continue to advance.
- The human element will be a part of the process.
    - Via operation or command center, devices for detection will be released.
        - In live color or infrared video
        - Body camera
        - UAV, UUV
        - Ground robots

EOD Command Center concept

- An integrated tactics, training, protocol toolset
- Enables current threat information to be entered in and TTPs out.
    - Inputs a toolset (e.g., UAV, UUV, ground robots, cameras, energetic tools etc.)
    - Inputs data (e.g., on-scene interviews, threat images, Biometrics etc.)
    - Outputs custom strategies, what equipment, tactics, techniques, and procedures be used.
    - Share intelligence on a global scale.

AI/ML for Driver Assists and AI-Mine Detection Process

AI plays a critical role in assisting ground robots in navigating complex terrains, pre-mapping obstacles, detecting hazards, and identifying infrastructure details. These capabilities are pivotal for ensuring safe and effective EOD operations. Furthermore, AI and machine learning are harnessed for the detection and mapping of landmines, a process that significantly reduces risks to EOD operators during mine clearance operations.

In addition, comparing on-scene information as well as collected data with local infrastructure such as where utilities are located (natural gas lines, communication lines, water lines etc.)

The Cloud and Training

The adoption of cloud-based platforms is paramount for gathering and sharing data on explosive items. Collaborative consortiums involving government and academia can provide secure environments for comprehensive data sharing, similar to the aviation industry's "black box thinking." This approach ensures that EOD operations are informed by real-world experiences and fosters a learning culture rather than a punitive one. Cloud-based data reservoirs enable the utilization of Augmented Reality/Virtual Reality (AR/VR) for training, facilitating the practice of real-world scenarios and enhancing predictive capabilities among EOD operators. This approach draws parallels to successful implementations in aviation and medicine, further accentuating its efficacy.

Current Technologies in use, Development or Close to being Fielded. Safe Pro AI Use Case.

One exemplar of AI in EOD is Safe Pro AI [1], which is applying their technology to detection mines in Ukraine. This software, developed by Safe Pro AI, employs machine learning to detect and map landmines effectively [2]. Through a drone survey conducted using commercial off-the-shelf Quad or Hex copters, the Spotlight AI system creates a geographically accurate map and predicts surface ordnance locations. It can identify over 90 types of mines and unexploded ordnance. This innovative technology is pivotal in reducing the risks and enhancing the efficiency of EOD operations [3].

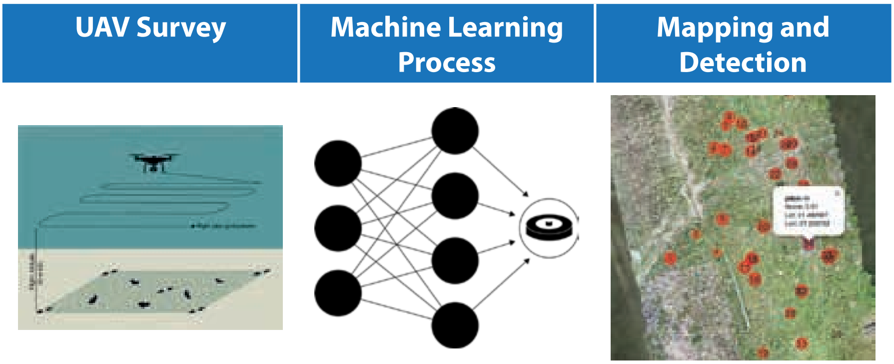

Figure 2, Safe Pro AI, Demining Research Community Testing

Technology in the Field, Spatial Computing. OD Dynamics Cellular Phone Application

In the field, the deployment of artificial intelligence, machine learning, augmented reality, virtual reality, and advanced microsensors enhances detection, safety, and operational capabilities. The development of lighter, faster, and more capable tools is pivotal for ensuring the safety of both the public and EOD technicians. Simultaneously, spatial computing leverages open-source technology to create a 3D experience for EOD technicians and humanitarian deminers, thus improving training and operational planning [4].

Conclusion

In conclusion, the future of Explosive Ordnance Disposal is characterized by significant advancements in artificial intelligence, machine learning, robotics, advanced detection technologies, and collaborative cloud-based platforms. These innovations are instrumental in enhancing safety, increasing operational efficiency, and ensuring the well-being of our EOD operators and civilians. Developing and accepting these technologies is essential for EOD to remain at the forefront of operational capabilities while upholding the highest standards of security and protection. As we adapt and integrate these advancements, we continue to fulfill our mission of safeguarding the public and keeping operators safe. Through advancements in technology and innovation, we as a community will continue to protect those in harm's way as well as innocent civilians.

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Rapid-cycle learning for effective remedial action & dissemination: Ukraine EOD case study

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Colonel (ret.) Dr Yuriy Pashchuk

Rapid adaptation has always been an imperative for military organizations facing dynamic threats. Learning lessons from experience is equally familiar as a way of tackling problems to military personnel. However, militaries have often struggled to institutionalise that learning so that it becomes available at scale and in potentially strategic ways. 'Lessons Learned' is a highly-developed NATO process supported by a NATO Handbook [1], related other NATO handbooks and courses, and consultancy services from the NATO Joint Analysis and Lessons Learned Centre (JALLC). And yet our current study and recent others [2] show that most lessons-learned systems fail to achieve their full potential impact. Just how that happens, and why that shortfall persists even in the face of direct threat, is puzzling; it indicates that learning involves far more than just resources like databases and training to collect new information.

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Introduction: Learning for EOD - Ukraine's Experience

The Ukrainian Armed Force's maturing capabilities illustrate the challenge highlighted to achieve effective organizational learning [3], a problem heightened in the rapid-cycle context of direct and deadly threat. This chapter will show how chronic gaps may persist between concepts and implementation of good learning, even in the vital case of addressing EOD. By tracing Ukraine's evolution of Lessons Learned in terms of the conditions that foster it and practices that bring it alive, we can better understand what it takes for leaders at all levels to convert EOD lessons-learned into effective action and capability transformation. We outline how progress has been achieved, unevenly but significantly, in Ukraine, in three stages.

Stage 1: Building from Weak Foundations (2014-2018)

Prior to 2014, the Ukrainian Armed Forces (UAF) had few robust mechanisms for organizational learning. Mine warfare received little priority. Tactics and procedures instead relied on informal sharing within stove-piped units and a centralized database was launched only in Oct 2017 that was difficult to access. The 2014 outbreak of armed conflict in the Donbas exposed debilitating gaps, as mine and IED incidents accumulated with deadly consequences. Between 2014 and 2018, in Donetsk and Luhansk regions the UAF engineers checked more than 2,500 hectares of territory for the presence of mines, detecting and neutralizing 122,000 units of EO (LL bulletin October 2018).

In the 5.5 years from April 2014, 601 mine incidents caused around 1,000 UAF casualties and killed or injured 833 civilians due to the density of mining (Figure 1). Yet Ukraine lacked systematic information flows, analytical expertise, effective communication capabilities and implementation capacity to transform episodes into solutions.

Figure 1: Ubiquitous danger of multiple types of EOD

Initial attempts at centralization demonstrated difficulties in institutionalizing disciplined learning processes without foundational elements in place. From 2014-2018, the military expanded data gathering through new, but relatively ad hoc channels. Observations passed from frontline units towards a newly-established Lessons Learned (LL) cell in the Antiterrorist Operation (ATO) HQ. However, untreated tactical reports flowed directly into basic military channels for dissemination without supporting assessment. This raw information pipeline reinforced existing orientations, rarely stimulating capability growth.

Further constraints (human, procedural, and technical) inhibited exploiting available data. Inadequate resourcing left the UAF General Staff LL cell understaffed and undertrained, struggling to keep pace with inputs or produce actionable outputs. Analytical products focused narrowly on technical considerations, rarely integrating human and organizational factors. Reliance on manual dissemination methods constrained timely sharing across the ATO force and in particular limited dissemination to the wider UAF. Cultural obstacles also persisted, as the habits of secrecy reduced transparency. Without leadership emphasis on learning, frontline teams were reluctant to expose errors or uncertainty up their chain of command. This constrained open flows of knowledge necessary for improvement.

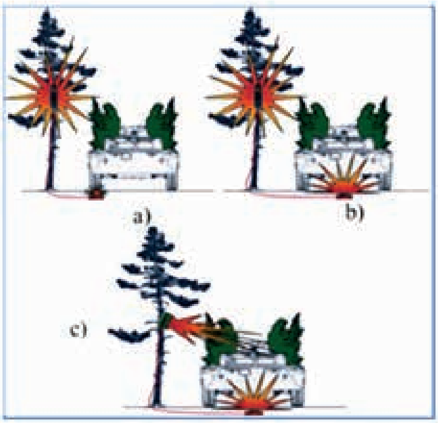

Figure 2: Variants of Russian tactics using combined EO from 2016.

Learning is always a dynamic challenge - the adversary also learns. The Russians used the Donbas war as a training area to polish and improve their mine warfare tactics. While at the beginning the enemy used mostly unguided landmines, since 2016 Russian troops have been actively using wire and radio-controlled landmines, including those controlled by mobile phones. Figure 2 illustrates variants of a specific method of mine warfare (combined landmines EO, for the simultaneous destruction of a vehicle and troops located on its armour) that Russian troops began actively using from at least 2016. Drone-based munitions have more recently added a whole new aspect to EOD tactical challenges, enabled by rapidly evolving technological possibilities.

In summary, stage 1 established a more formalized architecture for collecting lessons, but substantial maturation was required. Poor analytical capacity, dissemination barriers, and ingrained pathologies prevented meaningful organizational change. The same root causes of problems recurred in reports, evidencing weak implementation of recommendations.

Stage 2: Building Analytical Muscle (2019-2022)

With guidance from NATO advisors, Ukraine updated its LL structures and processes between 2019-2022 to enact Lessons Learned doctrine. National LL courses launched in 2021 trained 82 LL officers, with clearer responsibilities assigned across the chain of command that designated on-site collection points (LL Staff Officers (LLSO)/LL Points of Contact (LLPOC)), analysts at tactical and operational headquarters (LL Analysts), and a central LL Section for aggregation. While the intensity of hostilities decreased from late 2018, and frequent LL bulletins had some effect in raising awareness of EOD threats, learning about the changing technologies continued to be a lifesaver. Whereas in 2015, IED accounted for the majority of attacks (123 IED accidents), by 2018 anti-personnel mines had become prominent (20 attacks 2018; 17 in 2019; of which PMN-2 APMs accounted for 12 and 16 accidents respectively).

These data were collected via the Lessons Learned process. However, progress remained slow and information quality was variable; even acknowledged lessons typically took three months to be disseminated. This was evidenced clearly in the frequent repetition of the same root causes for mine problems in the 21 LL bulletins issued in the period leading up to February 2022; it was also reflected in the repeated recommendations regarding the need to implement remedial actions in fundamental areas: (i) recruiting and proper training of EOD personnel to fill often half-strength units; (ii) mine awareness training of troops and junior officers; and (iii) urgent needs to repair and provide spares for key engineering equipment. The implementation of remedial actions improved to a degree through the innovation of deploying Mobile Lessons Learned Teams (MLLT) that could engage units at their worksites; but resourcing of the MLLTs and senior leadership attention to their findings were not adequate.

Leadership attention improved, however, after the UAF Lessons Learned branch led a cross-functional systematic evaluation from January 2021 to February 2022 of why learnings from 2014-2016 - with EOD a key issue - and more recent data collections were failing to have enough impact. One of the best examples was the cross-functional team (CFT) established in the Joint Forces Operation HQ (J7) in January 2021 to study combat experiences and pursue remedial actions across procurement, doctrine, training and related issues. Six MLLTs operated from April 2021 to November 2022 to provide in-depth research on military operations and analyze the most important experiences of the Donbas war in 2014-2015. Following that internal review, the UAF implemented refinements to begin to convert tactical observations to overarching insights. The central Lessons Learned Section provided technical oversight, publishing recurrent analytical products drawing together narratives that helped explain the evolving situations in terms that previous 'Cold War' mindsets could not easily embrace. This formalized architecture facilitated the accumulation of data for trend analysis and developing of linkages between themes.

Resulting procedural improvements addressed some of the identified key shortfalls. Mandatory mine safety training courses increased familiarity with fundamentals of good practice across the force; central guidance expanded perspectives beyond basic mine awareness to broader capability issues like maintenance of the outdated engineering equipment. Analysts increasingly paired problems with recommendations for action. Linkages to knowledgeable actors working with civilian communities for humanitarian de-mining, in particular the HALO Trust[1], provided a source of best practices that the UAF could learn from. Year-on-year, the LL bulletins helped reduce mine accidents in the UAF (Figure 3).

However, turning recommendations into actions remained stubbornly challenging. Implementation and enforcement procedures remained weakly developed. Dissemination timelines marginally improved but still averaged

Figure 3: Number of Mine accidents in the UAF (2015-2019); Source: LL Bulletin, June 2020, NAA

two months. Without modern information systems, reports depended on adhoc emails, bulletins and military journals. Enduring manpower and skill gaps undermined analytical quality. Furthermore, the antiquated database was not replaced by an easily-accessed LL portal, despite the many recommendations made by the LL function; weconclude that cultural resistance to transparency persisted.

1 https://www.halotrust.org/where-we-work/europe-and-caucasus/ukraine/

Stage 2's strengthened analytic focus honed Ukraine's ability to identify lessons. But observations seldom led to solutions. Chronic inadequacies in implementation procedures, dissemination, training and leadership engagement restricted learning's strategic impact.

Stage 3: Adapting Under Fire (2022-Present)

Russia's 2022 invasion provided an unprecedented stress-test, as Ukraine fought to rapidly adapt lessons-learning to new realities. With the nature of conflict transformed, previous observations in the EOD area faced increasing irrelevance. Priorities shifted to challenges like breaching fortified zones and clearing mines under fire – capabilities that lagged due to underemphasis and under-resourcing. Long-identified gaps in specialized engineering units continued to prove challenging, if not potentially catastrophic given the intensity of operational demands.

In response, the UAF moved to reinforce successful innovations while addressing persistent weaknesses. Mobile Lessons Learned Teams again expanded, leveraging their proven embedded role for rapid collection and analysis. Since there were no opportunities to train LL officers at stationary courses, in summer 2023 the LL mobile training group operated in the frontier zone and trained more than 170 LL Officers (LLPOCs and LLSOs). Enhanced training increased the pool of qualified specialists able to translate observations into insights, streamlining lines of communication to accelerate information flow. In these important ways, the UAF was improving its alignment with the evolving NATO Lessons Learned process (Figure 4), combined with an innovative approach to Mobile Lessons Learned Teams.

However, chronic deficiencies continue to hamper organizational learning's contributions to the UAF's overall effectiveness. Inadequate involvement of military leadership in organising the LL process is evidenced in continuing

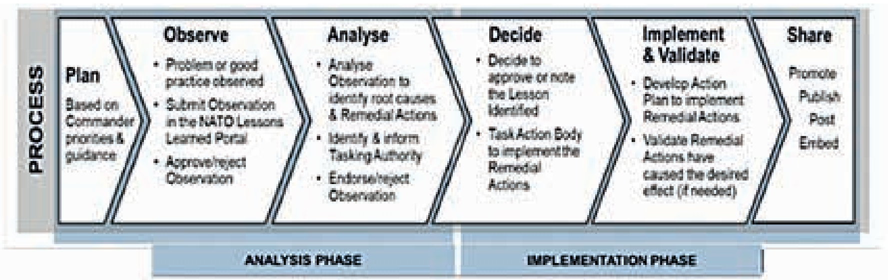

Figure 4: NATO JALLC Lessons Learned Process (source - reference (1)).

low LL awareness of UAF personnel and under-resourcing of learning relative to the complexities and intensity of the threat; these impact timelines and quality of analysis of learnings, and translation into meaningful action. Even with recent efforts to improve timeliness (lessons now taking typically one month to be disseminated), entrenched hierarchical gatekeeping and dissemination methods delay information sharing; weak enforcement procedures can restrict follow-through on recommendations.

Conclusions and Action Recommendations

Three key enablers stand out from the Ukraine case for determining the Lessons Learned process' ultimate impacts on EOD and other challenges, based on Ukraine's continuing maturation:

First, cultivating expertise through trained specialists with the access and trust to link perspectives – epitomized by Mobile Lessons Learned Teams – is invaluable for distilling observations into action. Second, becoming consistently rigorous in methodology, enabled by aligned doctrine, transforms information into knowledge. Finally, senior leadership engagement to mandate greater transparency and accountability breaks down cultural obstacles. Replicating the resulting innovations in EOD can unlock learning's latent potential for the wider military.

As action steps, we identify 10 recommendations that have been proposed to address these requirements to improve military learning:

1. Cultivate expertise through dedicated, trained Lessons Learned specialists able to link perspectives across the armed forces, e.g. Cross Functional Teams [4].
2. Embed Lessons Learned roles within operational units, facilitating trust and access.
3. Methodological rigor to improve information quality and enable better alignment of doctrine and standards with effective practice.
4. Senior leader emphasis on transparency and accountability to reinforce learning behaviors, prioritising the linking of tactical, operational, and institutional perspectives.
5. Timely dissemination channels unimpeded by hierarchies and geography.
6. Continuous analytical capacity for trend analysis of accumulated data.
7. Implementation procedures to transition from identified lessons to solved problems.

8. Validation processes to close feedback loops and confirm integration of identified lessons into remedial actions that transform capabilities.
9. Sufficient resourcing and personnel to maintain the analytical bandwidth under fire.
10. Responsive adaptation of systems and priorities to evolving threat environments.

For Ukraine, the jury remains out on applying lessons amidst an existential war where EOD is a central challenge. While maturing capabilities show promise, lagging institutional support fosters disconnects between concepts and implementation - for example, the UAF remains tied to an obsolete, under-used LL database rather than implementing the Lessons Learned Portal as recommended by the NATO JALLC. Overcoming chronic challenges will shape learning's contributions as the war pushes forward. Their model of progressive improvement, however, provides signposts for militaries worldwide striving to institutionalize success despite uncertainty. With willpower and resources, harvesting failures' benefits remains within reach.

Acknowledgments

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[4] On the potential of CFTs to enhance military learning, see Tom Dyson, "A Revolution in Military Learning? Cross-functional Teams and Knowledge Transformation by Lessons-learned Processes," European Security 29, no. 4 (2020): 483-505, doi: 10.1080/09662839.2020.1795835.

** NATO practitioners interested in discussing CFT good practice are welcome to contact Prof. Dyson at tom.dyson@rhul.ac.uk.*

Virtual Reality For EOD Training

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The work of EOD operators is extremely demanding and requires a great amount of knowledge, skills and ability to utilise them correctly depending on the situation. On the other hand, there is a technology, that has a potential to support the EOD training substantially. Virtual Reality, by its nature, has endless possibilities and can be very helpful in places, where real-world solutions are impossible or very demanding. This article deals with the possibility of connecting technological world with the military and offers a decisive conclusion about the importance of implementing Virtual Reality in the training of EOD operators with regards to all the main advantages and disadvantages of this technology.

Introduction

In 1962, the first Virtual Reality machine was patented by cinematographer Morton Heilig. It consisted of a large booth, fitting four people at a time and combining various technologies to stimulate different senses. The machine included full colour 3D video, audio, vibrations, smell and even atmospheric effects like wind. [1]

For the following 62 years, this technology, as any other technology, has been advancing rapidly, up to the form as we know today – a headset connected wirelessly with a couple of controllers (Figure 1). The design of the headset blocks all other visual possibilities, thus immersing a user inside the computer-programmed software, which is in the form of a completely new environment. Using the controllers in each hand and potentially with additional hardware a user can act in this virtual environment as they would normally in real life. Even though most actions of real life are imitable in virtual reality, some actions, especially those requiring precision or very specific skill, are not yet able to be effectively utilised.

Figure 1 – Classic VR set – headset and a pair of controllers

VR has been introduced into all kinds of specializations, starting with gaming and slowly moving to assist workers in different industries, including the military. Since ancient times, simulations have been used by commanders to help prepare for battles. Nowadays, with more advanced simulators also enhanced by VR, the possibilities are much bigger, with the arguably biggest advantage lying in its potential for the training. Overall, the real-life effects of weapons and combat actions are difficult to emulate in a training area. However, most challenges of the modern training, like risk, time and material are easily overcome by using virtual reality.

Virtual Reality for EOD training

Explosive Ordnance Disposal is a very specific branch of the military, especially in regards to the training. While the extent of the theoretical knowledge required for one to become an EOD operator is relatively large, it is parried

1 https://virtualspeech.com/blog/history-of-vr

with a need for a great understanding of different processes, as well as the ability of making the correct decisions all the time, depending on the varying conditions and circumstances. For all of these requirements, solutions exist in real-life training, which is approached by nations in various ways. These solutions, however, demand time, effort and resources and may be very exhausting, outdated, dangerous and for some people difficult to follow.

On the other hand, the possibilities of virtual reality have a huge potential to tackle all of the aforementioned challenges. By its nature, a virtual environment can be anything we want it to be. The conditions for the training in VR can be easily set up and accommodated to the training needs of an user, using different ordnances, accessories or tools comes with no cost nor limitations, except for those programmed by the software engineers. Furthermore, tasks can be repeated as many times as necessary, without any risk whatsoever, thus making this a perfect tool for repetitive training, enhancing required skills and saving time. [2]

In today's world, much more than ever, it is very difficult to focus on one specific task like studying or conducting long and exhausting EOD training with all the distractions around us. And that is where the overall advantage of virtual reality lies, in the very nature of the technology, which means immersing an individual in the virtual environment and completely absorbing themselves in their task. Blocking all the noise by removing any interferences leads to enhanced focus, whether it is learning about ammunition or practising EOD scenarios, also helping with memorizing and developing decision-making skills.

Additional (secondary) benefits of using VR

Using modern innovations in EOD is detrimental to keeping up with other branches of the military, that have been using the latest state-of-art technologies, to a great extent due to the potential of taking part in combined joint exercises, which seem to be the future of the operational planning and battle preparation. [3]

Currently the overall focus in the extended reality sphere is to support an individual in their training or mission. However, with the development of higher computing power and network speed, we may see a shift towards the

2 https://www.pwc.com/us/en/tech-effect/emerging-tech/virtual-reality-study.html

3 https://www.idsa.in/issuebrief/military-applications-of-virtual-reality-and-beyond-aupadhyay-140923

metaverse – digital three-dimensional worlds shaping the next generation of the internet and allowing conducting large-scale military operations completely in the virtual environment. [4]

On top of that, using new technologies is more appealing to the younger demographic, which may be needed to attract the next generation of EOD operators. This will become more necessary in the future, where technologies will be a dominant part of most professions, and those occupations that will not keep up with the latest trends will have a hard time attracting young operatives to do the required job.

Drawbacks of conducting EOD training in Virtual Reality

As with any other technology, Virtual Reality has proven to have some issues, especially when the technology is still being developed and updated. Amongst the commonly known problems belong the health concerns, especially motion sickness, eye strain, discomfort and physical issues caused by the lack of movement or loss of awareness of the real-world surroundings. [5]

In regard to the EOD training, however, many advantages of this technology are balanced by various challenges. The EOD being a very specific area of expertise shows differences in the procedures, tools and overall approach to the training amongst different nations, even within the NATO. Thus, developing a tool that would fit all of the nations' standards and requirements is more challenging than it first may seem. Moreover, the nature of EOD is that it is a very sensitive activity, with extreme attention to detail. Current versions of VR hardware either do not offer a desired quality of virtual images or their achievement is very challenging and costly. However, with constant advances in the technologies and computing power, it is very possible, that tackling most of these challenges will be a matter of time and resources.

Conclusion – Project ETACS

Finally, there is a project ETACS – being conducted by the Explosive Ordnance Disposal Centre of Excellence, that focuses mostly on developing a specific tool to address EOD training in NATO countries. As time showed, dealing with the mentioned challenges is the most important part of the de-

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4 RITTERBUSCH, GEORG DAVID; TEICHMANN, AND MALTE ROLF (February 9, 2023). „Defining the Metaverse: A Systematic Literature Review". IEEE Access. 11: 12368–12377. Found at: https://ieeexplore.ieee.org/document/10035386

5 https://capsulesight.com/vrglasses/disadvantages-of-virtual-reality-vr/

velopment of the project, in order to create a software that will be generally useful for EOD training units across NATO as well as EOD operators as individuals.

The results of the development so far showed that possibilities of the VR even today allow us to tackle every challenge successfully, either directly or by choosing different methods, for example combining a PC application with VR glasses and creating a toolbox of different options, to be applied to conduct EOD tasks according to each nations' procedures (Figure 2). Moreover, when new updates of the technology are available, the EOD COE will be ready to implement new possibilities and create a solid, well-founded tool to support EOD training in NATO.

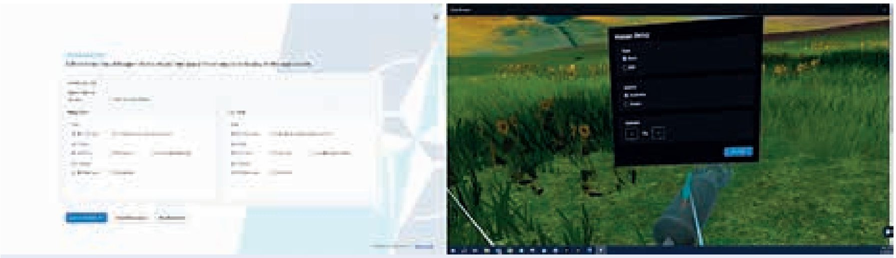

Figure 2 – Connection of the PC application and virtual environment

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Considerations in the light of the NATO EOD Demonstrations and Trials 2023

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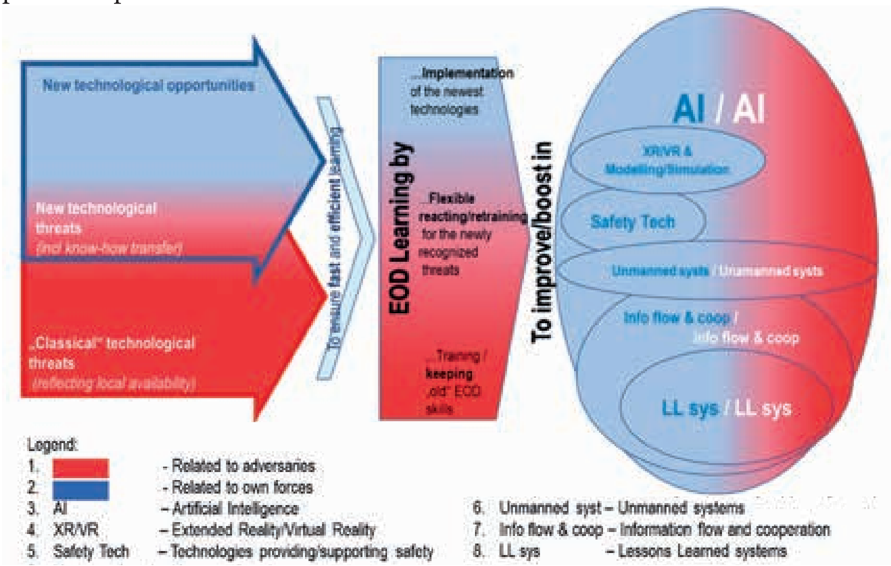
Mr. Vojtech Fucek serves as an analyst of the Lessons Learned and Analysis Branch at the NATO EOD Centre of Excellence. Drawing from his extensive background in the Slovak Armed Forces, his expertise spans across various command, staff, and international roles. Since 2012, after retiring from military service, he has dedicated himself to the EOD community, specializing in insightful analyses and long-term projects designed to make a positive impact in the EOD capability transformation efforts.

The eponymous event provided the EOD COI with networking opportunities, introducing new technologies, and discussing various perspectives on particular issues. At the same time, the participating SMEs and guest speakers shared their experiences, knowledge, and ideas worth considering further. The event served as a valuable source of thoughts to be analysed and worked out for the future benefits of EOD COI. In line with that, the EOD COE internally analysed various event aspects and worked out some considerations in light of the NATO EOD Demonstrations and Trials 2023.

The considerations below are purely aimed at being a kind of **inspiration and food for further thoughts** on how to address some of the current and upcoming EOD challenges. The summarized considerations are not to be **strict guidance or commitments for the EOD COI. Their designations are primarily for use** by the EOD staff officers responsible for the national/international EOD capability developments, commercial technological project developers, or some research entities. All readers are asked to note that some of the considerations are not based on particular scientific studies/research and verified procedures or standards. Still, they reflect the EOD COE´s creative and visionary thinking about the future technology utilization in the EOD area. In addition, no guest speaker shall be denounced for the derived considerations, perspectives, and recommendations.

The concept of the considerations reflected the conference block topics and was focused on some chosen EOD-related clusters as depicted and simplified in picture 1.



Picture 1 – The concept of the considerations.

In general, the EOD COI as an integral part of security and defence capabilities is influenced by technological advances. Such a progress brings at least three challenges:

- New technological opportunities
- New technological threats
- Further misuse of "classical" technologies

These three situations require the EOD COI to ensure their **fast and efficient learning**. Such learning might demand establishing the following mechanisms:

- **Implementation** of the newest technologies
- Flexible response and retraining for newly recognised threats
- **Maintaining** and training "traditional" EOD skills

Each national EOD COI is at a different level of developing their EOD capabilities and the particular EOD COI differs in its ambitions. Despite that, the mentioned mechanisms may require further advancement and improvements in these EOD and technology-related clusters:

1. Simulations/modelling/extended reality (XR)
2. Technology supporting safety for EOD SMEs
3. Unmanned systems
4. Information flow and cooperation (including LL systems)
5. Artificial Intelligence

1. Simulations/Modelling/Extended Reality (XR) as a supporting tool for EOD operator training

1.1. Purpose and Features:

Simulations and modelling software have been used for several decades and also XR systems are not new things at this time. In general, simulations imitate either situations or processes or both of them. XR takes the issue further as it can not **only** simulate situations and processes but can mirror, combine, and augment the real physical world with extra data from cyberspace. Such features provide opportunities to support human objectives at least in **education and training, research and experimentation, analyses, evalua-**

tion, optimization, and problem-solving. As the development and employment of EOD capabilities also embrace particular objectives in the mentioned areas the EOD COI could benefit from such technologies on a bigger scale. It is needed to recognize more deeply what positives and challenges can be expected when the EOD COI is more eager in their implementation and usage.

1.2. Potential benefits for EOD COI:

1.2.1. Depicting any benefits of XR systems for EOD requires looking at them via settled objectives for EOD capability development embracing at least:

- Ensuring adequate **EOD qualifications and experience** to conduct successfully particular EOD tasks and missions
- Having a properly established **EOD training system** for individual and collective EOD training
- Having a settled **mechanism for fast new technology implementation** within the EOD capability development

1.2.2. Each of the mentioned objectives could benefit from the XR systems as such solutions provide several key advantages:

- **Complex Problem Solving/Handling** (e.g. simulation would refer not only to the EOD operator´s task but tasks also executed by the other involved parties)
- **Decision-making Support** based on Data Collection and Analysis (e.g. 3D pictures provide EOD operator with a better understanding of possible problems or solutions)
- **Safe Learning Environment** (e.g. handling explosives in virtual reality)
- **Accelerated Learning, Customization, Repeatability, Interactivity** (e.g. very easy to change or pre-set climate or terrain conditions to practice similar tasks in very different circumstances; setting up learning tasks in incremental steps and repeating them by the tracked progress)
- **Team Training** including broader accessibility (e.g. getting a better picture of what a teammate is doing at the same time, interchanging roles in an EOD team, evaluating the team cooperation)

- **Cost and time Efficiency** (although XR systems have higher acquisition costs, they would save resources on EOD operator training by providing adequate preparation before hands-on training)

1.3. Some synergic effects amongst the XR systems and other technology progress:

Naturally, progress in other technologies will influence the possibilities of the XR systems. It can be expected that headways, at least in the following four areas, will boost synergic effects for XR systems:

a) **Data collecting technologies** (e.g. new sensors attached to nano-drones can provide more or different details for XR systems)

b) **Data processing** (e.g. faster big data processing in line with further miniaturization could make some XR systems more utilizable for EOD operator´s personalized training or situational awareness)

c) **Artificial intelligence** (e.g. AI can bring more realism into XR training for EOD SMEs as it can play intelligent adversaries and provide dynamic changes in the situation evolution)

d) **Video/audio/haptic interfaces between technology and humans** (e.g. not only head-up displays on the EOD operator´s helmet but some smart textiles could indicate or display some data as temperature growth or so)

1.4. Some limits/risks/challenges related to the XR Systems:

Besides numerous advantages and benefits, there are some concerns to be considered when implementing or using XR systems within the EOD area. The EOD COI should familiarize itself with at least the following limits and challenges before clarifying their requirements for designing “their” XR systems:

a) **Simplification and Inaccuracy of 3D Models:** As the simulations naturally do not embrace real-world complexity and model fidelities are limited, such simulations can potentially lead to inaccurate assumptions, results, or predictions. In true, many things are difficult to simulate for instance human behaviour (e.g. EOD operator´s preference of particular RSP/technology/tools) or external influences (e.g. movement in muddy soil, or typical smell in a particular situation that can EOD operator recognize) or unexpected events/acting (e.g. dynamic and unclear adversary response on particular EOD operator´s deeds).

b) **Limited Real-Time Feedback and Adaptation:** It would be more realistic if the real-time feedback and system adaptation were perfectly harmonized during simulations of the EOD training (e.g. simulation of the scenario when an EOD operator approaches the explosive ordnance and suddenly heavy rain starts falling and he/she has to react immediately on the different terrain conditions, different visibility etc.).

c) **Human-Machine Interaction:** It should be considered that simulations of the EOD robot operating might have some limits as (at least):

   - Delays in real-time communication (e.g. delayed robot actions, latency in a robot control)
   - Inaccuracy in sensory feedback (e.g. more limited data delivered from a simulated robot than data from a real EOD robot)
   - Different physical limitations of the simulated robot and the real one (e.g. simulated robot can go up to a 45-degree slope as programmed but the real one can go even further due to favourable terrain conditions or vice versa).

d) **Psychological Factors:** There are challenges to simulate some fundamental human factors within EOD tasks (e.g. management of the EOD operator's psychological stress, pressure, fear, mental state, or/and other decision-making factors in high-risk situations). In addition, there may be some mental blocks in using simulations in the EOD training as such technology requires new approaches to learning (e.g. long-serving generation of EOD SMEs used to be taught mainly through hands-on methods while youth is generally familiar with virtual reality and computer games/simulations) and EOD COI should consider to use verified and reliable procedures, tools and technologies. There is a need to work on mindset to be ready to implement new supportive technologies while not compromising the EOD operator´s safety.

e) **Over-Reliance and False Confidence:** Relying purely on current simulation systems could lead to false confidence and not being ready for unpredictability and threats of the real world. Simulations should be seen as a supplement to, but not a replacement for, practical field training and experience.

f) **Cyber Security Concerns:** As with other computing/communication systems, the simulation training technologies are facing security breaches and cyber-attacks (e.g. leaking RSP to the third party) so protection for data and system disruptions should be in place when implementing simulation technologies.

Images source: https://www.bing.com/images

g) **Cost and Resource Demands:** Although practical field training is costly, the initial setup and development of simulation systems can require higher resources. In addition, maintenance or updating can be demanding as well as it needs not only financial inputs but also adequate expertise support.

1.5. Some Outcomes and Inspirations for the EOD COI

In line with the aforementioned benefits and drawbacks, the EOD COE believes that XR technologies can and could be exploited by the EOD COI on a wider scale, especially in the EOD training. XR systems should not replace practical field training but there is a big space for utilization of the XR technologies within the EOD training. The EOD COI is recommended to analyse further the following ideas and proposals:

A. **Training enhancement.** The progress in XR technologies is speeding up, thus XR products will inherently mature accordingly. Therefore, the EOD COE advocates for boosting efforts in the development and implementation of the XR systems into the EOD individual and collective training. Such efforts could be focused on (at least):

a) interactive XR EOD exercises either as standalone or in a wider context of force deployment

b) setting incremental mind challenges for the EOD training audience (e.g. replicate a layered EOD training gradually challenged within the XR environment)

c) establishment of a database of explosive ordnance (EO) with its 3D models for XR systems (including sequencing of building up particular 3D models of EO)

d) more complex and efficient evaluation of the EOD team or individual training via XR systems (e.g. possibilities to track performance down to particular personal activities)

B. **More realism** is needed in the XR systems designed for the EOD simulations and therefore EOD COI is encouraged to:

a) Establish regular platforms for cooperation with developers to design XR systems for EOD training purposes. It could embrace several projects in designing standalone/interconnected simulations purely focused on particular EOD responsibilities and training objectives (e.g. simulations to practice the EOD operator´s approach to UXO in different climate/terrain conditions or simulations of how to operate particular EOD robot)

b) Incorporate (into current and future XR systems designed for the EOD scenarios) many missing features as simulations of:

- particular terrain/weather conditions (e.g. heavy rain, strong wind, snowfall, etc.)
- some cues/entries recognisable by an EOD operator (e.g. smell of some explosive components, or feeling unstable surface when an EOD operator steps into mud or soft sand, or feeling of touch of some types of surfaces or its temperature)
- some human factors relating to an EOD operator (e.g. a sensation of being wounded or in pain, fatigue, stress or fear, reaction in confined areas)
- communication difficulties such as limited radio range, interference, jamming, or other unpredictable situations (e.g. a child suddenly appearing on the spot despite cordoning).

C. **Improve EOD situational modelling** by exploiting Artificial Intelligence (AI) support for reading photos to get more realistic simulations of particular environments. In addition, AI could incorporate also some historical photos (e.g. displaying the current state of a particular urban area and if needed a filter could display how the same area looked like before).

D. **Targeted recruiting.** In general, the EOD COI is facing challenges with recruiting new EOD operators. The computing games and virtual world are natural and attractive to young generations. Such an interest and abilities could be a significant factor for the young generation. Within EOD COE we believe that EOD COI could be more initiative in the development of virtual EOD games not only as a training tool but also as virtual games for particular interest groups (e.g. groups of age 3-6, 7-11, 12-16 years old). Such virtual games would develop the technical skills of upcoming generations and shape the EOD picture of life-saving missions. These factors could contribute to the attractivity of EOD jobs for future generations.

2. Technologies supporting safety for EOD SMEs:

2.1. Purpose and Features: Protection and safety in the EOD must be considered as a mosaic of interconnected security aspects for:

- EOD individuals and teams (e.g. when an EOD operator approaches an EO or safety measures during training)
- military bases (e.g. blast protection of military bases during an expeditionary mission)
- particular entry points (e.g. scanning for explosives luggage at the airport or suspicious vehicles at the checkpoints)

Such complex security requires the harmonization of contributions and advancements in several EOD areas and technology–related clusters (e.g. EOD education/training including XR systems, Personal Protective Equipment, Unmanned systems, Communications systems, Lessons Learned mechanisms, and Artificial Intelligence). This cluster is primarily focused on security aspects for the EOD individuals and teams while the other EOD-related technologies are detailed in the other chapters of these considerations.

2.2. Some considerable benefits for EOD COI:

The benefits of the mentioned technologies for the EOD should be perceived through at least two paramount EOD goals:

- To save lives from the danger of EO
- To preserve the lives of EOD personnel

Concerning the safety of EOD personnel, the long-term goal is to protect the EOD operator from any unexpected life-threatening action/explosion appearing on the scene. The best way how to make it is to let technology do dangerous jobs on the spot (work remotely). All above and below-mentioned technological advancements, headways, and inspirations in the other clusters are and will be even more supportive of these efforts in the future. Before the majority of jobs are done by autonomous unmanned systems, improvements, and innovations in Personal Protective Equipment (PPE) will provide the EOD operators with the following benefits:

A **Physical:**

a) Enhanced Protection from Explosions and other threats (e.g. fragmentation, blast effects, and chemical hazards)

b) Reduced Risk of Injury and Death as a result of multi-threat protection

B **Operational:**

a) Improved Ability to Perform Duties (e.g. enhanced mobility, dexterity, comfort, integrated improved communication, improved visibility, sensing, and further customization options according to individual requirements)

b) Extended Operational Duration (e.g. increased longevity and durability as better resistance to abrasion or punctures)

C **Psychological:**

a) Improved Psychological/Social Well-being (e.g. boost the EOD operator's mental confidence, trust in technology, and minimize stress)

b) Reduced Reliance on Remote Methods (e.g. incremental development of trust in own individual capabilities not only reliance on remote controlled technologies)

c) Enhanced Image and Public Perception (e.g. protection of the EOD experts seen as responsible attitude towards the deployed personnel. It can indirectly and positively influence recruiting for EOD).

2.3. Some Synergic effects of the progress in Personal Protective Equipment and other technologies:

Advancing in several technological clusters will have synergic effects on the further development of PPE and related contributors to the safety of EOD personnel. The innovations in the following areas could have a cumulative influence on further improvements for the EOD operators:

A **Physical protection and support**

a) New materials for bomb suits, body armour or helmets (e.g. smart textiles heading from passive smart textiles through active ones up to very smart textiles capable of adapting their behaviour to the circumstances, or new types of carbon fiber-reinforced polymer composites with high durability and lightweight, or usage of the new closed cell foams ensuring better water resistance)

b) Advanced exoskeletons (e.g. hybrid or powered exoskeletons providing additional strength and endurance)

c) Wearable health monitoring (e.g. heart rate, stress levels, blood glucose, and other physiological parameters providing valuable insights and indirectly supporting the EOD operator´s safety)

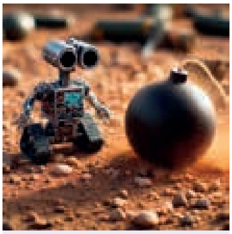
B **Operational contributors to the EOD operator's safety**

a) Progressive smart sensors and monitoring (e.g. technologies providing real-time monitoring)

b) Connected intelligent PPE Networks, Internet of Things, and advanced communication (e.g. Hard hat networks tracking if the EOD operator´s helmet and head were exposed to a sudden impact and providing data to a supervisor)

c) Data Analytics, Extended Reality, and Decision Support (e.g. emerging big data technologies in connection with AI will provide alternative insights supporting the EOD operator´s safety)

d) Further developed robotics and unmanned systems (e.g. nano-robots capable of very close detection of a particular IED without initiating its explosion)



Images source: https://www.bing.com/images/create/a-picture

2.4. Some limits/risks/challenges related to the PPE and other supporting technologies:

Although progress in PPE developments is remarkable the innovations are connected with several current challenges as highlighted by some EOD subject matter experts:

A **Balancing Protection and Mobility:** Bomb suit armour is designed to withstand the impact and fragmentation of explosions so it can be bulky and heavy, limiting the operator's mobility, and agility, and to perform delicate and intricate tasks. In addition, upcoming solutions such as powered exoskeletons also face several technical challenges for instance limited power and recharging for exoskeletons.

B **Heat and Discomfort:** The high heat inside an EOD bomb suit can cause heatstroke if body temperature is above 40 degrees Celsius or the EOD operator can suffer from heat exhaustion and dehydration. Also, an adequate breathing system and level of bomb suit customization/personalization (including easy doff/don and durability) make a difference in conditions for EOD task execution.

C **Limited Visibility and Situational Awareness:** The helmet itself and the whole bomb suit restrict the EOD operator from his natural observation of surroundings. It brings extra burden to perform the EOD tasks at his or her best.

D **Integration of Technology and Compatibility with Tools and Equipment:** To integrate some particular innovative technologies (e.g. XR, AI, or the advanced head-up displays) requires resolving several technical issues in the future. Also, there are recorded some difficulties in using specialized tools while having the bomb suit on.

E **Communication Challenges:** The suit itself can limit (verbal and electronic), communication. Also, such communication can be degraded by other conditions, technical issues, and problems like device malfunction, incompatibility/interoperability, slow or unreliable internet connections, data usage limitations, latency, digital noise, etc.

F **Cost and Accessibility:** Unfortunately, innovations in PPE are connected with higher expenses, so some entities can have some acquisition concerns.

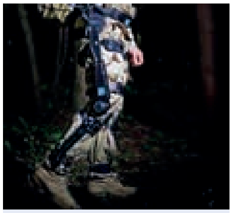
G The challenges related to the development of new smart sensors, advanced communication technologies, AI, unmanned systems, and XR capabilities are addressed in detail in other paragraphs of these considerations.

2.5. Some Outcomes and Inspirations for the EOD COI

EOD COE recognises the development of PPE as an intermediate step towards increasing the utilization of unmanned systems for EOD tasks. The Centre also acknowledges that fully autonomous systems will remain a long-term aspiration. For the foreseeable future, remote-controlled (RC) or semi-autonomous systems will play a significant role in augmenting the capabilities of EOD technicians. Therefore, the efforts in PPE development should fervently seek solutions for current recognized limits/risks/challenges related to PPE and other supporting technologies. The EOD COI could be of immense assistance in these endeavours by further articulation of EOD requirements and imaginative ideas. The EOD COE presents the following considerations and inspirations concerning:

A **Balancing Protection and Mobility by development and using:**

- **Advanced materials** providing better protection while not compromising flexibility and dexterity (e.g. Kevlar or other fibres, graphene, carbon nanotubes, shape memory polymers changing their shape in response to an external stimulus)
- **Layered coating ensuring multiprotection** (e.g. nano-coatings enhancing resistance to chemicals, heat, or biological agents, self-activated protective shields, and emergency response textiles providing shelter in emergencies)



Images source: https://www.bing.com/images

- **Customization of PPE** (e.g. 3D printing utilizing personalized and fitted PPE minimizing restriction of the operator's movement)
- **Powered exoskeletons** (to be equipped with quantum batteries) to enhance strength and endurance (e.g. the hybrid assistive limbs)

B **Heat and Discomfort mitigated via:**

- **Adaptive cooling and ventilation** technologies (e.g. Phase-change materials absorbing and releasing heat accordingly, thermoelectric coolers for localized body parts cooling, adaptive active liquid cooling systems, miniaturized and integrated vapour-compression refrigeration systems)
- **Advanced moisture-wicking materials** (e.g. hydrophilic polyurethanes and hydrophilic acrylics, nanofibers, bio-based cellulose, chitin polymers, and other biodegradable and sustainable alternatives)

- **Simplified doffing and donning** (e.g. newly developed quick-connect and quick-release mechanisms could ensure for instance one-step bomb suit doffing and donning)

C **Limited Visibility and Situational Awareness to be improved by utilization:**

- **Smart helmets** refined by:
    - **Built-in advanced sensors detecting multi-hazards** (including night vision, recognition of smells from outside, getting data from smart glows capable of identifying type of objects surfaces)
    - **Integrated cameras and displays** that allow the EOD operator to see 360 degrees around and above him/her
    - **Solid but transparent materials** to ensure both protection and better visibility
    - **Augmented reality technology** to provide overlay information onto the operator's field of view
- **Artificial Intelligence** to analyse data from various sources and provide predictive analytics for potential safety risks and even stimulate adaptive body armour to EOD operator´s movements

D **Integration of Technology and Compatibility with Tools and Equipment to be boosted by:**

- further development of **standardized interfaces** for PPE and tools
- utilization of **wireless technologies** allowing the EOD operator to control tools and equipment remotely (including voice operating)
- Implementation of **wearable information technologies** (e.g. picture 2 shows the AI platform introduced by Apple in 2023)

Picture 2 – AI platform from Apple Company
Source: https://link.springer.com/article/10.1007/s42235-022-00289-8

E **Communication challenges to resolve via:**

- **Smart communication** devices compatible with the PPE and resilient to electromagnetic countermeasures (e.g. Ultra-wideband, Free-space optical, Terrestrial laser communication, and Quantum communication devices)
- **Voice assistant and hands-free communication** systems (including voice amplification technology to help the operator communicate in noisy environments)
- **Text-to-speech** and speech-to-text technology to enable communication with the operator if he/she cannot speak.
- **Connectivity of PPE to the Internet of Things** (e.g. adaptive body armour would communicate with other technologies and if needed then propose to the EOD operator to activate adequate protection measures)

3. Unmanned systems:

3.1. Purpose and Features:

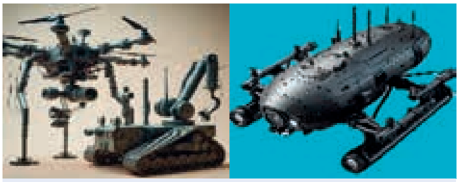
In general, unmanned systems (UmS) are either remotely controlled or autonomous devices designed to support a variety of EOD tasks including identification, neutralization, and disposal of explosives. The capabilities of these systems (e.g. remotely operable, communication and connectivity, versatility, data collection, autonomy, reliability, cost-effectiveness, adaptability, and learning) provide the EOD SMEs with:

- Improved safety (e.g. operating from a distance in hazardous or hostile environments)
- Improved efficiency (e.g. UmS provide more data even from hardly accessible spots, these systems can work continuously without breaks or reluctance)

UmS typically include robotic vehicles, drones, and other remotely operated platforms equipped with sensors, cameras, manipulators, and specialized tools to perform EOD and related tasks. Mostly, the UmS used for the EOD embrace:

- **Unmanned aerial vehicles (UAVs):** UAVs can be used to survey areas for potential explosive devices and to provide real-time imagery and data to EOD technicians.

- **Unmanned ground vehicles (UGVs):** UGVs can be used to approach and inspect explosive devices, and they can even be used to disarm them in some cases.



Images source: https://www.bing.com/images/create/a-picture

- **Unmanned underwater vehicles (UUVs):** UUVs can be used to inspect underwater explosive devices, and they can also be used to recover them from the water.

3.2. Some selected benefits for EOD COI:

The UmS benefits for the EOD COI are aligned with the above-mentioned purposes and capabilities. These systems support the EOD operator´s safety and their advantages can be exploited during any phase of the EOD mission (e.g. pre-deployment, identification, disarming, recovery). Overall, the EOD SMEs can utilise a great number of advantages provided by the UmS as:

- increased safety
- remote operation and control
- reduced physical strain and mental stress (e.g. moving some heavy materials or technology does not have a self-preservation instinct)
- rapid deployment and versatility
- increased situational awareness
- improved precision and accuracy
- extended operational reach (e.g. access into confined spaces or hazardous environments)
- reduced risk of collateral damage
- cost-effectiveness

3.3. Some synergic effects amongst the unmanned systems and other technology progress:

The current unmanned systems are the result of a continuous process of innovation and technological advancement going from the Industrial Revolution via the digital revolution up to the rise of robotics and unmanned systems in the 21st century. In line with headways in other technologies, even the UmS for the EOD reflects and will reflect trends to move from remotely controlled through semi-controlled to fully autonomous systems. Although there are and will be many challenges (technological, legal, and moral) to be resolved, the current and upcoming assets for the EOD could apply and integrate synergic effects of the following key technologies:

- Artificial Intelligence (AI) and Machine Learning
- Sensor Fusion
- Edge Computing.
- 5G Connectivity
- Extended Reality (XR)
- Swarm Robotics
- Energy Harvesting and Storage
- Advanced Materials and Manufacturing
- Robotics and Manipulation
- Cybersecurity Measures
- Autonomous Navigation Systems
- Human-Machine Collaboration Interfaces

3.4. Some limits/risks/challenges related to unmanned systems

New things bring new challenges. Also, the implementation of the unmanned systems into the EOD must take into consideration these three aspects:

A **Technical:**

Source: https://www.peninsulaclarion.com/wpcontent/uploads/2021/09

- **Sensor misidentifications/limits** (e.g. a grenade identified as a rock; or unstable TATP identified as relatively stable TNT, or a chemical/biological contamination not recognized at all)
- **Communication limitations** (e.g. data transfer problems due to signal range/loss, interference, inadequate bandwidth, latency, and terrain obstacles)
- **Navigation limitations** (e.g. navigating difficulties in confined spaces or poor visibility conditions)
- **Appealing for cyber or physical countermeasures** (e.g. need for strong protection against cyberattacks including jamming, hacking, and attempts to take control of the unmanned system by adversaries or their unmanned systems – for example: an adversary UAV overtakes control of the EOD robot and guide it for blowing the EO and itself on the spot)
- **Limited autonomy** (e.g. Most of the current UmS have limited ability for sophisticated judgments and decisions reflecting and adaptable to very complex and unpredictable situations. The

EOD operator´s expertise, experience, and intuition are often needed in the decision-making process for such challenging scenarios.)

- **Technical reliability and maintenance issues** (e.g. malfunction of assets; software glitches; mechanical failures; limited battery life; demand for expertise maintenance and user-friendliness of the UmS)
- **Other technology-related limits** (e.g. limited payloads capacity of UAVs require more flights with smaller payloads; limited dexterity of UmS does not allow removal of the EO fuses; majority of UmS do not have self-preservation mode or black box tracing capability supporting a kind of technological self-protection or tracing for investigation purposes)

B **Human:**

- E**OD manpower, proficiency, and training requirements:** To utilize UmS within EOD requires and will require a sufficient number of EOD SMEs with huge EOD expertise and solid technical background at the same time. This means that requirements for the EOD SME's proficiency and specialized training will be rising. It can be foreseen that updates in EOD proficiencies and training programs will have to keep pace with evolving technologies (e.g. enhanced interpretation of big and fused data provided by several sensors from deployed UmS; understanding of sensing and analytical capabilities/limits of UmS; better orientation and exploitation of 3D visualizations).
- **Umbrella control and decision-making:** Although the current and upcoming UmS can support the EOD tasks in many aspects, only supervision and umbrella control from the "supreme" EOD-qualified personnel will ensure balanced and responsible decision-making.
- **Legal and Ethical Considerations:** The use of unmanned systems raises several concerns:
    - Regulations for the usage of UmS in domestic and international environments (including determination of responsibilities for any failures with lethal consequences)
    - Right to privacy and its potential misuse or invasion

- Public or/and individual perception (e.g. how a hostage can perceive an EOD robot approaching to help him/her instead of help from an EOD operator in a bomb suit)

C **Operational:**

- **Costs and resource challenges** (e.g. acquiring, implementing, operating, maintaining, and training for utilization of the unmanned systems require adequate resourcing which can be challenging for the EOD COI)
- **Limited infrastructural support:** Although many UmS are designed to be deployed independently on local/regional sources still some of them may not be able to operate effectively in areas with limited or destroyed local/regional infrastructure (e.g. power or communication networks).
- **Environmental aspects:**
    - Most UmS are developed to operate effectively in a range of certain conditions/circumstances (e.g. difficulties in cold/hot weather as minus 30°C or more than 40°C, muddy area, windy/foggy weather, or a particularly hazardous environment).
    - Some usage may leave behind negative environmental impacts such as noise pollution, collision with wildlife, propellant residues, emissions, etc.

3.5. Some outcomes and Inspirations for the EOD COI

The UmS has proved to be a very efficient support so their further development and utilisation will be much wider and complex. Analysing current and possible benefits for the EOD and keeping in mind connected challenges, the EOD COE highlights some inspirations for further analyses as below:

- **Intelligent sensing and advanced imaging technologies:** To minimize sensor misidentifications/limits and improve imaging for the EOD operators some promising technologies could be utilized in the EOD area as:
    - Multispectral, hyperspectral, ultrasound and electromagnetic imaging provide identification of materials and structures with greater precision and accuracy

- Terahertz imaging capable of penetration into non-metallic materials
- Photoacoustic imaging for the detection of subtle changes in the structure of explosive materials

Source: https://h4-solutions.com/2019/10/18/passive-terahertz-scanning

- Gas (vapour) and chemical sensors with advanced algorithms for real-time analysis and threat assessment (more senses involved provide the EOD team with better situational awareness)
- "Swarmed sensors" and data fusion to ensure verification of data by several independent sensors (note swarming of specialized sensors seems to be more reliable than multisensory)
- Comprehensive Interconnected Secured EOD "super-database" providing data for the specific AI application developed only for the EOD COI (note such a "super-database" would have to have a well-established data verification mechanism)

- **Real-time data fusion and advanced re-routing connectivity technologies:** To ensure complex information transfers and minimize communication limitations (e.g. signal loss, interference, inadequate bandwidth, latency) some challenges must be addressed:
  - developing robust and reliable data fusion algorithms
  - ensuring interoperability between different data sources
  - protecting sensitive data (including balancing the need for real-time data with the need for data security)
  - training for EOD operators to use these technologies

  Despite these issues, the emerging technologies (as depicted below) could support and be tailored for the EOD SME needs:

  - Multimodal Sensor Data Fusion, Machine Learning-Powered Data Fusion, XR Integration, Cybersecurity for Data Fusion Systems, Networked Data Fusion and Learning Platforms, Adaptive Data Fusion for Dynamic Environments, Hybrid Data Fusion Approaches, Human-in-the-Loop Data Fusion, etc.

    - Software-defined networking, Multiprotocol Label Switching, Dynamic Multipath Routing, Resilient Packet Ring, Quality of Service and Traffic Engineering, Segment Routing, Self-Healing Networks etc.

- **Improvements in cyber countermeasures and resilience of UmS:** In the future, taking control over unmanned systems will become one of the ultimate goals for any party in armed conflicts. Therefore, along with new procedural measures some advanced technical cybersecurity measures could play a crucial role in these efforts as:
    - intrusion detection systems based on:
        - dynamically adjusting detection algorithms reflecting the behaviour of the system or network
        - utilizing clouds to ensure centralized management, scalability, and the ability to leverage advanced analysis capabilities
        - analyses of big data to identify patterns and anomalies indicating malicious activities (note that exploitation of Artificial Intelligence and machine learning in these efforts will become irreplaceable)
        - Combination of different approaches for intrusion detection (e.g. signature-based, anomaly-based, and behavioural-based)
    - Advanced approaches in data backup protocols:
        - Decentralized/Continuous/Encrypted/Automated data backup solutions
        - Cloud-based data backup offering scalability, redundancy, and access to advanced backup capabilities
        - Data loss prevention solutions monitor data usage and identify potential data leaks or breaches
- **Incremental increase of UmS autonomy:** Despite natural reluctance and suspicion of EOD COI about full autonomy of technologies the remarkable progress heading towards more autonomous unmanned systems is unstoppable. Within the EOD COE, we believe that the continual flow of innovations in some technologies (e.g. advanced sensor technologies, improved artificial intelligence and machine learning capabilities, enhanced communication and data exchange,

development of specialized EOD payloads, integration of autonomy into mission planning and execution) will ensure adequate and reliable matureness of the UmS autonomy. The EOD COI is encouraged to monitor developments in aforementioned technologies and consider implementation and employment of such advanced autonomous UmS within:

- Tactical decision-making (e.g. autonomous UmS systems could make partial decisions on extending their data collection range based on real-time sensor data, situational awareness, and their task parameters. For instance, a surveillance UAV can decide to perform its job outside of the planned monitoring area if it has recognized some suspicious adversary actions just behind the settled surveillance area borders).
- Collaborative autonomy (e.g. multiple autonomous UmS communicating together, sharing obtained information, and coordinating their actions to accomplish a common higher commander objective. For example, the EOD robot on the spot will communicate some queries with several UAVs flying over the area and when details are provided by UAVs directly to the robot then it will act accordingly without requiring an intervention from the EOD operator).
- Augmented human-machine teaming (note that instead of replacing humans with autonomous UmS it will be more about intelligence amplification by integrated co-operation between humans and machines. In such teaming, the EOD operator will provide situational awareness, judgment, and creativity while autonomous UmS will be providing real-time support and assistance throughout big data analysis, pattern recognition, and repetitive tasks (e.g. UmS as a supporting

Image source: https://www.bing.com/images/create/a-picture technology will propose some solutions based on info from the spot. However, the only EOD operator will make a final overall decision.)

- **Development of self-checking/repair/preservation features for UmS:** To increase the reliability of UmS the EOD COI will hold out for self-checking/repair features that could minimize malfunction of assets, software glitches, and demands for expertise maintenance/repairs. There are already some approaches and developments that could help the EOD operators to operate more reliable UmS as:
    - Sensor Fault Detection and Correction (e.g. sensor monitoring anomalies or malfunctions of other sensors)
    - Actuator Functionality Monitoring and Maintenance (e.g. monitoring engines/servos for detecting excessive wear, temperature fluctuations, or power supply irregularities; also, it should make notifications/alerts for preventive maintenance alerts)
    - Embedded Self-Diagnostics and Prognostics (e.g. UmS would run their regular self-tests to self-preserve from either technical problems or even tactical mistakes)
    - Fault Tolerance and Redundant Systems (e.g. UmS could operate in a reduced mode when some of their sensors/components are down (like humans who can act despite feeling a fever/unhealthy) and initiate their backup systems)
    - Reactive Repairs and On-Site Maintenance (e.g. the EOD robots could be able to replace their flatting batteries to be able to continue without returning from the spot when the situation requires working without interruptions)
    - Remote Monitoring and Support (e.g. EOD operator or specialized service should be able to monitor the system's health and performance from a safe distance and if a need to initiate emergency procedures remotely including a back-home mode).
- **Advanced manipulation capabilities of UmS:** Human-like tactile abilities and improved dexterity of the upcoming UmS would significantly influence their utilization within the EOD. Any innovations in delicate manipulation capabilities, remote manipulation, and teleoperation are subjects for continual monitoring and possible implementation in the EOD area.

- **EOD mindset, proficiency, and training requirements:** Further developments in UmS will bring extra requirements for the EOD individuals and communities as well as:
    - Firstly, emerging more autonomous unmanned systems will challenge the EOD communities and particular individuals with a mental acceptance of such technologies as they are not going to replace them but augment their traditional capabilities. This change of mindset will require a certain time and that culture will be implemented incrementally as safety is the ultimate factor in the EOD missions.

Image source: https://www.bing.com/images/create/a-picture

    - Secondly, utilization of UmS will require educating and training operators to develop not only their EOD proficiencies but also to ensure their solid technical background at the same time. Therefore, particular EOD COI is motivated to consider the updating of EOD proficiencies and training programs along with new technology implementation steps (e.g. to improve interpretation of large data flows; understanding of sensing and analytical capabilities/limits of UmS; better orientation and exploitation of 3D visualizations).

4. Information flow and cooperation (including LL systems)

Having the right information in the right place at the right time has been and will always be a crucial assumption for successful missions. It is the same decisive issue for the EOD tasks. Of course, the area of communications is so broad and interconnected that this cluster revolves around only some selected challenges with EOD.

4.1. Purpose and Features:

Communication and data-providing technologies and procedures are purposed to ensure adequate information flows leading to the EOD operator´s decision on a proper RSP (Render Safe Procedures) and its successful execution. All in all, these current and future solutions must mirror and consider at least the following factors:

- established information flows within vertical command and control (C2) structures and EOD tasks in a particular period of EOD missions (see pic 3)
- info flows horizontally amongst involved parties (e.g. Supporting units, UN, or national entities)
- technologies used for communication within C2 and the particular incident area (see pic 4)
- established LL mechanism ensuring the EOD operator´s update within EOD training

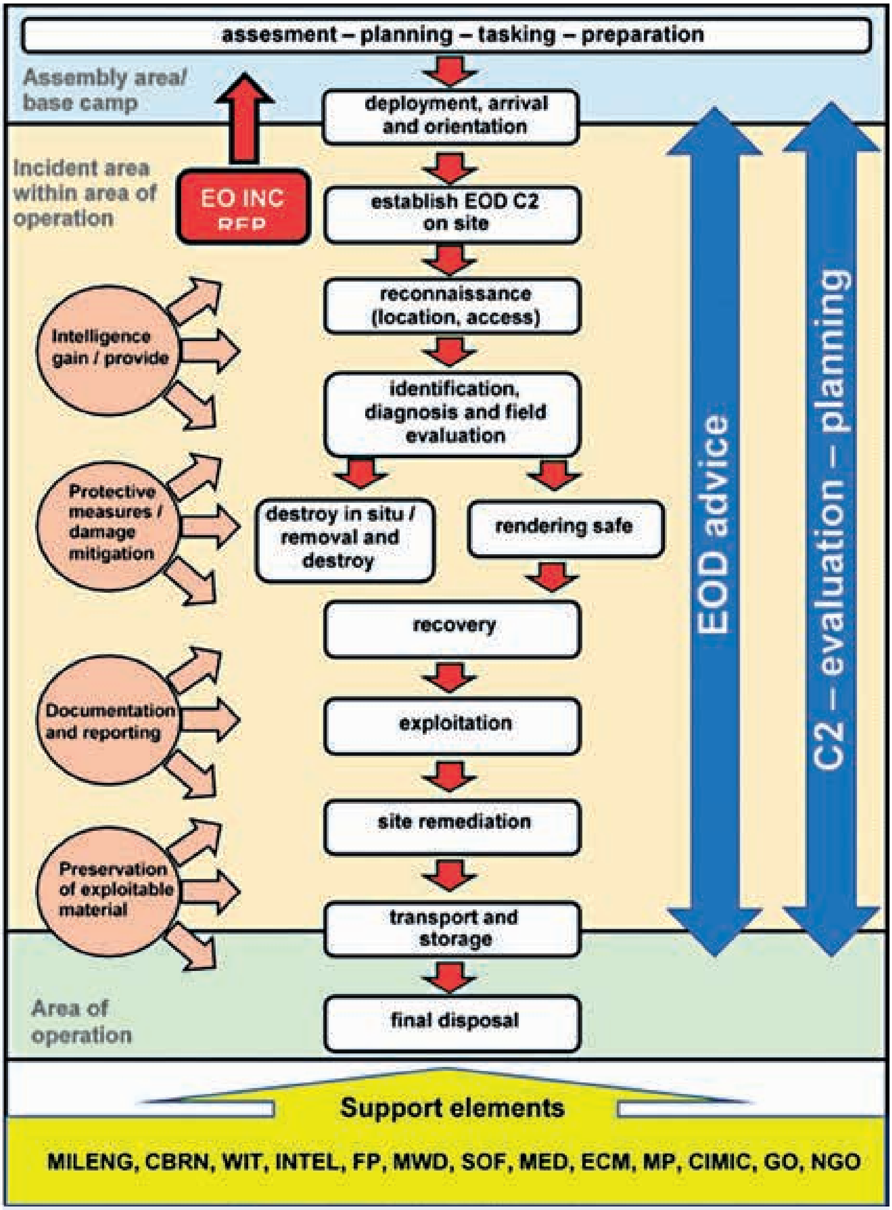
4.2. Some considerable benefits of advanced information flow/cooperative technologies and LL systems for EOD COI:

The exponential progress in these technologies and their application within the EOD area will incrementally support the following primary objectives:

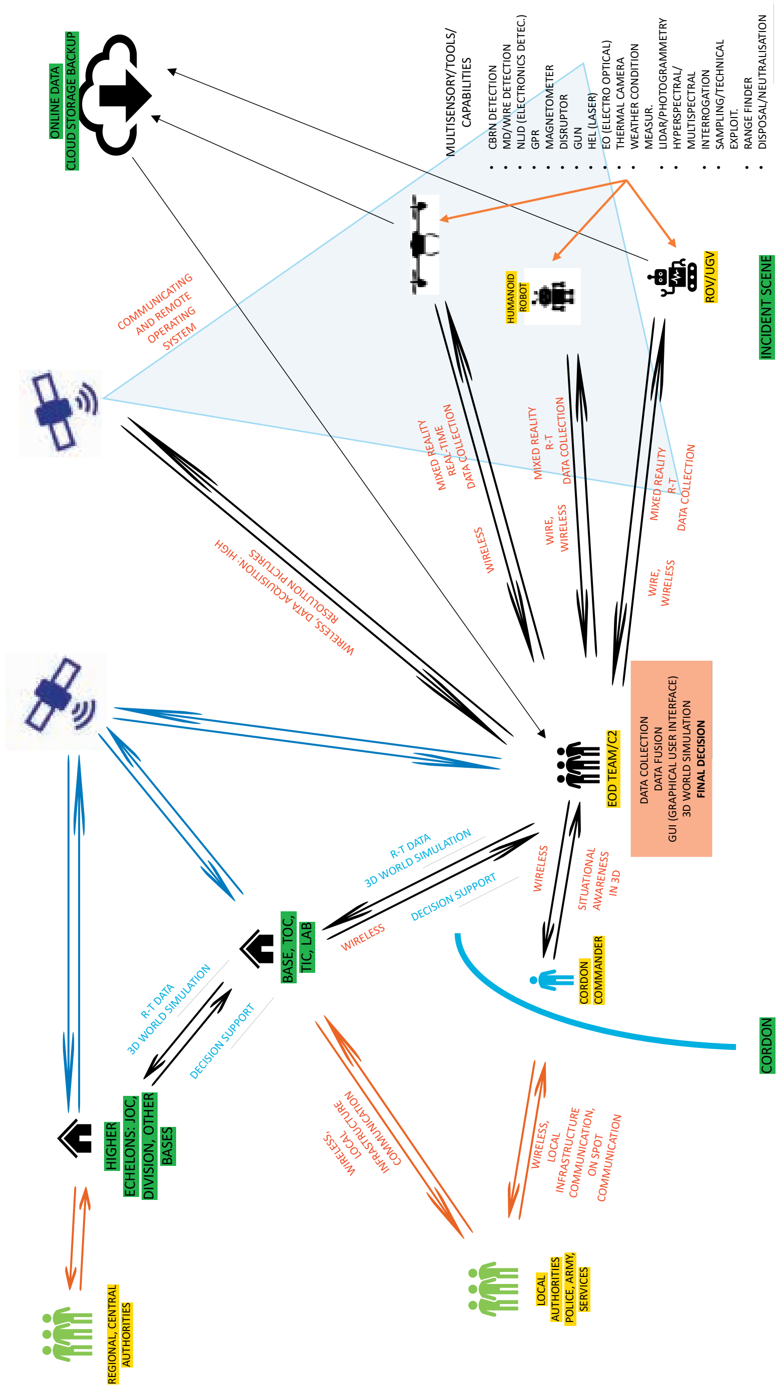
- to perform a successful EOD task to ensure the safety of others
- to minimize the danger for an EOD operator

In more detail, such innovations and new technologies could bring benefits within enhanced:

- **EOD training via:**
    - personalized training (e.g. info flow adjustable according to a particular student´s skill level or learning tempo)
    - Real-time feedback and performance evaluation at the selected training sequences or phases (e.g. an EOD operator receiving immediate feedback from multiplied sources during exercising a certain situation)
    - Advanced simulations (i.e. EOD training extensively supported by virtual and augmented reality technologies for example seeing some fused data on EOD operator´s helmet head-up displays)



Picture 3 – EOD information flow in a military operation



Picture 4 – Communication technologies within C2 in a particular incident area.

- **Situational awareness via**:
  - Improved accessibility of real-time data from various sources (e.g. data from collaborative UAVs/UGVs or online databases)
  - Faster and more efficient data fusion and analysis providing EOD operators with a holistic view of the situation and predictive analytics
- **Collaborative knowledge sharing and decision-making process via:**
  - Enhanced knowledge management systems (e.g. development of very efficient LL mechanisms; properly organized collaboration forums and workspaces enabling real-time coordination (Common Operational Picture); common databases with advanced AI filtering; access to the newest research and development).
- **EOD operator's safety via:**
  - Boosted and a wider variety of the remote control deployable and collaborative EOD assets (e.g. data fusion amongst swarming UAVs and UGVs; communication and pre-analyses of data from various sensors)
  - Pre-monitoring and background information flow from the spot to asses risks and hazards before the EOD mission (e.g. UAVs provide continual and historical big data from the area, AI applications could highlight recognizable and suspicious changes, and EOD operators can check available data and analyses to evaluate risks and possible solutions)
  - Continual EOD operator´s health monitoring (e.g. data about EOD operator's vital functions such as blood pressure, glucose, ECG and others provided for himself or/and for his teammates or health monitoring entity)
  - Real-time and instant information/expertise support (e.g. voice communication between the EOD operator on the spot and remote assistance/guidance expertise group out of the area of deployment; possibility of voice-controlled data searches in EOD databases when dressed up in the EOD bomb suit)
- Resource management and reduced costs due to minimizing technological insufficiency or miscommunication (e.g. more communication channels and access to the information sources contribute to the verification of provided info clarity and reliability)

4.3. Some synergic effects of progress in the information flow systems and other technologies:

There will be progress in other technological domains along with information flow system innovations. Synergy effects amongst such headways will exponentially boost technological support in the EOD area, particularly in training, situational awareness, collaborative knowledge management and decision making, safety, and innovations implementation. As of today, it is expected that communication and analyses could be revolutionized by the progress in the following areas:

- Artificial intelligence
- Extended reality (XR)
- 5G and edge computing
- Distributed ledger technology
- Internet of Things (IoT)

4.4. Some limits/risks/challenges related to the progress in the information flow/cooperative and LL systems:

To benefit from the expected technological progress some highlighted challenges should be addressed:

a) **Security, confidentiality, data quality, and reliability:** These requirements have life-threatening aspects in the EOD area as misleading or missing information can result (not only) in the EOD operator's death. Naturally, new technologies (capable of providing more complex EOD data) will be even more attractive for adversaries for cyber-attacks or information manipulation.

b) **Data availability versus data overload:** Demand for more comprehensive data and cooperation within the EOD data management will be increasing in the future. It seems that some current EOD databases would require either an upgrade or/and an update responding to a rising need for more complex EOD data. On the other hand, data overloading could become a kind of paralysing factor, so new, innovative, and specific EOD data management tools and data filtering systems will be needed.

c) **Availability and reliability of communication assets and infrastructures:** It must be considered that the local infrastructures will not be supporting military communication requirements fully or at all due to many reasons. Also, there are always some limits in deploying military assets including those for their communication. In other words, not all innovations in communication technologies will be available for each deployed unit so the enhanced management of allocated assets exploitation will play a crucial role in the future as well.

d) **Real-time technological support and cooperation:** The big data processing will require very powerful and sophisticated technologies (e.g. adequate interfaces and data traffic for the Common Operational Picture at the Joint Operational Centre). It stands for ensuring very adaptable and fast technological support for such deployed technologies (e.g. remote technical advisory for the EOD teams or IT specialists administrating any communication technological problems remotely).

e) **Limited data from the supportive entities:** Not all data relevant to the EOD tasks are and will be either collected or shared by supportive and collaborating entities. Such limits mirror several insufficiencies or circumstances as historical data from the particular spot were not recorded or there is no appropriate technology to collect and detect some data e.g. to detect material molecular structures remotely.

f) **Lessons Learned mechanisms:** Even though some nations have established very supportive LL mechanisms for their national EOD capability, the development of more interconnected LL systems will be needed in the future. The new technologies will ensure more data and therefore enhanced real-time data fusions amongst national and international entities would speed up learning processes.

4.5. Some Outcomes and Inspirations for the EOD COI:

Headways in information flow technologies will be crucial for achieving information superiority and efficiency in the EOD missions and training. The EOD COI is encouraged to monitor such progress and be proactive in the implementation of those solutions within the EOD area. For that effort, the EOD COE highlights some inspirations for further analyses as follows:

a) **Tailored/personalized Adaptive Electronic Countermeasures (ECM):** New technologies could enable the tailoring of ECM systems to the specific needs and requirements of deployed individual EOD team members (e.g. personalized adaptive ECM bubbles for an EOD operator approaching the spot and such bubbles could be capable of identifying enemy electronic signals in real-time, and then selecting and applying the most appropriate countermeasures).

b) **Directed broadcasting systems (DBS) within the EOD missions:** Despite current challenges related to DBS (e.g. complexity, costs, vulnerability to interception, dependence on infrastructure, limited data bandwidth, interference, lack of interoperability), these systems provide for the EOD many advantages as precision targeting, effective signal penetration, a low acoustic signature, and flexible data transmission. Such possibilities could support the EOD missions with:

- remote assistance and guidance of EOD personnel as the DBS systems could be used to transmit video and audio from EOD personnel to a remote command centre
- provide situational awareness by scanning for explosives in urban areas (signals can penetrate through walls and other objects)
- augmented 3D imaging including the location of explosive devices and the potential hazards (e.g. EOD Enhanced Visualization helmet-mounted display systems, the Laser Detection and Ranging (LADAR) systems)
- capability to neutralize explosives remotely in different environments (e. g. the Underwater Miniature Explosive Ordnance Disposal Remotely Operated Vehicle)

c) **Superpowered wiring systems:** Further developments of cables capable of transmitting both data and "high" power over a single conductor could provide the EOD SMEs with enhanced safety and flexibility in applying the most appropriate render-safe procedures (RSPs). To keep track in searching for innovative EOD solutions, the EOD COI should be monitoring progress in:

- miniaturization and material science
- new cable insulation materials
- improvements in cable connectors,
- power management technology
- new signal processing algorithms
- advances in artificial intelligence applicability

d) **"Secured" Interconnected EOD-related databases and AI:** To support the EOD operator´s decision-making process with relevant data and analyses the EOD COI should consider the development of interconnected databases to be used by "secure" AI (within or a kind of "tailored" Target Information Centre) in the future. The future "specific" EOD AI applications will need data from "Secured" Interconnected EOD-related databases as incident reports, historical data, real-time sensor data, historical and current images and videos from the spot, and lessons learned data.

e) **Satellite communication and internet connectivity at the EOD Team level:** Although having such assets and services at the EOD Team level will need to resolve some challenges (e.g. costs, security, bandwidth, latency, additional equipment space, maintenance), it will exponentially enhance safety and efficiency of EOD tasks. Some trials and experiments collecting lessons from such technology exploitation at the EOD team level would help to identify its weaknesses and strengths in detail.

f) **Utilization of new and future dynamic, secure, and tailored communication routes for EOD purposes:** To enable big data flow without disruptions and securely, some of the newest communication technologies and measures could be exploited for the EOD for example:

- Tailored Satellite Communication (e.g. constellation of low-Earth-orbit satellites as the Starlink)
- Network Slicing and Adaptive Routing (e.g. the creation of dedicated communication channels for EOD teams)
- Artificial Intelligence – Powered Routing: Such AI-powered routing could detect potential threats or technical problems and ensure data flow by the communication routes optimization.
- Enhanced Security Measures (including advanced adaptive encryption, multi-factor authentication, end-to-end encryption, allied hub(s) for sensitive information flows, software/hardware “multi-verifications” for data reliability, properly organized data feeding procedures and mechanisms, etc.)
- Drones and Robots with Communication Relay Capabilities: Such capabilities would be helpful for EOD teams in areas with poor or unusable traditional telecom infrastructure or hazardous environments. Some of the current drones and robots with communication relay capabilities (e.g. SkyHub drone from FLIR, The Bat VTOL drone from Matternet, ANYmal HC robot from ANYbotics) could serve as examples for development/modification of upcoming EOD drones/robots with such communication capabilities.

- Software-defined networking (SDN): This type of networking could provide EOD teams with dynamic communication routes adjustable in real-time.

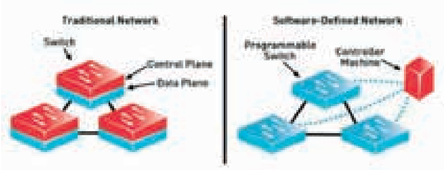


Image source: www.commsbusiness.co.uk/features/software-defined-networking-sdn-explained/

g) **Incremental development of technologies for the remote detection of material structural compositions:** Progress and innovations in several technologies (e.g. X-ray diffraction, hyperspectral/terahertz imaging, laser-induced breakdown spectroscopy) could remotely provide the EOD SMEs with very accurate and molecular details about the suspicious objects in the future.

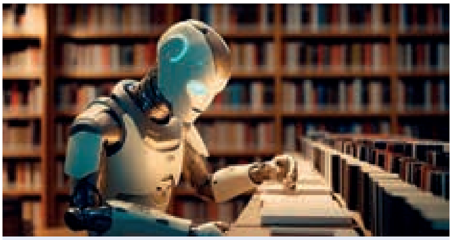
h) **Enhancing EOD Lessons Learned systems:** The innovative information flow technologies and mechanisms will enrich the current LL collection tools with unprecedented insights data (e.g. XR training technologies as the ETACS could track student errors down to nearly every second of his/her acting with explosives). On the one hand, it will enable much comprehensive analysis and subsequently derived lessons for the EOD operators, but on the other hand, it will require:

- Technologies to process big data and AI applications to support analysis for the EOD
- To update or establish appropriate procedures for database feeding and data sharing to ensure that current LL mechanisms will be applicable in real learning cycles
- Enhanced cooperation amongst the particular entities of the EOD COI in data sharing to achieve and maintain an upcoming high learning tempo

5. Artificial Intelligence

Artificial Intelligence is a prominent phenomenon these days as its application and progress reaches all aspects of our lives. Within the EOD COE, we strongly believe that AI is not a fashionable tool for a temporary period, but it is a real gamechanger that will shape our future in an immeasurable scale. Our world will never be the same from today on.

To further explore the potential of AI in EOD, the EOD COE has initiated an open study called "AI for EOD". The works on this study are currently in progress, and the first draft will be available throughout the year 2024. Those who are interested in receiving more details about AI and EOD are encouraged to monitor the EOD COE´s efforts and its progress on the EOD COE website https://www.eodcoe.org/en/



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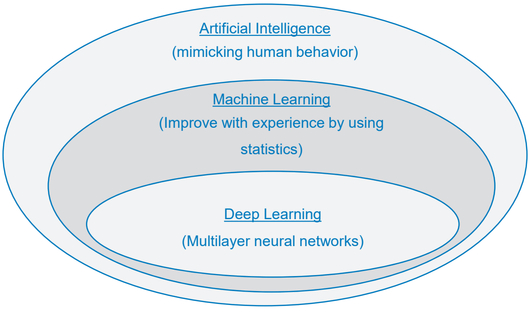
ARTIFICIAL INTELLIGENCE & MACHINE LEARNING

Emphasis on Machine Learning

- Development tools matured to a useful state
- Tangible results with realistic time frames and reasonable investment



DL is a subset of ML which is a subset of AI

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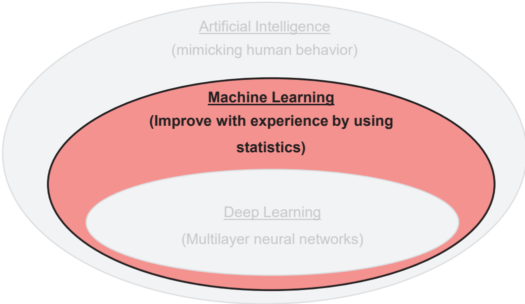
ARTIFICIAL INTELLIGENCE & MACHINE LEARNING

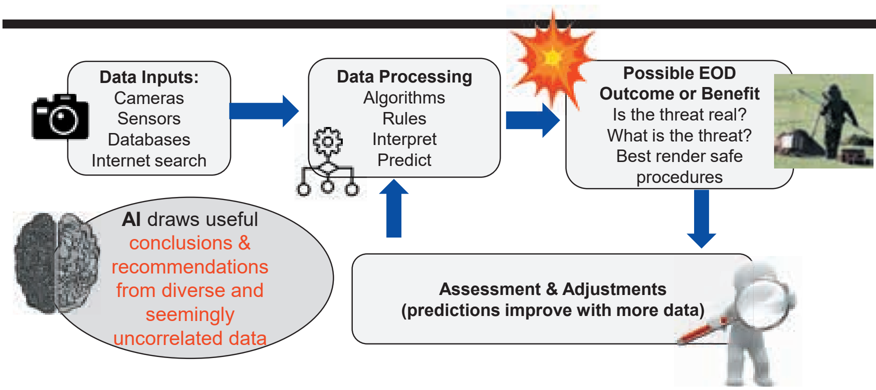
Emphasis on Machine Learning

- Development tools matured to a useful state
- Tangible results with realistic time frames and reasonable investment



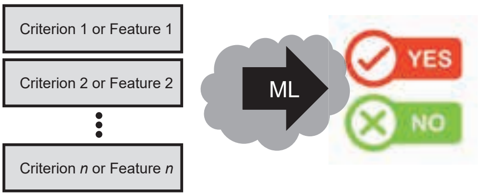
DL is a subset of ML which is a subset of AI

ARTIFICIAL INTELLIGENCE PROCESS OVERVIEW FOR EOD



MACHINE LEARNING

Classification



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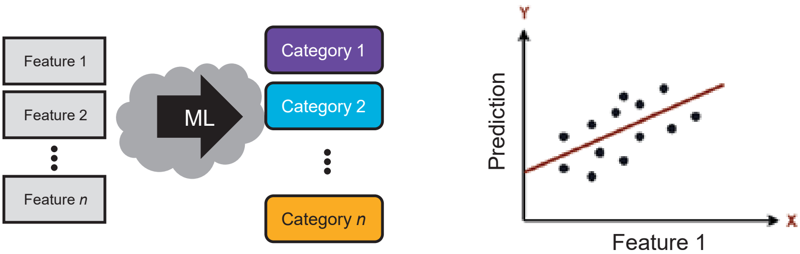
MACHINE LEARNING

Classification

Regression



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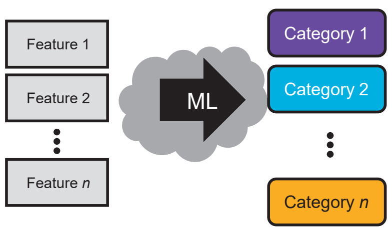
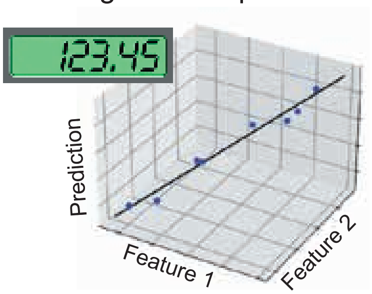
MACHINE LEARNING

Classification



Regression: quantitative



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CLASSIFICATION: TITANIC SURVIVAL – RAW DATA

First 5 entries of the RMS Titanic log

Name	Sex	Age	Class	Ticket	Fare	Cabin	Survived
Owen Harris Braund	M	22	3	A/5 21171	7.25	n/a	0
Florence Briggs	F	38	1	PC 17599	71.28	C85	1
Laina Heikkinen	F	26	3	STON/02. 3101282	7.93	n/a	1
Lily May Peel	F	35	1	113803	53.10	C123	1
William Henry Allen	M	35	3	373450	8.05	n/a	0

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CLASSIFICATION: TITANIC SURVIVAL – RAW DATA

First 5 entries of the RMS Titanic log

Sex	Age	Class	Survived
M	22	3	0
F	38	1	1
F	26	3	1
F	35	1	1
M	35	3	0

Features Classification

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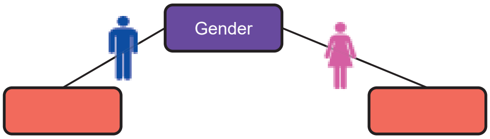
CLASSIFICATION (DECISION TREE): TITANIC SURVIVAL



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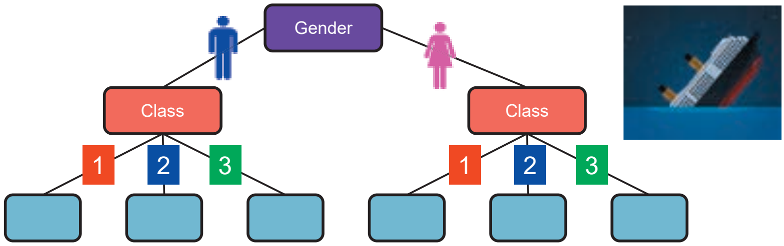
CLASSIFICATION (DECISION TREE): TITANIC SURVIVAL



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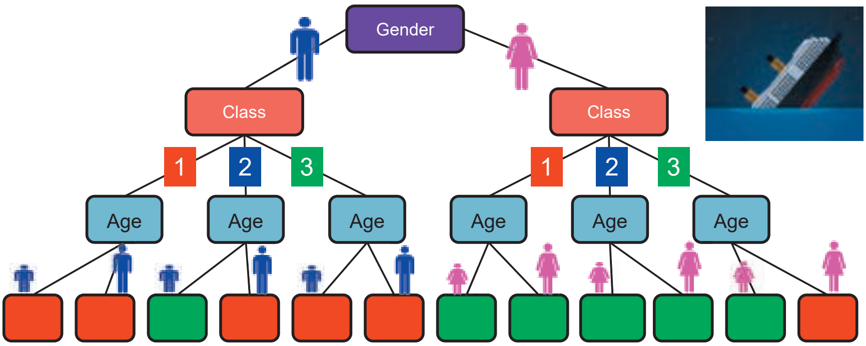
CLASSIFICATION (DECISION TREE): TITANIC SURVIVAL



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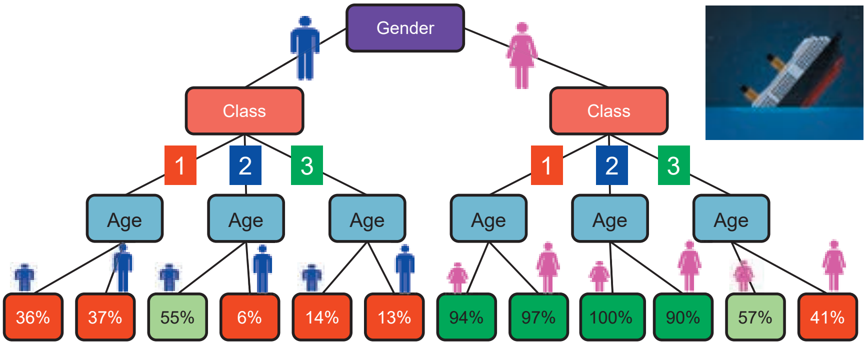
CLASSIFICATION (DECISION TREE): TITANIC SURVIVAL



REGRESSION – LIFE EXPECTANCY CALCULATOR

REGRESSION – LIFE EXPECTANCY CALCULATOR

0 or 1 | Age | # / day | # / week | # / week | hrs / week

$$y = \beta_0 + \beta_1 \times sex + \beta_2 \times age + \beta_3 \times smoke + \beta_4 \times drinks + \beta_5 \times fruits + \beta_6 \times sport$$

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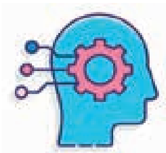
REGRESSION – LIFE EXPECTANCY CALCULATOR

0 or 1 | Age | # / day | # / week | # / week | hrs / week

$$y = \beta_0 + \beta_1 \times sex + \beta_2 \times age + \beta_3 \times smoke + \beta_4 \times drinks + \beta_5 \times fruits + \beta_6 \times sport$$



$\beta_0, \beta_1, \beta_2, \beta_3, \beta_4, \beta_5, \beta_6$

Found by a ML algorithm after inputting actual data to teach the “machine”, or “machine to learn”

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MACHINE LEARNING FOR EOD AND BLAST

Current Applications

Successfully implemented

MACHINE LEARNING FOR BLAST PRESSURE SENSORS

MACHINE LEARNING FOR BLAST SENSORS

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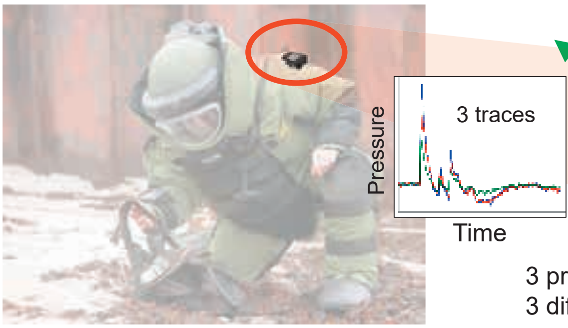
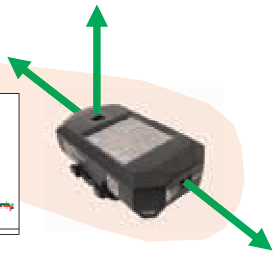
MACHINE LEARNING FOR BLAST SENSORS





3 pressure sensors
3 different directions

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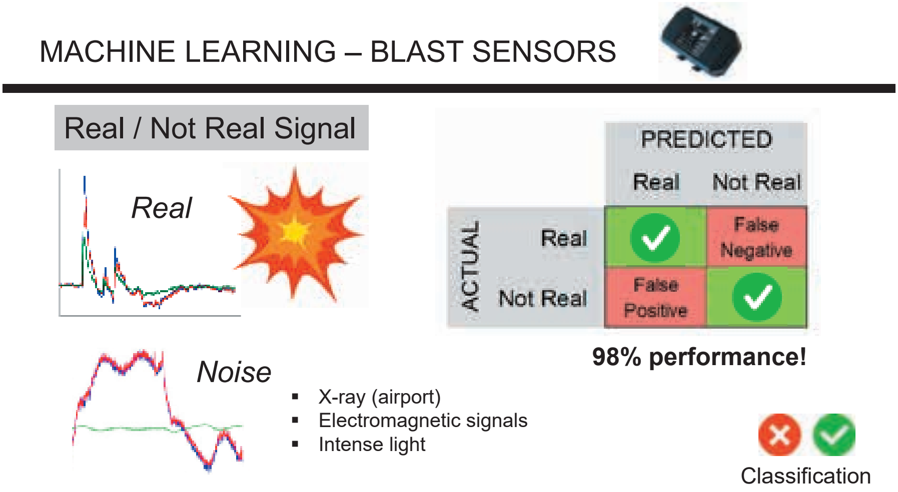
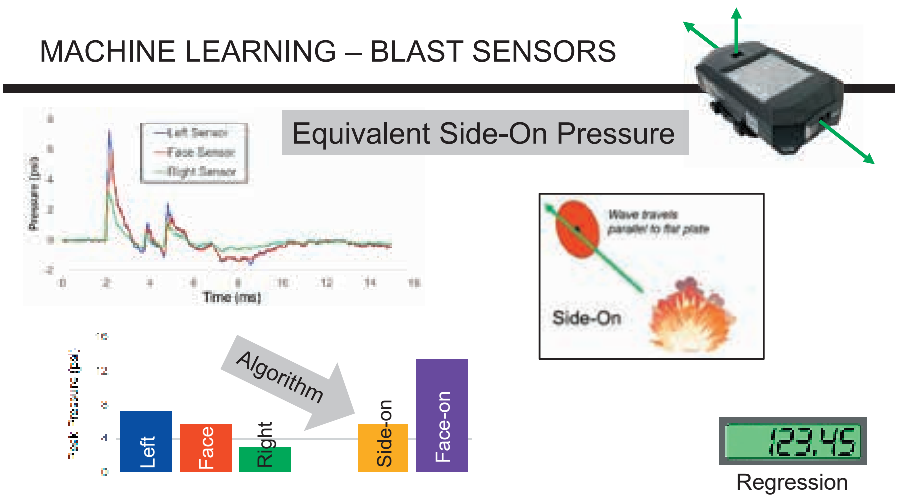
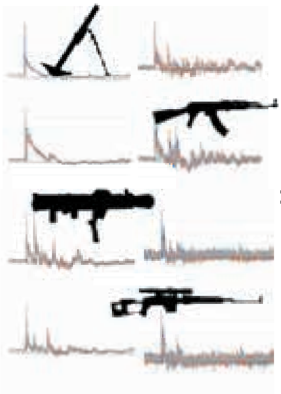

MACHINE LEARNING – BLAST SENSORS
Real / Not Real Signal
Real
PREDICTED
Real
Not Real
ACTUAL
Real
Not Real
False Negative
False Positive
98% performance!
Noise
X-ray (airport)
Electromagnetic signals
Intense light
Classification


MACHINE LEARNING – BLAST SENSORS
Equivalent Side-On Pressure
Left Sensor
Face Sensor
Right Sensor
Pressure (psi)
Time (ms)
Wave travels parallel to flat plate
Side-On
Algorithm
Left
Face
Right
Side-on
Face-on
123.45
Regression

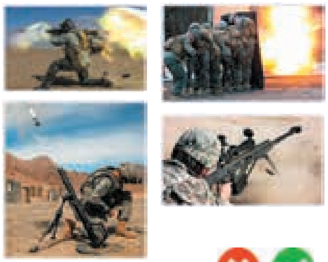
MACHINE LEARNING – BLAST SENSORS



- Ability to recognize specific weapon based on pressure traces

>90% performance!

Weapon ID

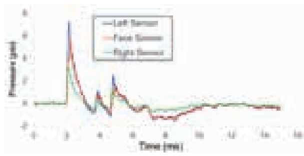


Classification

MACHINE LEARNING – BLAST SENSORS

Blast Directionality

Is the blast coming from the front? Back? What angle?

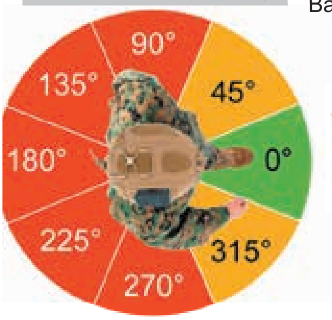


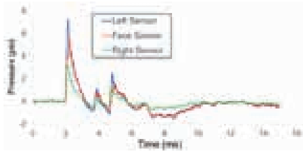
Regression

MACHINE LEARNING – BLAST SENSORS

Blast Directionality

Is the blast coming from the front? Back? What angle?

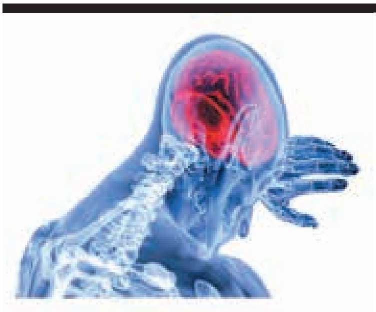




86% correct!
96% within one octant

Classification

MACHINE LEARNING – BLAST SENSORS



Blast-induced
Traumatic Brain Injury

- # blasts > 4 psi
- Largest blast
- Total impulse
- Time since last blast
- (…)

Classification

MACHINE LEARNING – BLAST SENSORS

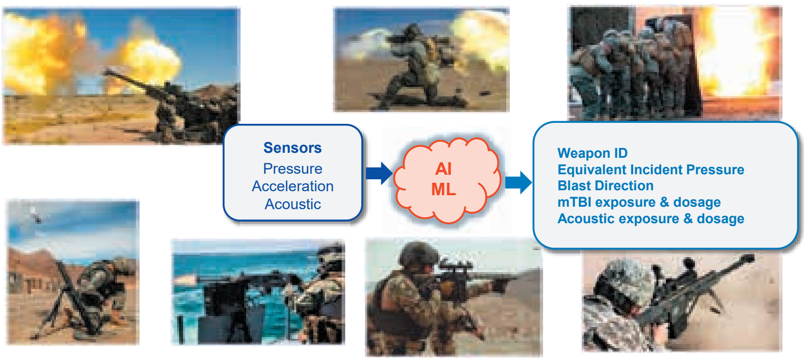
Blast-induced
Traumatic Brain Injury

- # blasts > 4 psi
- Largest blast
- Total impulse
- Time since last blast
- (…)

$$prob = \beta_0 + \beta_1 \times \#_{blasts} + \beta_2 \times P_{max} + \beta_3 \times I_{total} + \beta_4 \times t_{last} + \beta_5 \times (\ldots)$$

Regression

BLAST DATA FROM SENSORS & MACHINE LEARNING



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MACHINE LEARNING – BOMB SUIT SIZING

Sizing Trials – Multiple Volunteers

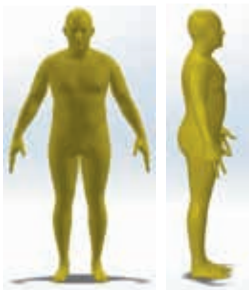
Users determine which size fits best

BOMB SUIT SIZING – AVATAR BUILT FROM APP

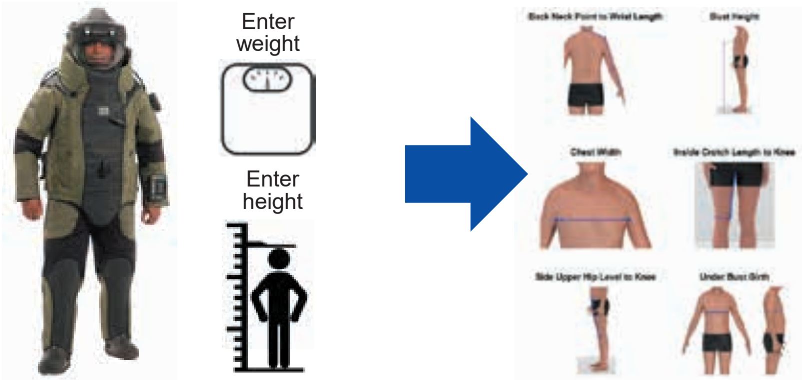
Sizing app

Actual Photos

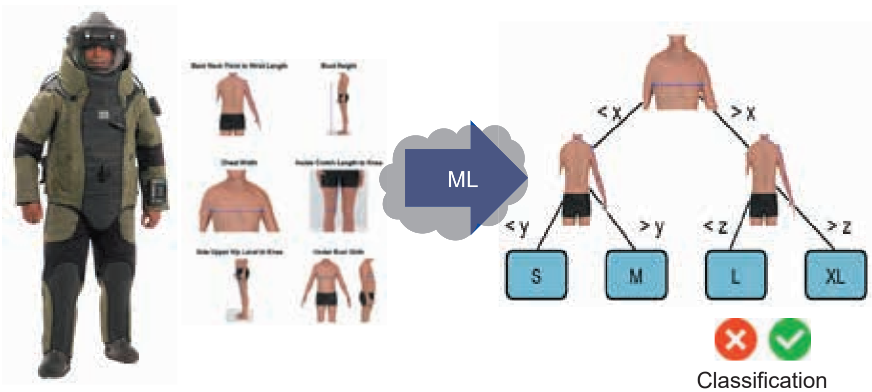
Avatar



BODY DIMENSIONS ESTIMATES FROM AVATAR (APP)



DECISION TREE BASED ON AVATAR MEASUREMENTS



MACHINE LEARNING – MINEFIELD ORDNANCE DETECTION

- Drones flying over fields
- Machine learning training to identify terrain image features associated with mines
- Input images or videos from data bases

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MACHINE LEARNING – MINEFIELD ORDNANCE DETECTION

- Drones flying over fields
- Machine learning training to identify terrain image features associated with mines
- Algorithm detects presence of threats

Classification

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MACHINE LEARNING –MINE, MUNITION DETECTION

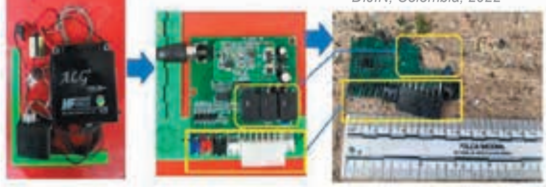
- Machine Learning algorithms trained to detect all sort of mines and munitions from data bases and inputs to algorithm
  - Different angles, environmental clutter, vegetation, thermal view
  - Buried or not, wet, dry, color

Classification

MACHINE LEARNING – IED CIRCUIT RECOGNITION

Mock device found at Canadian airport CBC, 2017

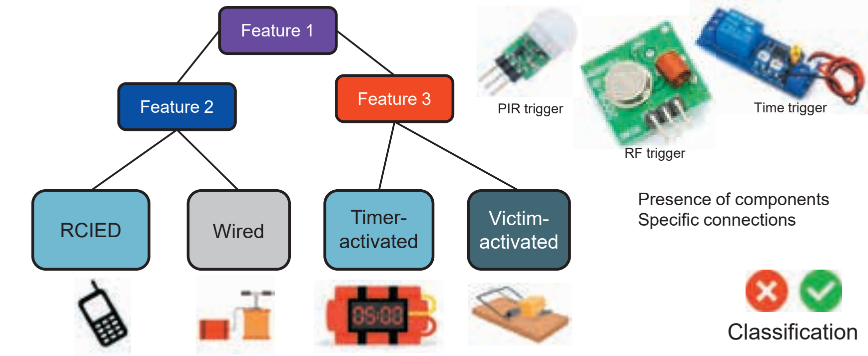
Recovered IED electronics DIJIN, Colombia, 2022



- Machine Learning to recognize electronic circuits
  - *Are all components for a real IED present?*

Classification

MACHINE LEARNING – IED CIRCUIT RECOGNITION



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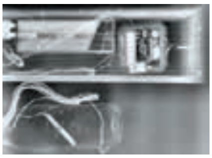
MACHINE LEARNING IN EOD – FURTHER POTENTIAL

Voice recognition Improve understanding through “practice”



Automatic threat recognition (x-ray, vision processing)

Interpretation of fused images (normal, thermal, x-ray)

Automatic aiming of disruptors based on image analysis

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AI & MACHINE LEARNING IN EOD

AI / ML Tools have matured

Potential further EOD applications



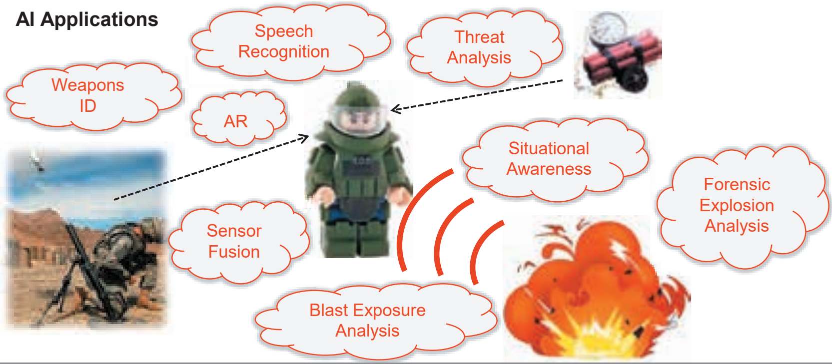
Assess Benefits

Estimate effort

Develop roadmaps

MACHINE LEARNING IN EOD → ARTIFICIAL INTELLIGENCE

AI Applications



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CONCLUSION

- AI & ML to impact many aspects of EOD – Some already implemented
  - Remove cognitive burden from Responders:
    - EOD Operator Situational Awareness Downrange & Decisions
    - Command Post Threat Assessment & Decisions
    - Optimization of TTPs
    - Training
    - Forensics
- Successful implementation of ML to Blast Sensor outputs
- All sources of data, sensing, vision (sensors, detectors, ROVs, UAVs, tools) can feed into Machine Learning and AI in near future
- Must convey information to EOD operator through HUD, AR, VR, etc.
- Full Autonomous Response by EOD AI Robot may become possible!

Intentionally blank

YOLO – deep learning model for UXO detection in thermal video

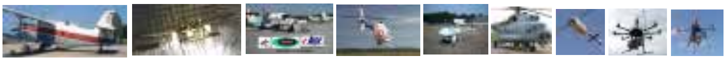
Milan Bajić Jr.

Department of IT and Computer Sciences, Zagreb University of Applied Sciences, Zagreb, Croatia

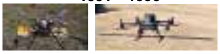
Overview

- From 1991 – AI - HV/HCR/HCR CTRO
- Introduction
- Evaluation Dataset UXOTi_NPA
- YOLO Architectures
- Results
- Discussion and conclusions

HV/HCR/HCR CTRO



1991 – 1996 2001 – 2004 2001 – 2003 2007 – 2008 2012 - 2015



2022 2023

3

Application of Aerial NTS in Croatia 2008 – 2009 in Bosnia & Herzegovina 2009 - 2011

Croatia	Area of Interest km^2	Proposal for reduction km^2	Reduced km^2/%	Included km^2
Gospić	56,84	5,22	28/49,2	6
Bilje	36,12	14,2	15,1/41,5	0
Sum	92,96	19,5	43,1/46,2	6

B & H	Area of Interest km^2	Proposal for reduction km^2/%	Proposal to Include km^2
Bihać	16,3	4,8/29,4	1,15
Mostar	16,5	10,4/63	2,7
Trebinje	7,4	3,7/50	0
Sum	40,2	18,9/47	3,85

YOLO – deep learning model for UXO detection in thermal video
Milan Bajić Jr.

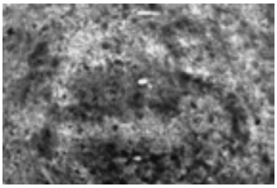
Introduction

- Thermal imaging/video
- Explosive remnants of war (UXO, Landmines)
- Object detection thermal imaging/video
- Deep learning object detection (UXO)

YOLO – deep learning model for UXO detection in thermal video
Milan Bajić Jr.

Evaluation Dataset UXOTi_NPA

- NPA data collection
- 808 annotated images
- 1 to 3 objects per image



- 11 classes
- 79 to 161 occurrences/class in dataset
- Training: 640 images; Validation: 80 images; and Testing: 88 images

Class	Name and Type	Number of Occurrences in Dataset	RGB Image	Thermal Image
0	Mortar mine M.60 mm	139		
1	Fuse M.125 mm	161		

YOLO – deep learning model for UXO detection in thermal video
Milan Bajić Jr.

YOLO Architectures

Comparison of five mainstream YOLOv5 and two YOLOv7 models, trained and evaluated on the COCO dataset

Model	mAP@0.5	mAP@0.5:0.95	Parameters (in Million)
YOLOv5n	45.7%	28.0%	1.9
YOLOv5s	56.8%	37.4%	7.2
YOLOv5m	64.1%	45.4%	21.2
YOLOv5l	67.3%	49.0%	46.5
YOLOv5x	68.9%	50.7%	86.7
YOLOv7 tiny	56.7%	N/A	6.2
YOLOv7	69.7%	N/A	36.9

YOLO – deep learning model for UXO detection in thermal video
Milan Bajić Jr.

EDGE computing devices

1. Raspberry Pi
2. NVIDIA Jetson

YOLO – deep learning model for UXO detection in thermal video
Milan Bajić Jr.

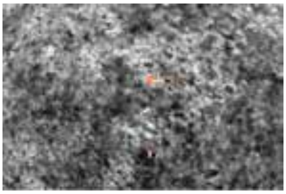
Experiment

- 5 models YOLOV5 (Bajić & Potočnik, 2023, 'UAV Thermal Imaging for Unexploded Ordnance Detection by Using Deep Learning', Remote sensing, 15, 967.)
- 2 models YOLOv7 (Bajić jr., M.; Potočnik, B. UNEXPLODED ORDNANCE DETECTION ON UAV THERMAL IMAGES BY USING YOLOV7. In Proceedings of the ROSUS Univerza v Mariboru, Univerzitetna založba, March 16 2023.)
- Google Colab Tesla T4 GPU
- Detection time on video (inference)

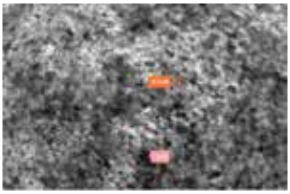
Results – Inference time

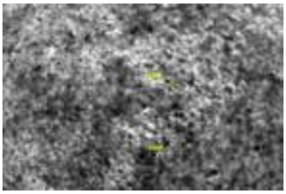
Model	Model Size	Inference time (s)
YOLOv5n	1,8	8,253
YOLOv5s	7,1	8,345
YOLOv5m	21,1	11,921
YOLOv5l	46,4	19,074
YOLOv5xl	86,6	36,863
YOLOv7tiny	6,1	17,438
YOLOv7	36,8	22,730

Eleven class detection - example



Annottated image





YOLOV5n detection YOLOV7tiny detection

The class index and detection probability are written next to the bounding box.

YOLO – deep learning model for UXO detection in thermal video
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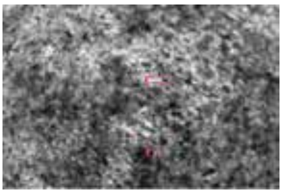
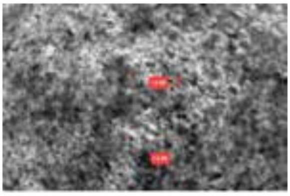
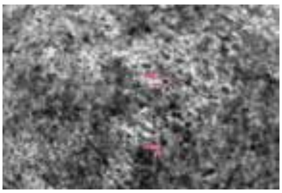
One class detection - example



Annottated image





YOLOV5n detection YOLOV7tiny detection

The class index and detection probability are written next to the bounding box.

YOLO – deep learning model for UXO detection in thermal video
Milan Bajić Jr.

Eleven class detection video precision

Model	mAP@0.5	mAP@0.5:0.95	Parameters (in Million)
YOLOv5n	99.5%	87.0%	1.9
YOLOv5s	99.5%	88.5%	7.2
YOLOv5m	99.5%	89.9%	21.2
YOLOv5l	99.5%	90.5%	46.5
YOLOv5x	99.5%	89.7%	86.7
YOLOv7 tiny	**99.5%**	**86.8%**	**6.2**
YOLOv7	**99.5%**	**89.7%**	**36.9**

YOLO – deep learning model for UXO detection in thermal video
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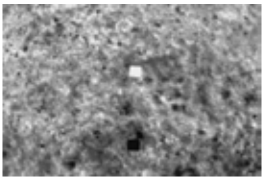
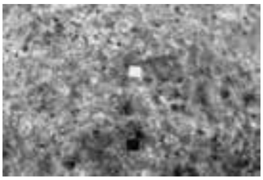
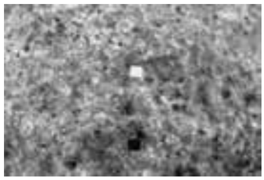
Eleven class detection video speed





8,253 sec



17,438 sec

YOLO – deep learning model for UXO detection in thermal video
Milan Bajić Jr.

OTHER SENSORS AND AI SOLUTIONS FOR FUTURE

1. GPR – positive AI results
2. HYPERSPECTRAL – waiting for AI in domain
3. MAGNETOMETER – waiting for AI
4. NLJD – waiting for reliable sensors and AI

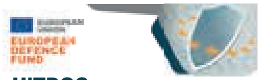
1. VISUAL TRANSFOMERS
2. SEMI SUPERVISED SELF LEARNING
3. NON SUPERVISED SELF LEARNING
4. GAN NETWORKS FOR CREATING AUGMENTED DATA FOR TRAINING

YOLO – deep learning model for UXO detection in thermal video
Milan Bajić Jr.


EDA-monitored project links ground and aerial systems to detect explosives

YOLO – deep learning model for UXO detection in thermal video
Milan Bajić Jr.

STARTED PROJECT ACTIVITIES THAT INVOLVE AI AND EO DETECTION



HiTDOC

Hidden Threat Detection

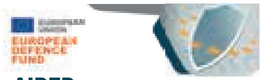
SELECTED PROJECTS EUROPEAN DEFENCE FUND (EDF) 2022

CALL TITLE:	Research actions – Technological challenge
TOPIC TITLE:	Unmanned ground and aerial systems for hidden threats detection
DURATION OF THE PROJECT:	48
TYPE(S) OF ACTIVITIES:	Studies, Integrating knowledge
ESTIMATED TOTAL COST:	€ 4,985,439.64
MAXIMUM EU CONTRIBUTION :	€ 4,985,439.64

SHORT DESCRIPTION OF THE PROJECT:
HiTDOC will organise the technological challenge on hidden threats detection.

The objective of HiTDOC is to organize a challenge, based on the design and development of test procedures and methodologies, that will allow evaluating the performances of detection technologies. During the iteration of four challenges, the testing procedures will be further updated, aiming at being able to propose, at the end of the project, recommendations on standardized test procedures to objectively evaluate system performances.

This project is linked to the projects performing the R&D actions under the same call.



AIDEDex

Artificial Intelligence for Detection of Explosive Devices - Extended

SELECTED PROJECTS EUROPEAN DEFENCE FUND (EDF) 2022

CALL TITLE:	Research actions – technological challenge
TOPIC TITLE:	Unmanned ground and aerial systems for hidden threat detection
DURATION OF THE PROJECT:	48
TYPE(S) OF ACTIVITIES:	Generating knowledge, Integrating knowledge, Studies, Design
ESTIMATED TOTAL COST:	€ 4,995,883.46
MAXIMUM EU CONTRIBUTION :	€ 4,995,883.46

SHORT DESCRIPTION OF THE PROJECT:
AIDEDex will improve the neutralisation of Improvised Explosive Devices, IEDs.

With a view to clean areas from buried Improvised Explosive Devices (IED) and landmines, AIDEDex main focus, when participating to the technological challenge, is on the automated detection of those hidden threats using Artificial Intelligence (AI) techniques on data collected from a large suite of sensors. AIDEDex will use AI across the whole chain of command, control, planning, IED and landmines detection and classification, navigation and multi-robot decisional autonomy.

Discussion and conclusion

1. Solution for detection of objects of similar colour as background
2. Automated solution for large area survey
3. YOLOv5 superior to YOLOv7
4. Many more technologies and algorithms for research
5. Enhance funding and cooperation possibilities

Thank you for your attention,
questions?

YOLO – deep learning model for UXO detection in thermal video
Milan Bajić Jr.

Oklahoma State University

Center For Fire & Explosives Forensic Investigations, Training & Research (CENFEX)

Global Consortium for Explosive Hazard Mitigation

FORENSIC SCIENCES

Future of EOD

- Robotics, ground, UAV, UUV
- Artificial Intelligence, Generative AI
- Machine Learning
- The Cloud
- Training/AR/VR
- Processes
- New Applications

Future of EOD

- There will be a human factor involved in EOD. (training, tactics, techniques, procedures, observation)
- Decision process
- Logic process, probability, confidence score
- Tool selection
- Precise processes
- Improve safety the most important goal.

Robotics

- As robotics continue to advance, robots currently in use will become increasingly antiquated and in need of replacement.
- Legged robots (e.g. Boston Dynamics) with tremendous speed, load bearing capacity, and detection/tool options will become normative.
- Initial interrogations will include both arial surveillance and detection combined with a plethora of other detection capabilities.

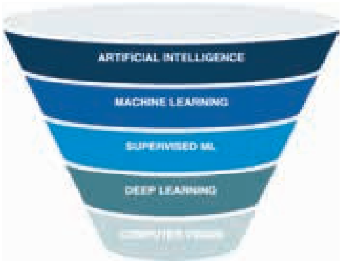
Robotics

- Newer platforms of robotics, ground, air and sea
- Robots and UAV's, UUV's using various types of explosives. Deploy foam viscous fluid and similar types of explosives
- Able to navigate under canopies in tunnels, and water
- Emerging technologies in robotics, UAV, UUV offer sustainable competitive advantage to move the human away from the target.

Robotics

- Detection
- Software and hardware, various types of cameras, X-rays, detection equipment, air monitoring technologies use AI/ML to recognize hazards, ordnance, devices, device components
- Sensors, detect if a hazard is present, chemical, explosive, or other

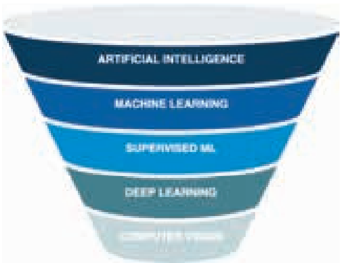
AI Hierarchy



Artificial intelligence is the simulation of human intelligence processes by machines, especially computer systems. Specific applications of AI include expert systems, natural language processing, speech recognition and machine vision.

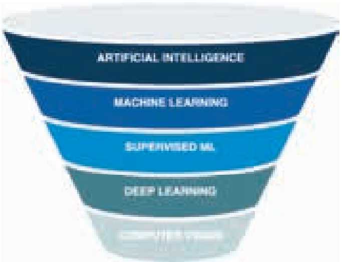
Machine learning is a branch of artificial intelligence (AI) and computer science which focuses on the use of data and algorithms to imitate the way that humans learn, gradually improving its accuracy.

AI Hierarchy



Supervised machine learning, is a subcategory of machine learning and artificial intelligence. It is defined by its use of labeled datasets to train algorithms that to classify data or predict outcomes accurately.

AI Hierarchy



Deep learning is a method in artificial intelligence (AI) that teaches computers to process data in a way that is inspired by the human brain. Deep learning models can recognize complex patterns in pictures, text, sounds, and other data to produce accurate insights and predictions.

Computer vision is a field of artificial intelligence (AI) that enables computers and systems to derive meaningful information from digital images, videos and other visual inputs — and take actions or make recommendations based on that information.

Generative AI

- Generative AI refers to deep-learning models that can generate high-quality text, images, and other content based on the data they were trained on.
- ChatGPT, DALL-E, and Bard are examples of generative AI applications that produce text or images based on user-given prompts or dialogue.

Neural Network

- A neural network is a method in artificial intelligence that teaches computers to process data in a way that is inspired by the human brain.
- It is a type of machine learning process, called deep learning, that uses interconnected nodes or neurons in a layered structure that resembles the human brain.
- It creates an adaptive system that computers use to learn from their mistakes and improve continuously. Thus, artificial neural networks attempt to solve complicated problems.

Neural Network

- Neural networks can help computers make intelligent decisions with limited human assistance.
- Neural networks can comprehend unstructured data and make general observations without explicit training.
- Feeding the neural network
- Training is the process of teaching a neural network to perform a task. Neural networks learn by initially processing several large sets of labeled or unlabeled data.
- Collecting and inputting data sets.

Interpretation

- AI to interpret/diagnose data and recommend procedures providing confidence rating on options as complex as threat context.
  - "Am I in danger?" What is the threat in the area?
    - Understanding if all the components for an IED are present
    - Processing other metadata
      - Where am I?
      - What has happened here recently? (historic battlefield information)

AI/ML for Decision Support

- Could it be an IED, are the components recognized as part of an IED. Explosive detection, recognition.
- Use of automated detection will continue to advance.
- The human element will be a part of the process.
- Via operation or command center, devices for detection will be released.
  - In live color or infrared video
    - Body camera
    - UAV, UUV
    - Ground robots

AI/ML for Decision Support

EOD Command Center concept
- An integrated tactics, training, protocol toolset
- Enables current threat information to be entered in and TTPs out
  - Inputs a toolset (e.g., UAV, UUV, ground robots, cameras, energetic tools etc.)
  - Inputs data (e.g., on-scene interviews, threat images, Biometrics etc.)
  - Outputs custom strategies, what equipment, tactics, techniques and procedures be used.
  - Share intelligence on a global scale

AI/ML For Driver Assists

- Navigating a ground robot through certain areas maybe difficult due to obstacles
  - Help do real-time path planning over obstacles, detection of hazards
  - Pre-mapping, Lidar, GPS
- Comparing on-scene information with local infrastructure
  - Where are the gas lines buried?
  - Where is the fiber-optics buried?
  - Is this bomb threat for soft targets or is there a larger infrastructure target?

AI/ML for Decision Support

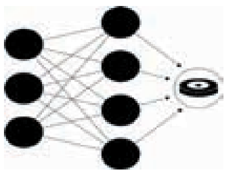
EOD Siri type concept:

- Cross reference your threat with a database of threats
  - "Siri", what can you tell me about this threat"
    - How did others deal with this threat
    - What critical information should I know
- Identify and troubleshoot equipment issues
  - "Siri – why is my radio not working"
    - RF radio link troubles and solutions

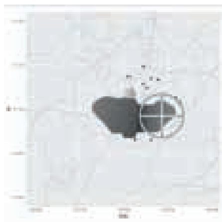
AI-Mine detection process example

Drone Survey

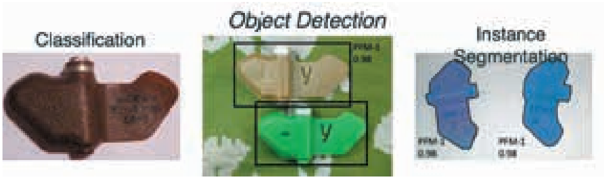
Machine Learning Process



Mapping and Detection



Computer vision for landmine detection



AI Mine detection process in action

UAV Survey

Machine
Learning
Processing

Mapping Detection

The Cloud

- There is a need to gather all known explosive items, push it into the cloud and use AI/ML to rapidly search.
- Governments and agencies by their nature tend to be rather territorial with such data and it seems the safest way to share this sort of data comprehensively will be through, government and academia consortiums.
- Formation of global partnership of willing universities will be the most efficacious way to bring this to reality.

(AWS Amazon Web Services references used)

The Cloud

- Move towards "black box thinking" found in aviation. Law enforcement largely relies on body cams, but EOD has been slow to adopt, retain, and study incidents using real world footage.
- Recording events, getting them into a cloud, having as many operators see them as possible to learn what to do, or not to do. This is not punitive, it is science. Imagine a shared reservoir of EOD responses for both experienced and new EOD operators.

Training

- As cloud-based data reservoir's grow, the ability to use Augmented Reality/Virtual Reality (AR/VR) to train personnel will be able to increase dramatically. Recreate real world collected scenarios into actual training problems.
- Operator should be able utilize new technology advances (e.g. AR/VR) as part of their training. Having EOD operators see more problems will help them solve more problems, and ultimately increase predictive capabilities.
- Aircraft simulators work in aviation, AR/VR works well in medicine, and this will work in EOD.

No longer the future but current processes

- Artificial intelligence and machine learning
- Augmented reality
- Virtual reality
- Microsensors used for detection
- Calculation assistance, safe distances, target acquisition
- Tool selection
- Lighter, faster with greater capabilities
- ALL to keep the public and EOD tech's safer

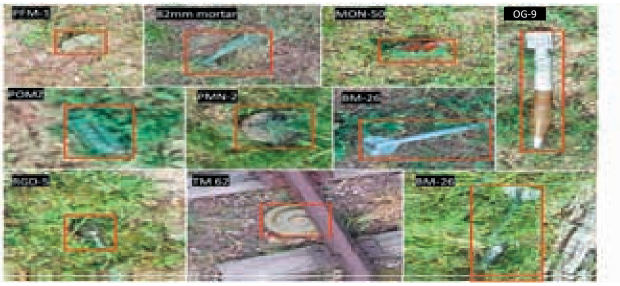
New Applications

- Machine Learning Process Spotlight
- Conduct a Drone Survey COTS Quad of Hexi copter
- Build machine learning model, via training set, trained model, testing, finally predictions.

SAFE PRO AI

New Applications

Examples of detected items via Spotlight



Spatial Computing

- EOD Dynamics
- Phone App
- 3D experience for EOD techs and humanitarian deminers.
- Leverage spatial computing from open source computing to training product.

New Applications

- Quantum Sensing
- QSPD Quantum Single Photon Detection
- Quantum= the minimum amount of any physical entity
- Photon= single quantum of electromagnetic radiation
- Sensor is configured at target height on a robotic platform
- Uses quantum single photon detection in capturing ultra weak backscattered optical signals amid strong background noise.
- This technique measures the variation in photon flux that occurs when the target surface is slightly displaced or titled at a single photon level.

Conclusion

- Technology is rapidly evolving for the EOD Community
- Artificial Intelligence
- Machine Learning
- Virtual Reality
- Augmented Reality
- Various types of sensors, smaller, faster with greater capabilities.
- Technology is rapidly moving forward to help our community and to keep our operators safe.

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Rapid-cycle learning for effective remedial action and dissemination of learnings:

Ukrainian Armed Forces lessons-learned processes and military innovation in EOD

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Col. (Ret) Dr. Yuriy Pashchuk, National Army Academy, Ukraine
Dr. John Tull, Department of Politics, Royal Holloway College

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Context: the rise of military 'lessons-learned' processes

- We know that the **capacity to perform inter- and intra-organisational learning is key** to effective military adaptation, innovation and emulation.
- **Militaries have always had 'lessons learning' processes**
  - Typically semi-formal, unit and brigade-based
  - Plenty of data, very limited analysis, semi-formal dissemination
  - **Local** adaptation (TTPs, training, 'fixes') versus **institutional** change
- **Permanent, formal lessons learned processes** have proliferated.
  - NATO lessons learned process continues to evolve
  - Promotes **interoperability, standardisation, cross-functional and cross-border communication**
- But empirically[1] we find a **wide range of experiences in *how*** it is implemented and used
  - Researchers have given little attention to **actual practices** in military learning.

(1. ESRC Grant ES/V004190/1 2021-24: *'A Revolution in Military Learning? Uncovering the Potential of Lessons-Learned Processes*)

Annex 4

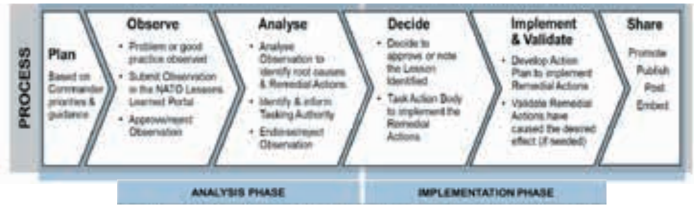
Rapid-Cycle learning for effective remedial action and dissemination of learnings EO threat

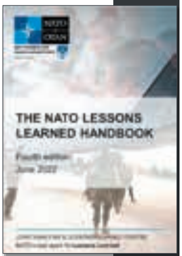
Dr. John Tull

NATO Lessons Learned
– process, tools, training, norms, community

Globally, the **major challenges with *learning*** in any complex organisation are:
(i) how does learning **translate** from individual-level to organisational level?
(ii) how does organisational learning **transform** into improved competitive performance?

NATO Lessons Learned process follows well-known **problem-solving** routines:



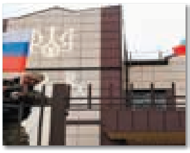


NATO recommends ways to implement this Lessons Learned process.
How this is adopted and used *in actual practice*, and what its *implementation requires* in order to address each military's needs, are **not well understood**.

Lessons Learned for EOD in Ukraine: a compelling example
– a rapidly evolving situation demands timely, well-informed response

Lessons Learned adoption in Ukraine
– sustained improvement

4.2014-12.2018 | **1.2019-2.2022** | **2.2022-present**



System of Lessons Analysis and Dissemination (SLAD) – phase 3:
Refined in-house process:
- **Basic-level database** and **data collection** process
- lacked templates and processes for disciplined inputs, **reducing quality** of the information
- **dissemination** of information essentially manual.

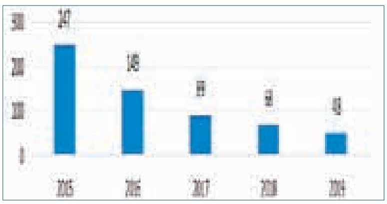
Lessons-Learned System (LLS) – phase 1:
Closer alignment with NATO:
- **formalisation of LL**: JFO/ATO LL organisation extended, doctrine, SOP, standardised process, national LL training.
- **Innovated** Mobile Lessons Learned Teams (MLLT).
- **no LL Portal**; dissemination is still mostly manual (bulletins, supported by LL staff)

Lessons-Learned System (LLS) – phase 2:
Intensification of LL:
- Further refinements of LL, informed by **internal reviews** of and Dyson/Paschuck article.
- **MLLT** doubled; a**nalysis and report capabilities** improved; attempt to enhance **remedial actions**.
- dissemination timelines have improved; but still **no LL Portal**.

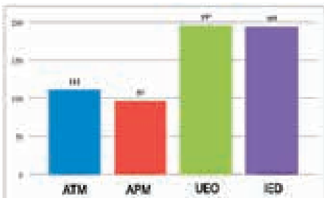
Effectiveness of Lessons Learned for EOD

The Challenge: By 2023, Ukraine is the **most mined country globally** (in 2019: top-5).
Between April 2014 and December 2019 around **1,000 UAF casualties** were sustained from mines, and **269 civilian** people, including 27 children, were killed In Eastern Ukraine.

The contribution of LL: LL focus on mines and related ordnance, combined with NATO-led training (2015-21) and NGOs (e.g. HALO Trust best-practice sharing from 2016), have **reduced accidents and improved analysis.**



Number of Mine accidents in the UAF (2015-2019)
Source: LL Bulletin, June 2020, NAA.



Types of Mine accidents in the UAF 2015-19
Source: LL Bulletin, June 2020, NAA.

Annex 4

Rapid-Cycle learning for effective remedial action and dissemination of learnings EO threat

Dr. John Tull

Understanding Threat Dynamics
– via LL data collection and analysis

The majority of mine accidents each year [2015-2019] were caused by:

- 2015 - IED (123)
- 2016 - UEO (43)
- 2017 - UEO (49)
- 2018 - APM (20)
- 2019 - APM (17)

- In 2018-2019 period, with the decrease in the intensity of hostilities, the number of mine incidents in the UAF **significantly decreased**. At the same time most of the mine accidents were caused by APMs, primarily **PMN-2** anti-personnel mines (12 accidents in 2018, 16 accidents in 2019).
- Russians used the Donbas war as a **training area** (polygon) to 'polish' and improve their "mine warfare" tactics. While at the beginning of the ATO, the enemy used mostly **unguided** landmines, since 2016, Russian troops have been actively using **wire and radio-controlled landmines**, including those controlled by mobile phones.
  - Figure 1 shows a specific method of mine warfare **(combined landmines EO)** for the simultaneous destruction of a vehicle and troops located on its armour) that Russian troops began actively using around 2016 (possibly earlier).

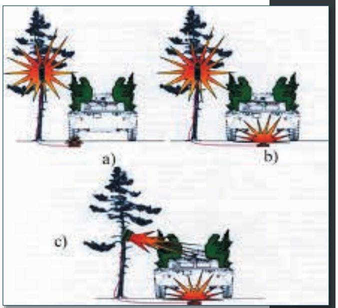


Fig. 1

What can we learn from Lessons Learned application to EOD? (1)
-- a progressive deepening of applying learning to planning and organising of action

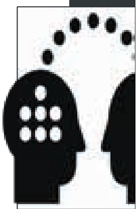
	SLAD: (2014-2018)	LLS1: (2019-2.2022)	LLS2: (2.2022-today)
Core learning capabilities for EOD	Data collection Semi-formal, tactical procedures	Data collection and formalised procedures for analysis	Improved analysis by LL/MLLT Higher-order focus
Focal topics (LL data):			
1. Technical	**IED/Mines** **Demining**	**Protective measures** Mines/IED; Demining **Incident analysis** ('14-19)	**Obstacle breaching and clearance**
2. Tactics	**Engineering issues**	**Enemy analysis** **Counter-tactics analysis** Sapper modernisation	**Engineering Recce** **Counter-IED and mines** **Experience of using Engineering units**
3. LL Organisation/ Planning	**Organisation of LL**; formal LL procedures in Anti-Terrorist Operation/Joint Force Operations (ATO/JFO) **LL Database** (2017)	**Establish LL bodies in UAF, assign roles** (LLSO, LLPOCs) (2019) LL Doctrine & SOP; training courses **MLLT set up, deployed**; evaluation of LL processes in JFO HQ	Establish LL Centre (J7-GS) **Increase speed of LL collection, analysis, sharing** **Standardise LL bodies** – all levels of UAF On-site LL training **Double MLLT** (6-11+)

What can we learn from Lessons Learned application to EOD? (2)

-- Issues identified and remedial steps have been taken in the learning process itself

	SLAD: (2014-18)	LLS1: (2019-21)	LLS2: (2022-today)
<u>Conclusion</u>: Progressive deepening – but LL effectiveness depends on (i) the resources, standards and people assigned, and (ii) how they align to the actual/emerging needs (focus, relationships, quality, timing).	**Semi-formal, tactical procedures come naturally** - lacked discipline, impairing quality. Some refinements. **MLLTs established** 2014 had effects: 2015-23: **21** LL Bulletins on Mines/ IEDs **Limited translation** of learning into education; incorporated into some officer education **Cultural inhibitors to sharing** – especially vertical. Some inter-generational changes improved **transformation** into better capabilities.	Formalised procedures **modelled on NATO LL** – standardised, but some only **on paper**. **LL extended** to all of UAF. **Staffing/training/ resources** inadequate. Low **analytical quality** at times – training issues: observations and recommendations repeated – lack of implementation. **MLLTs** tasked to study Donbas War. Activity higher: but LL database hits exaggerated. **Dissemination slow**.	Further **NATO LL doctrine and SOP** alignment – but imperfect. **Improved analysis by LL/MLLT** on specific EOD-related topics; enhancing organisational capabilities of the UAF. **Devolve LL:** MLLT onsite training for 170 LL officers. Expansion of MLLT specialist tasks. But: resources, training lag continue to affect **quality**. **Dissemination** improved (1 month); still too slow; no **LL Portal** for search/ dissemination

Conclusions & implications for Rapid Cycle Learning in EOD



Ukraine case: Maturing organisational learning process, with improving adherence to **good practices and standards**, looking beyond tactics to **organisational effectiveness:** improved coordination, quality of information for decisions, and timeliness.

Process execution however continues to require improvement:

- The same **root causes for mine problems and recommendations for remedial actions** were often repeated in LL bulletins leading up to February 2022
- Confirms that there were **no clear procedures for planning and implementing remedial actions**
- Suggests that **organisation and ownership of LL** throughout the chain of command is essential

Leadership attention *at all levels* matters – for improved process quality and timely transformation of information into improvement:

- ***how* standards are enacted** -- UAF leadership still tolerates 1 month dissemination delays, inconsistent analysis standards, lack of a LL Portal with better search/dissemination capabilities
- ***who* is accountable for the transformation** of information into accountable remedial actions

A continuous process, demanding **rapid cycles of learning** (including about learning) **and its transformation into new capabilities.**

Thank You.

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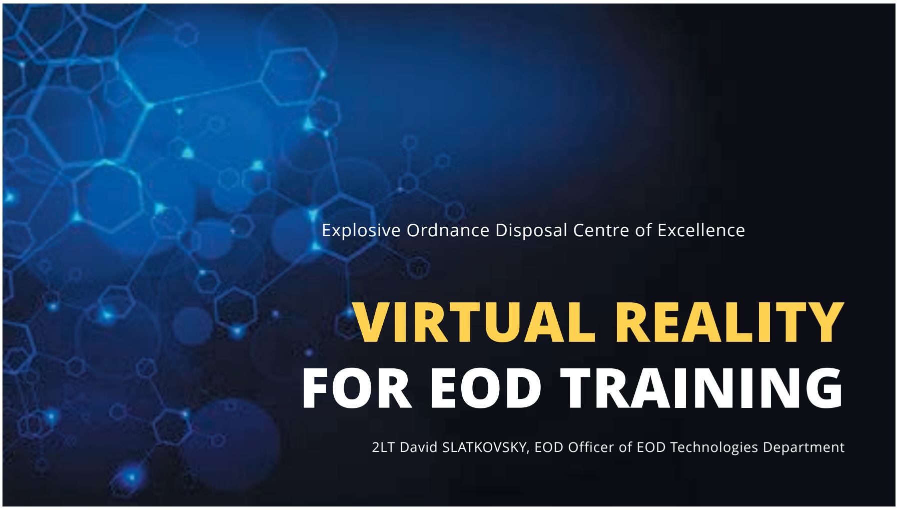
Supporting material

After significant defeats last year near Kyiv, in the Kharkiv and Kherson regions, the Russians managed to prepare for the Ukrainian counter-offensive (started in summer 2023) strong defensive positions, including extensive explosive obstacles (minefields).

- "In an urgent appeal to allies, Oleksii Reznikov (former Minister of Defence) told the Guardian his soldiers were unearthing five mines for every square metre in places, laid by Russian troops to try to thwart Ukraine's counteroffensive" *(Guardian: https://www.theguardian.com/world/2023/aug/13/ukraine-desperate-for-help-clearing-mines-says-defence-minister)*.
- The insidiousness of the Russians in mining (they call this approach as 'military stratagem') was manifested in the fact that when they retreated from their positions, they mined even the bodies of their dead comrades (CNN interview, Colonel Khomenko 2022): https://www.linkedin.com/posts/li-johnc_btwob-activity-6925057933588242432-3n2v/

See also: Dyson, Tom, and Yuriy Pashchuk. "**Organisational learning during the Donbas War: the development of Ukrainian Armed Forces lessons-learned processes**." *Defence Studies* 22.2 (2022): 141-167.


Explosive Ordnance Disposal Centre of Excellence
VIRTUAL REALITY
FOR EOD TRAINING
2LT David SLATKOVSKY, EOD Officer of EOD Technologies Department


1. Virtual Reality is like a cosmic **escape pod** for your **senses**, where you can trade the ordinary for the extraordinary, all without leaving your favorite chair. (AI, 2023)
2. VR is like a high-stakes game of make-believe for grown-ups, where your **imagination** gets a promotion and your **senses** take a vacation from reality. (AI, 2023)
What is Virtual Reality

SIGNIFICANTLY IMPROVE EOD TRAINING

Immersive Training

- Realistic & engaging environment
- Learn by doing

Improve Time Management

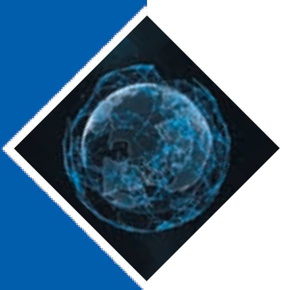
Conduct tasks that would take hours to prepare in real life repeatedly

Reduce the risk in training

Virtual environment is as safe as it could be.

More efficient training

Improving decision-making process by increasing overall time spent on conducting the tasks



POSSIBILITIES OF VR FOR EOD ARE LIMITLESS

Have all the tools at your disposal

- Use 3D models of explosive ordnance, tools and accessories
- Preparation of EOD tasks is a matter of seconds, conducting them is a matter of minutes

Be outside - inside

Accomodate parameters of the environment to your preferences and enjoy different conditions in the comfort of your home / office / classroom

Focus on what is important

Always be able to dive straight into your tasks, practicing repeatedly the EOD work, or just specific parts of it

NEW APPROACH TO EDUCATION & TRAINING

„A Breath of Innovation in EOD Training“

Implementing new technologies such as VR can have additional benefits:

- Attracting new generation of EOD personnel
- Refreshing the knowledge by using different tools and conditions

CHALLENGES OF VR EOD TRAINING

„Challenge is an opportunity to rise“

Compatibility within NATO

- Each country uses their own procedures to deal with EO threat
- Difference in tools, dummies
- **Create a tool which fits needs of all nations within NATO**

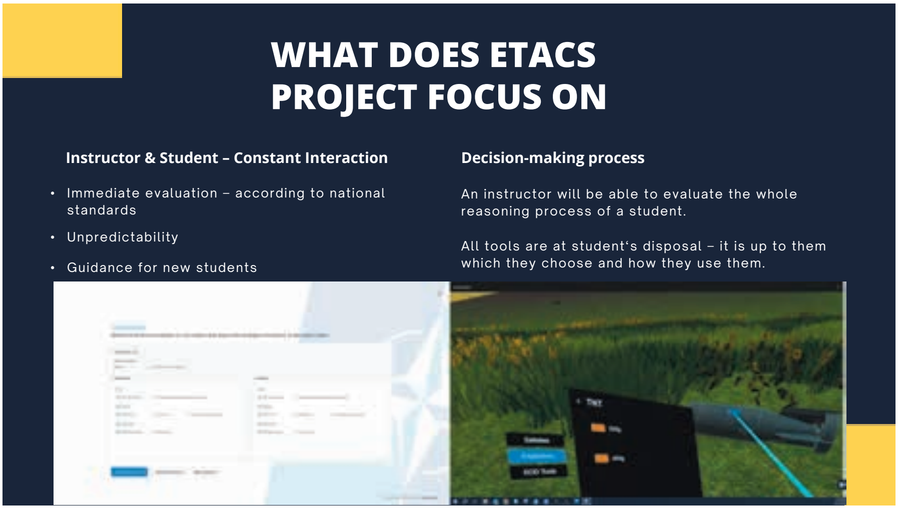
Paying attention to details

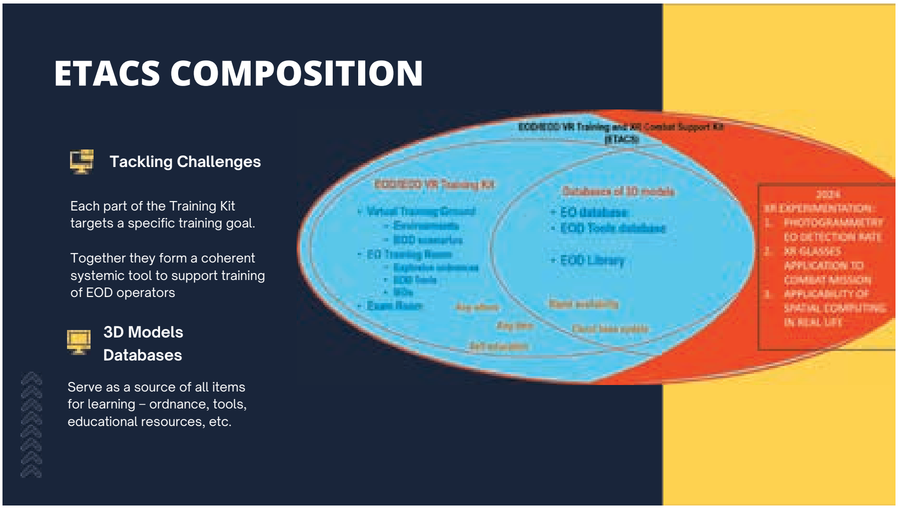
Every detail matters and there are many things to keep in mind at all times

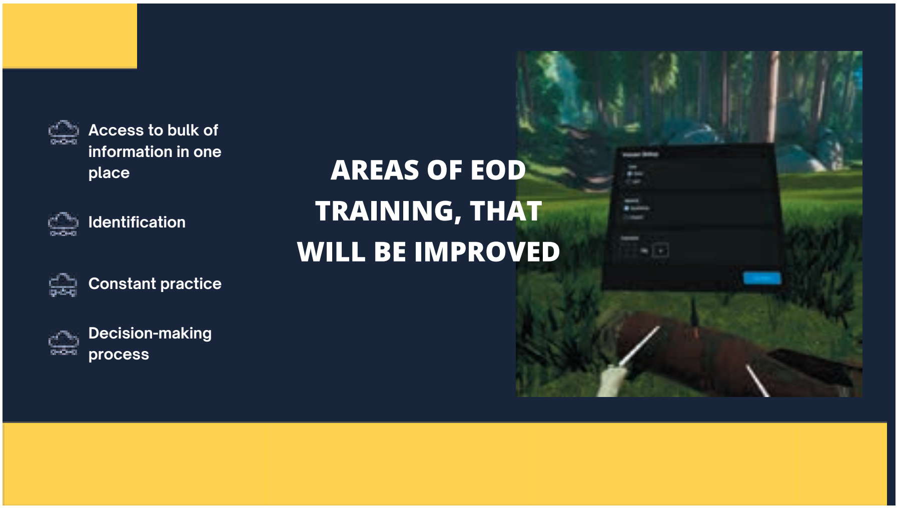
Achieve desired quality

Anything can be created, but the requirements for the quality of the product is very high


ETACS Project – Connection of Virtual Reality & EOD Training
EOD/IEDD VR/XR Training and Combat Support Kit
• EOD/IEDD VR Training Kit


WHAT DOES ETACS PROJECT FOCUS ON
Instructor & Student – Constant Interaction
• Immediate evaluation – according to national standards
• Unpredictability
• Guidance for new students
Decision-making process
An instructor will be able to evaluate the whole reasoning process of a student.
All tools are at student's disposal – it is up to them which they choose and how they use them.


ETACS COMPOSITION
Tackling Challenges
Each part of the Training Kit targets a specific training goal.
Together they form a coherent systemic tool to support training of EOD operators
3D Models Databases
Serve as a source of all items for learning – ordnance, tools, educational resources, etc.
EOD/IEOD VR Training and XR Combat Support Kit (ETACS)
EOD/IEOD VR Training Kit
Virtual Training Ground
Environments
IEOD scenarios
EO Training Room
Explosive ordnances
EOD Tools
Exam Room
Database of 3D models
EO database
EOD Tools database
EOD Library
2024
XR EXPERIMENTATION:
1. PHOTOGRAMMETRY EO DETECTION RATE
2. XR GLASSES APPLICATION TO COMBAT MISSION
3. APPLICABILITY OF SPATIAL COMPUTING IN REAL LIFE


Access to bulk of information in one place
Identification
Constant practice
Decision-making process
AREAS OF EOD TRAINING, THAT WILL BE IMPROVED

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https://www.eodcoe.org/en/technology-dept/eod/iedd-vr/xr-training-combat-support-kit/


THANK YOU!!
IN THE FUTURE TECHNOLOGY IS DEVELOPING VERY FAST

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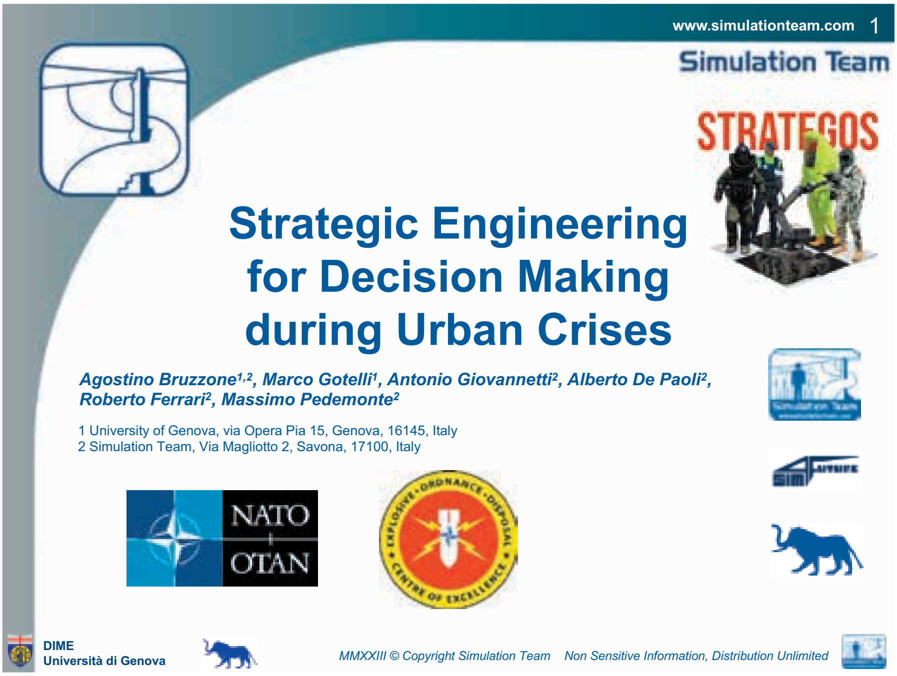
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Strategic Engineering for Decision Making during Urban Crises
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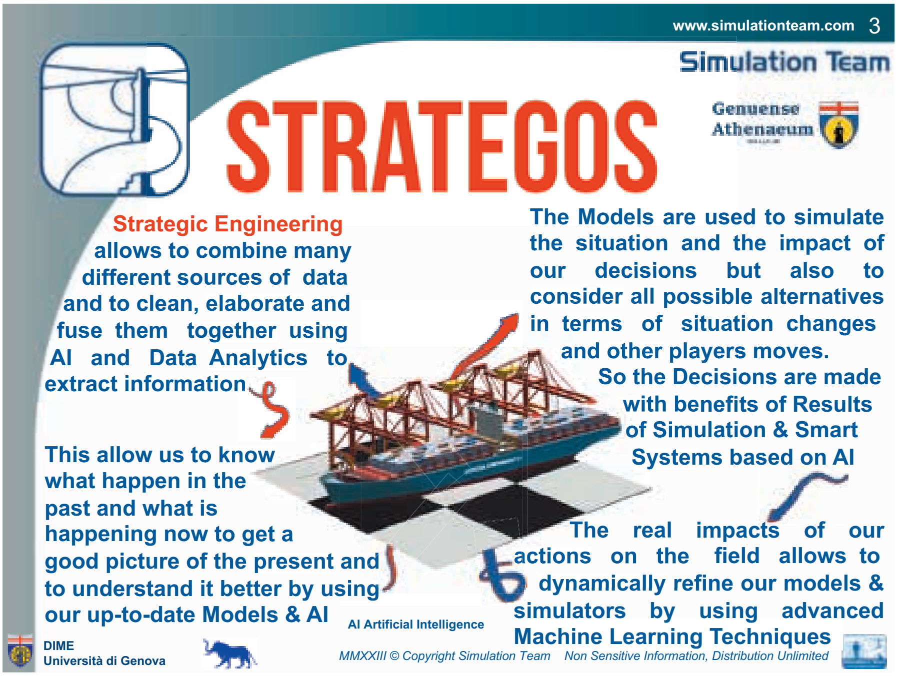
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STRATEGOS
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Strategic Engineering allows to combine many different sources of data and to clean, elaborate and fuse them together using AI and Data Analytics to extract information
The Models are used to simulate the situation and the impact of our decisions but also to consider all possible alternatives in terms of situation changes and other players moves.
So the Decisions are made with benefits of Results of Simulation & Smart Systems based on AI
This allow us to know what happen in the past and what is happening now to get a good picture of the present and to understand it better by using our up-to-date Models & AI
The real impacts of our actions on the field allows to dynamically refine our models & simulators by using advanced Machine Learning Techniques
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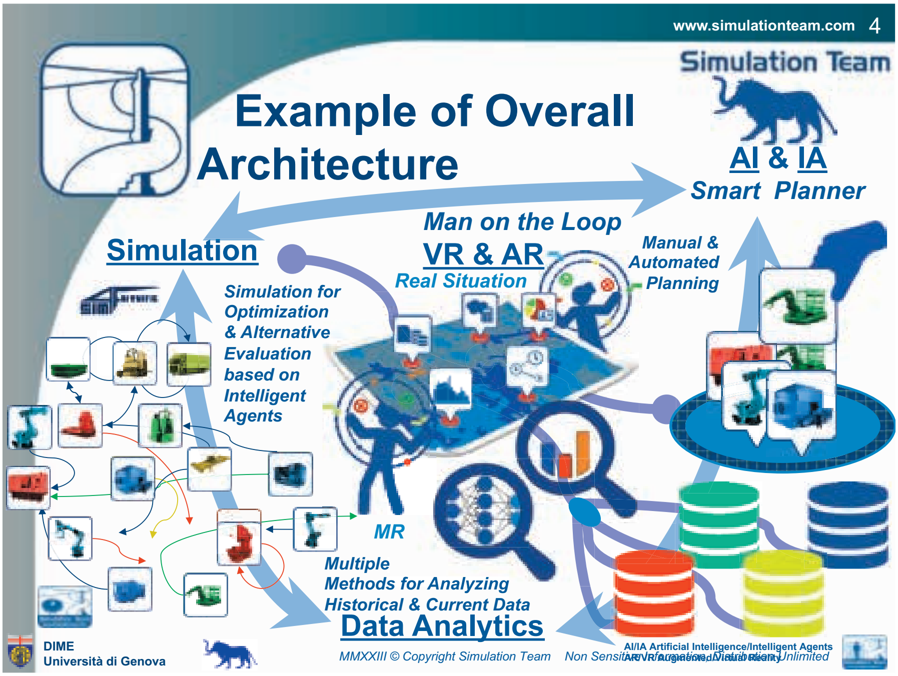
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Example of Overall Architecture
AI & IA
Smart Planner
Man on the Loop
VR & AR
Real Situation
Manual & Automated Planning
Simulation
Simulation for Optimization & Alternative Evaluation based on Intelligent Agents
MR
Multiple Methods for Analyzing Historical & Current Data
Data Analytics
AI/IA Artificial Intelligence/Intelligent Agents
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Dangerous Substances
Accidents involving dangerous materials represent constant threats to environment and people, especially if nearby populated urban centres.
In the past big accidents already happened, among which can be cited:
• Bhopal disaster, 1984, Methyl Isocyanate
• Seveso disaster, 1976, Tetrachlorodibenzodioxin
• Tokyo subway, 1995, Sarin
• Aqaba port, 2022, Chlorine
DIOXIN
SEVESO
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Simulation
Simulation today plays important role in crisis management. Simulation can be used to prepare emergency plans, training activities of personnel as well as to analyze outcomes under different conditions. In order to have effective results, simulation should take advantage of innovative models, able to integrate all different aspects involved in real event, and not just limited to transportation effects of dangerous material.
Relevant Data should be provided to models; in fact, due to updates of data banks or real-time monitoring, the model should be correct in light of different conditions. In this way, it is possible to have constant monitoring of situation
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Modeling Threats in Urban Area I

Models addressing diffusion of gas in cities should take in consideration numerous factors together chemical and transport effects.
In fact, many aspects have to be taken into account, such as:

- Chemical/Transport processes of the agent
- Weather Conditions
- Territory Conformation
- Urban Areas
- People

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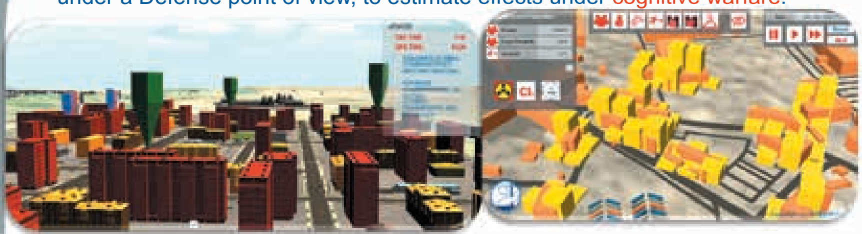
Modeling Threats in Urban Area II

In this case it is necessary to develop interoperable models, able to integrate the aspects of each "entity", while at the same time affect the other models. One of the advantage of this approach is the creation of comprehensive models, able to integrate multidisciplinary factors.
In this way, for example, would be possible to integrate the behavior of human factor with gas dynamics, as to estimate losses and countermeasures but also, under a Defense point of view, to estimate effects under cognitive warfare.



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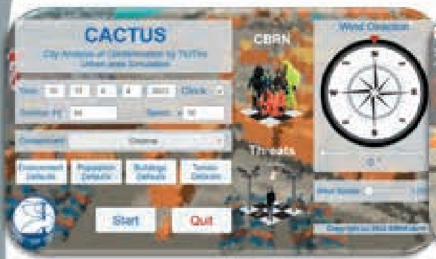
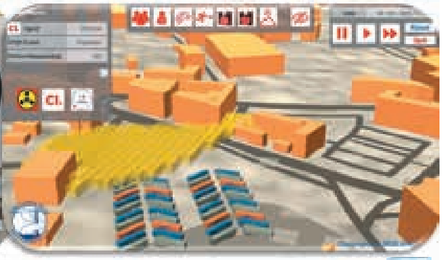
NATO OTAN

CACTUS Simulator

CACTUS (City Analysis of Contamination by Tic/Tim Urban Area Simulation) is proposed simulator to reproduce CBRN threats in urban areas.
Cactus is a real/fast time simulator, which allows to reproduce spreading of dangerous material in a 3D environment.
Cactus enables to forecast outcomes of releases integrating factors related to environment, weather and gas dynamics.





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Conceptual Model I

The 3D space is discretized in mesh composed by finite elements, which subdivide space of interest in bounded boxes.
Each box is characterized by state variables, which define the behavior of the bounded volume of air, which is supposed to fill the cube uniformly.
Each cube is then linked to near cubes, enabling mass flow between each other.

The dangerous gas is then defined, accordingly with its parameters and type of release in environment.
Dangerous gas can then be inserted inside one cube of origin, where the gas behaves accordingly to its own state conditions (like release Temperature, mass) and the state variables of the cube where it is settled.

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Conceptual Model II

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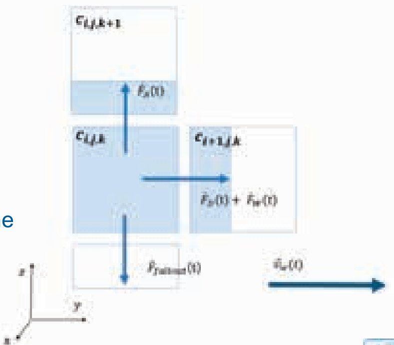
The evolution of gas during time is then reconstructed accordingly to the nature of the gas, and the interaction of external factors.
Among considered effects can be considered:

- Diffusion Effects
- Floating Effects
- Chemical Effects
- Transportation due wind

The gas is then able to move inside the Mesh, until the complete escape from the interest zone.



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Terrain and Urban Areas I

After the release of a substance, the material starts to spread in all direction in space. Thus, spreading model should take into account which are preferential ways of spreading and which could not be accessed.
This is particularly critical for narrow urban areas, where geometry of buildings and road networks play important role.
Terrain data should be acquired, such as Digital Elevation Model (DEM) and Digital Terrain Model (DTM).
Data can be used to associate a shaped model of terrain, representing geometrical characteristics of land and buildings.

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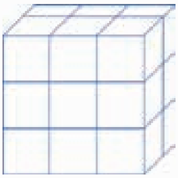
Terrain and Urban Areas II

The obtained terrain data provides information on terrain high, information of buildings and area occupied by water.
On the selected 3D area, a Mesh can be built taking into account the terrain below each cube of the mesh. In this way, each cube can be marked as empty or unreachable, dividing space that can be subject to spread of material.
Each Building can be reconstructed, associating state variables according to available information.

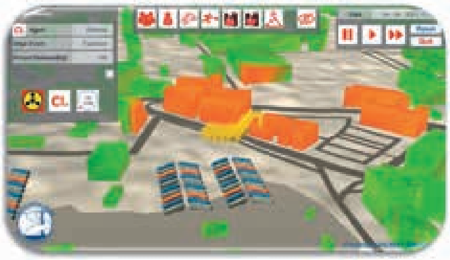


3D Mesh Model

→

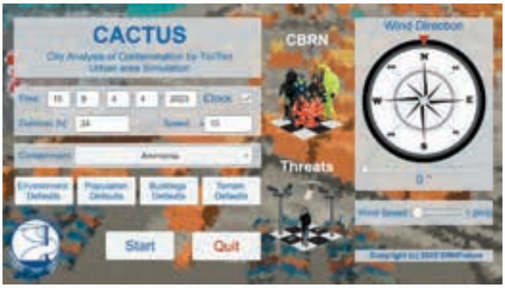
Wind Conditions

Weather conditions affects directly the spreading of the gas, and one of the most important factor is wind effect. Wind is characterized by direction and speed, which has to be defined for each point inside the area of interest. Available information can be integrated with computation and analysis of terrain, gradients and interpolation.
Winds is allowed to act in 3D Mesh, moving gas flow between cubes. In this way preferential directions are recreated as well as areas more likely to stagnation.



Population

Buildings reconstruction allows to estimate population distribution, and underline which zone is more dangerous to population.
Population is associated with cubes position, and can be affected by gas concentration in that area. Thus, considering lethality of gas, concentration and time of exposure, is possible to calculate people in dangerous area, injured and losses.



CACTUS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Conclusions
NATO
OTAN
Simulation of complex urban environments during crises is a complex task; experience, interdisciplinary knowledge and capability are required in order to develop an appropriate model.
CACTUS is the tool proposed by Authors, allowing the user to predict and evaluate impact of dangerous events in complex environment, also formulating what-if cases.
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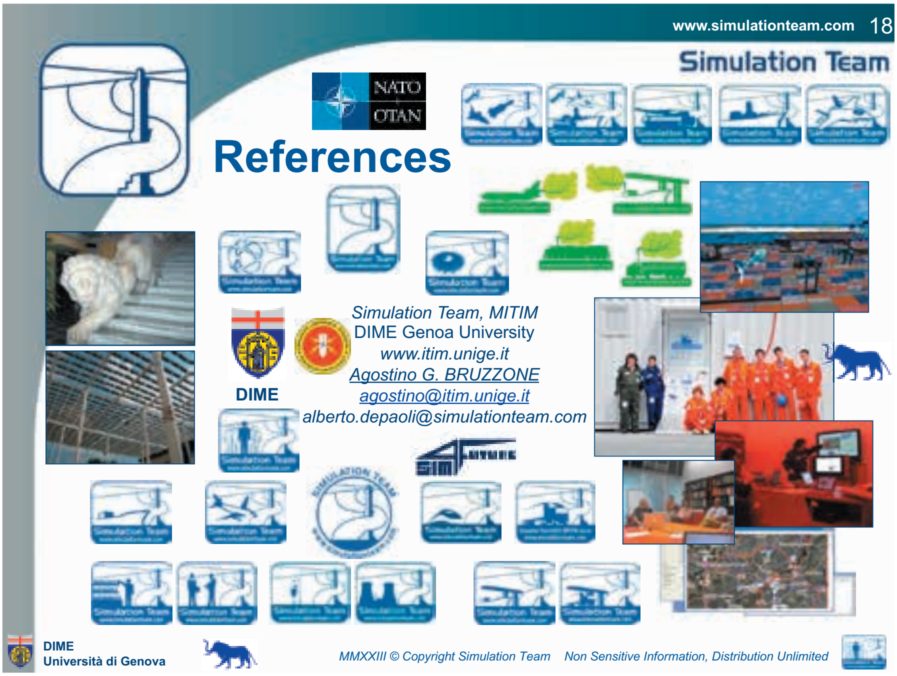
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U.S. Policy for Countering IEDs

Joint Program Office for Countering IEDs

Presented to

NATO EOD Demonstrations & Trials

October 11, 2023

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Bottom Line Up Front

- IEDs are the "weapon of choice" and a significant and enduring global security challenge that requires the diverse capabilities of many departments and external stakeholders; the current threat environment adds an additional sense of urgency to counter-IED efforts
- The U.S. has a whole-of-government policy and coordination framework to strategically counter the use of IEDs, via PPD-17 and the Joint Program Office for Countering IEDs (JPO C-IED)
- Currently efforts are on-going to ensure PPD-17 is up-to-date and aligned with global threats

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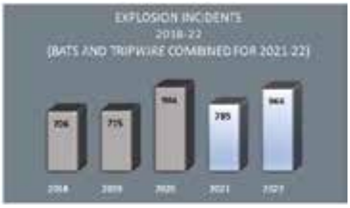
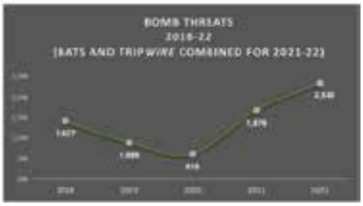
Domestic IED Threat Analysis – 2022

The U.S. Bomb Data Center (USBDC) 2022 Explosives Incident Report encompasses information reported to the USBDC through the Bomb Arson Tracking System and Open-Source information collected through TRIP*wire*.



23% Explosion Incidents: the total number of explosion incidents **increased** by **23%** from **785** in 2021 to **966** in 2022.



35% Bomb Threats: the total number of bomb threat incidents **increased** by **35%** from **1,876** in 2021 to **2,538** in 2022

Trending Concern – Mass Bomb Threats

- Bomb threats, include mass or serial attacks, are not new, but ***new technology and tactics*** makes their reach and impact far ***more scalable and disruptive***
- Prominent recent examples include ***Ivy League*** schools in November 2021 and ***Historically Black Colleges and Universities (HBCUs)*** in January and February 2022
- Threats to ***thousands of Jewish community facilities*** in the U.S., UK, Australia, New Zealand, Denmark, and Norway occurred in 2017
- In Ukraine, ***bomb threats are common in the context of Russian-backed information operations***, but jumped to nearly 10,000 in January 2022, including nearly 8,000 schools

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Annex 7

Mitigating the Threat of Terrorist Bombing Attacks

Mr. Jason Stewart, Mr. Michael Holt

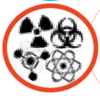
Current Strategic Counter-IED Challenges

Availability and Flow of Materials: Explosives and precursors are readily available, both internationally and within the United States.

Proliferation of Technical Knowledge: Operatives and returning foreign fighters spread knowledge, compounded by collapsing technology costs and use of Internet to motivate and instruct sympathizers to employ IEDs.

Sophisticated Concealment: As IED countermeasures advance, adversaries attempt to thwart them through clever bomb design, manufacture, placement, and masking. Recent examples include high-profile assassination and aviation plots.

Unmanned Delivery Systems: Terrorist groups have rapidly advanced the scale and sophistication of unmanned delivery systems. Remotely piloted ground vehicles and commercially available unmanned aircraft systems (UAS) are recent examples.



CBRN Enhancements: Terrorist groups continue to pursue the use of chemical, biological, nuclear, and radioactive devices. Chemical devices have been used recently in the ME.

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C-IED Mission Overview

- ***Challenging mission*** with ***no "silver bullets"***
- Required capabilities ***cut across policy portfolios***, intergovernmental ***authorities***, and ***role of the private sector***, general public, and international partners
- ***Aims to prevent incidents "left of boom",*** reduce consequences otherwise
- ***C-IED capabilities are fundamental*** to, and draw upon:
  - Defense
  - Intelligence and information sharing
  - Counterterrorism
  - Law enforcement
  - Infrastructure protection, aviation security
  - Preparedness/resilience
  - Diplomacy
  - Dignitary and special event protection
  - Soft target security
  - C-WMD, C-UAS, and countermeasures RDT&E
- **Capabilities are technical, perishable, and can be resource-intensive due to enduring *and* evolving tactics**
- Success ***requires effective strategic planning, coordination, and prioritization*** due to needed resources, capabilities, stakeholders

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Annex 7

Mitigating the Threat of Terrorist Bombing Attacks

Mr. Jason Stewart, Mr. Michael Holt

C-IED Mission Capabilities

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Evolution of C-IED Policy from 2005-Present

- **Historically, a patchwork of laws, policies, and guidance on IEDs existed within separate mission areas and disciplines of government, e.g., law enforcement, military, aviation security, consequence management, etc.**

- **The 2005 bombings in London prompted the U.S. to develop more proactive, comprehensive <u>domestic</u> C-IED policy:**
  - White House IED Task Force developed policy and predated JPO C-IED of today.
  - ***Homeland Security Presidential Directive 19 (HSPD-19)*** in 2007 emphasized a range of risk-management strategies and capabilities, from prevention though response.
  - The domestic focus largely divided civilian and military, domestic and international communities within U.S. Government.

- **New threats against global aviation beginning in 2009 prompted a policy review to <u>integrate domestic and international</u> efforts:**
  - A series of significant transnational incidents occurred, including the attempted "underwear" bombing of Northwest Flight #253 in December 2009 and October 2010 air cargo "printer toner" plot.
  - ***Presidential Policy Directive 17, Countering IEDs (PPD-17)*** in 2012 emphasized integration between domestic and international, military and civilian activities and also formally mandated the JPO C-IED.

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Why the Nashville Christmas Day Bombing Matters – Strategic Picture

- Sophisticated device made from ***hundreds of pounds of easily accessible chemicals***
- Subject ***able to conceal construction of large IED and emplace*** in high-risk urban area
- ***Subject was previously referred*** to law enforcement for potential bomb-making
- ***"Near miss" of a 2nd Oklahoma City***; adversary's choices mitigated potential consequences
- Blast ***caused cascading effects and demonstrated inter-relationship of physical-cyber consequences***
- ***Other cities and critical infrastructure still vulnerable*** to the highest-risk IED tactics, but also other threats could stress resilience

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JPO C-IED Process

- ✓ **National Security Council (NSC)**
  - Facilitates periodic Policy Coordination Committees (PCCs) or Interagency Policy Committees (IPC) to oversee policy implementation across U.S. Government
  - Consists of Assistant Secretary (or equivalent) members
- ✓ **Joint Program Office for Countering IEDs (JPO C-IED)**
  - Directed in PPD-17 to support NSC
  - Facilitates a periodic Executive Committee meetings at the Deputy Assistant Secretary (or equivalent) level to oversee progress
  - Facilitates a bi-monthly Implementation Committee at the program manager level to coordinate progress within the Working Groups
- ✓ **JPO C-IED Working Groups**
  - Task-based groups that coordinate implementation and address challenges at the working level
  - Consists of program managers and experts from throughout U.S. Government
  - Currently task-organized around the four C-IED strategic goals outlines in the PPD-17 IPlan

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The JPO C-IED Role and Structure

- ***Support the National Security Council*** to implement U.S. counter-IED policy
- Facilitate the ***integration and alignment*** of domestic, transborder, and international activities across the United States Government necessary to counter IEDs in accordance with national policy; and
- ***Coordinate, track, and, as necessary, escalate*** implementation issues relating to the execution of specific tasks to counter the use of IEDs.

The JPO C-IED is effectively a standing sub-IPC/PCC to the Restricted C-IED PCC/IPC used since the George W. Bush Administration.

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Key Themes of PPD-17

- **Enhance ability to deter, detect, and prevent IEDs before threats become imminent.**
  - Need to "*discover IED threats*" as early as possible - known as getting *'left-of-boom'* within the counterterrorism community
  - Examples include numerous IED plots that have been disrupted in the U.S. since 9/11, including numerous DVE plots in 2020
- **Ensure that protection and response efforts effectively neutralize or mitigate the consequences of attacks that do occur.**
  - Examples include the rapid, intergovernmental and whole community crisis response to the Boston Marathon, Austin, VIP mail, and Nashville bombings.
- **Enhance the effectiveness of counter-IED efforts in specific ways, including:**
  - Leveraging and integrating a ***"whole-of-government"*** approach across law enforcement, diplomatic, homeland security, and military disciplines;
  - Enhancing efforts to protect American lives at home and abroad; and
  - Promoting and enhancing ***information sharing and cooperation*** *between all levels of government, international partners, and the private sector.*

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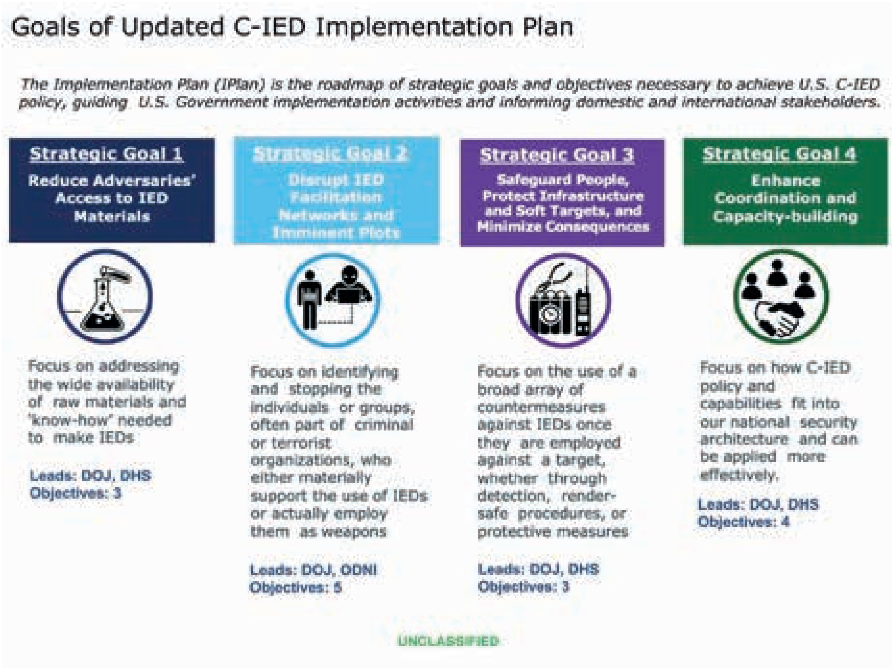

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EU TM MALI experience as J-3

LTC René Hečko

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EUROPEAN UNION TRAINING MISSION IN MALI

European Union

J3 EOD Experience from EUTM MALI

Lieutenant Colonel René HEČKO (OF-4)

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AGENDA

1. **EUTM MALI INFO**
2. MALI EO THREAT ASSESMENT
3. EOD JDs
4. EOD EXPERTISE PROVIDED

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EU TM MALI experience as J-3

LTC René Hečko

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Operation history

- The first mandate of the EUTM Mali mission was approved by the European Council on 17 January 2013.

1. mandate 2013-2014
2. mandate 2014-2016
3. mandate 2016-2018
4. mandate 2018 – May 2020
5. mandate 2020 – May 2024

- The mission area has expanded over the course of various mandates.

- EUTM Mali supports the start of the process of **d**isarmament, **d**emobilization and **r**eintegration (DDR) initiated by the peace agreement.

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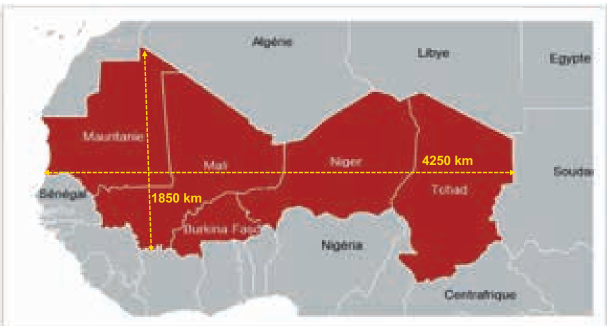
Area of Operation



- **Number of Countries: 5 (MAU – MLI – NER – BKF – CHA)**
- **Area: 7,8 mil. km² (4 846 695.29945 miles²)**

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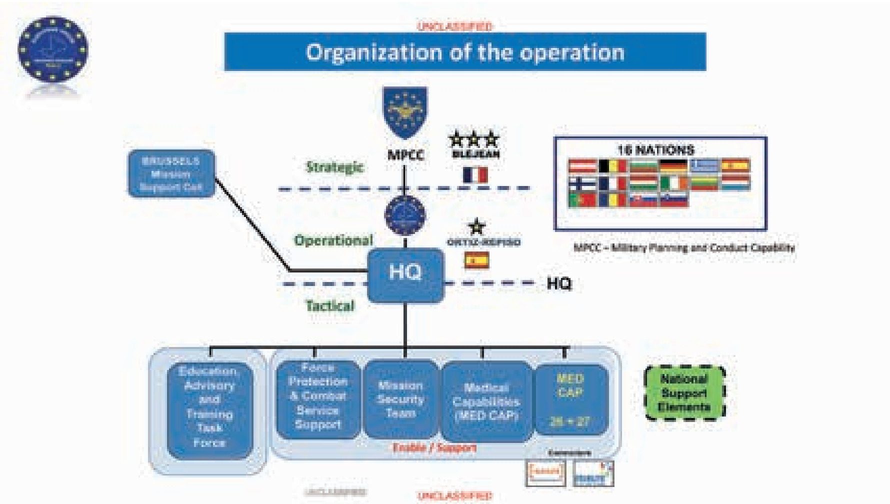
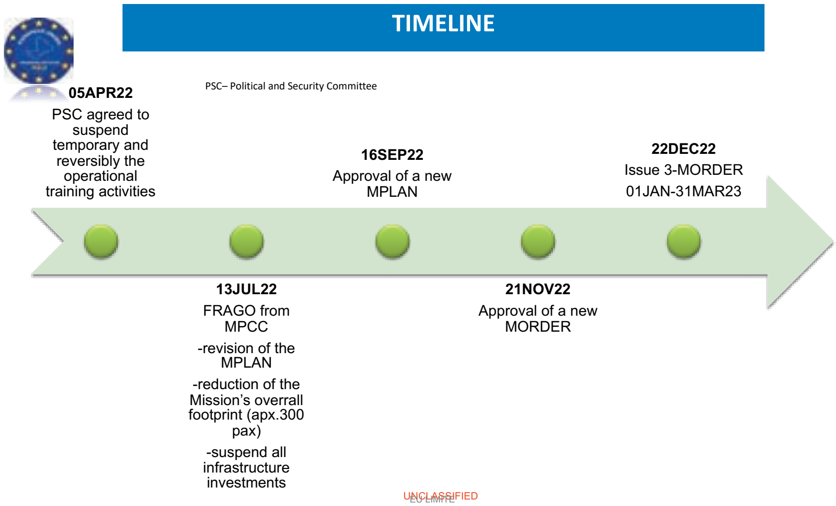
EU TM MALI experience as J-3

LTC René Hečko





MISSION PLAN

MISSION

EUTM Mali will focus the activities on support to:

- MaAF, on strategic advice and education only. All operational and non-operational training activities are temporary and reversibly suspended;
- BFA, NER, G5S JF and (other) G5S armed forces in order to support its/their operationalization.

MAIN EFFORT

Maintaining liaison with MaAF, supporting the MaAF reforms as applicable and (re)building mutual trust and confidence with MaAF.

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MISSION ORDER

MISSION
MFCdr will conduct millitary asssistance to:
- MaAF, focussed on Strategic Advice and Education and develop plans to resume training;
- BFA Armed Forces;
- G5S JF.

MAIN EFFORT
The main effort will be to mantain liaison with MaAF by rebuilding mutual confidence.

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EU LIMITE

„Current“ security situation MALI

The facts	• République du Mali • Republic of Mali
The heads of state and government	Interim president: COL. ASSIMI GOITA Interim prime minister: CHOGUEL MAÏGA
Capital city	Bamako
Population	• (2021 estimated) 21,120,000 • (2030 estimated) 28,020,000
Official languages	French Bambara
Area (km²)	1, 240,192
currency	West African franc (CFA)
Urban and rural population	• Cities: (2018) 42.4% • Countryside: (2018) 57.6%
life expectancy	• Men: (2017) 65.7 years • Women: (2017) 68.2 years
Literacy	Percentage of literate population aged 15 and over: • Men: (2015) = 45.1% • Women: (2015) = 22.2%

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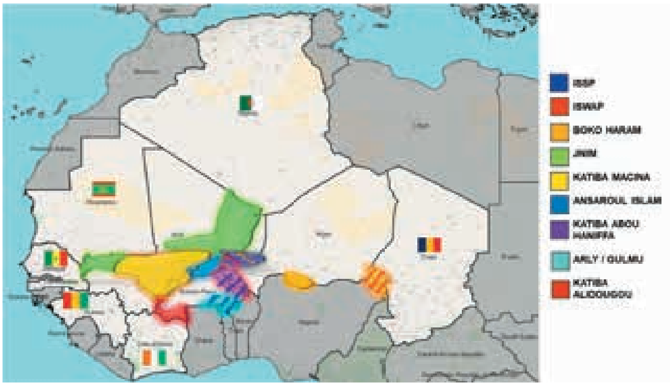
Annex 8

„Current“ security situation
Terrorist groups in the G5 Sahel



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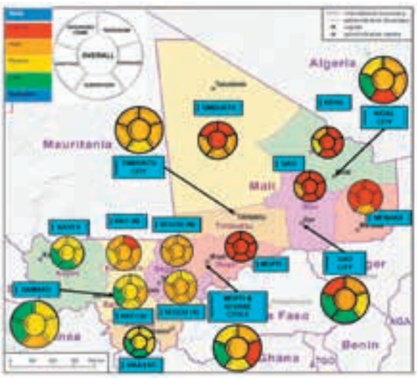
„Current“ security situation
MALI



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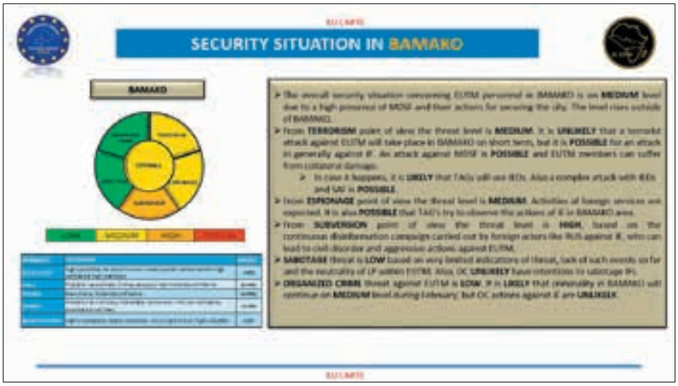
„Current“ security situation in BAMAKO MALI 28FEB23



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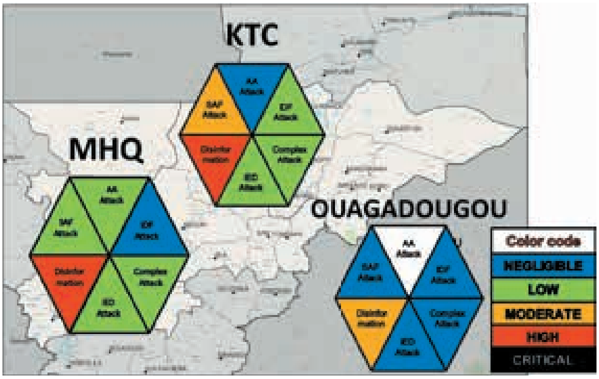
„Current“ security situation Threat of forces 28FEB23



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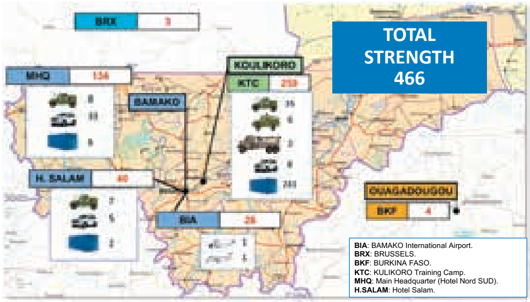
EUTM forces layout dated 15JAN23



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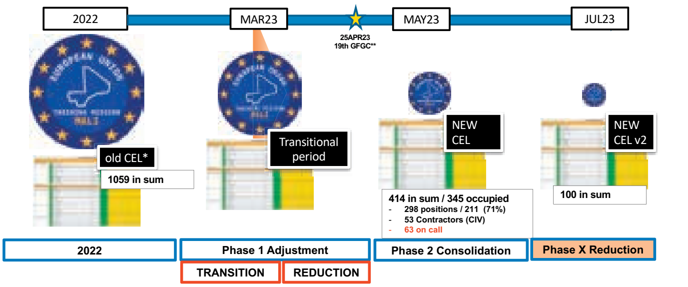
Organizational structure Strength



* **CEL:** Crisis Establishment List.
** **GFGC**: Global Force Generation Conference.

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Operational deployment within G5 Sahel

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Main Tasks of SLOVCON in EUTM Mali

Deputy Chief of J3 / J3 Plans / EOD CC | Chief of INFO OPS | J2 Analyst | Watch - keeper | Watch - keeper

- ❑ Deputy Chief J3
- ❑ Coordination, planning and management of EUTM Mali operations
- ❑ Management of the operational planning group
- ❑ Member of the MIRT (major incident response team)
- ❑ Member of the Mission security board and MSWG
- ❑ Coordination of EOD support to EUTM Mali
- ❑ Analysis and assessment of EO threats in the G5 Sahel
- ❑ Coordination of EOD and C-IED efforts of EUTM Mali
- ❑ Creation and revision of SOP
- ❑ Responsibility for the ammunition depots in EUTM Mali
- ❑ Head of working groups with MINUSMA and UNMAS
- ❑ Fulfillment of SNR tasks

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EU TM MALI experience as J-3

LTC René Hečko

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AGENDA

1. EUTM MALI INFO
2. **MALI EO THREAT ASSESMENT**
3. EOD JDs
4. EOD EXPERTISE PROVIDED

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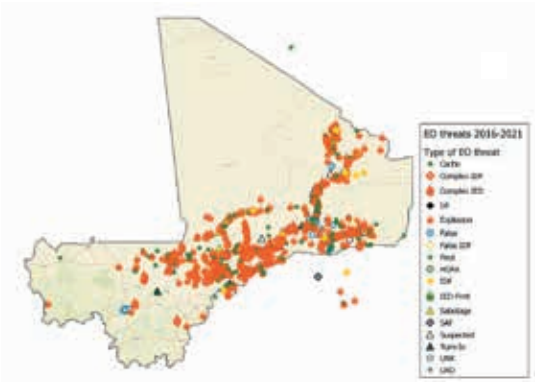
EO Threats in Mali 2016-2021



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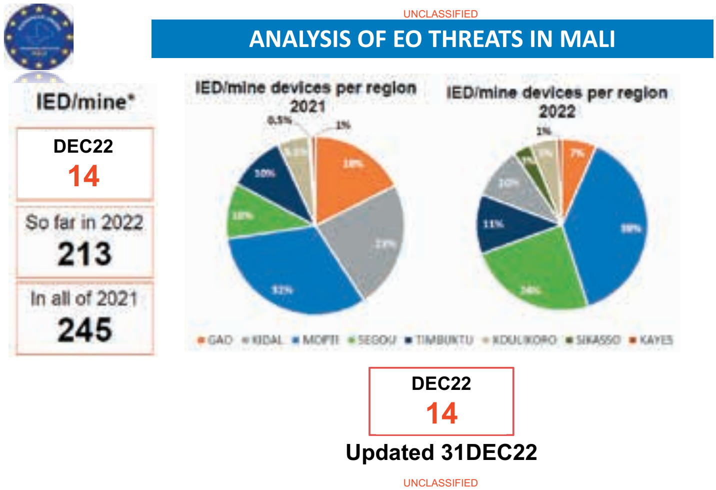
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ANALYSIS OF EO THREATS IN MALI
IED/mine*
DEC22
14
So far in 2022
213
In all of 2021
245
IED/mine devices per region 2021
IED/mine devices per region 2022
GAO
KIDAL
MOPTI
SEGOU
TIMBUKTU
KOULIKORO
SIKASSO
KAYES
DEC22
14
Updated 31DEC22
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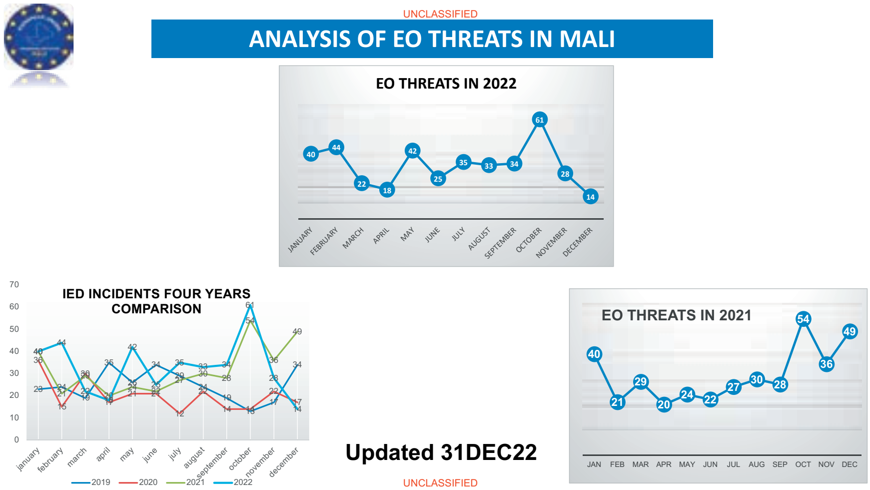
UNCLASSIFIED
ANALYSIS OF EO THREATS IN MALI
EO THREATS IN 2022
40
44
22
18
42
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33
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28
14
JANUARY
FEBRUARY
MARCH
APRIL
MAY
JUNE
JULY
AUGUST
SEPTEMBER
OCTOBER
NOVEMBER
DECEMBER
IED INCIDENTS FOUR YEARS COMPARISON
january
february
march
april
may
june
july
august
september
october
november
december
2019
2020
2021
2022
Updated 31DEC22
UNCLASSIFIED
EO THREATS IN 2021
40
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36
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JAN
FEB
MAR
APR
MAY
JUN
JUL
AUG
SEP
OCT
NOV
DEC

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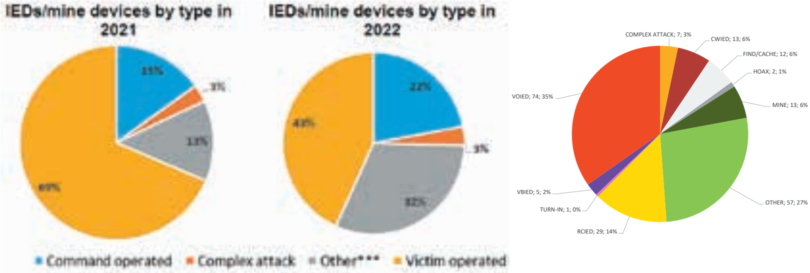
IEDs PER CATEGORY PER YEAR

Updated 31th December 2022 (source dated 31th December 2022)



- In order, **VOIED, RCIED & ERW/Mine** were the **3 most commonly encountered Explosive Hazards** in Mali in **2022**.
- **VOIEDs have continued to be the main threat in 2022.**
- **OTHER**: It is **assessed** that tasks falling into **OTHER (incl. ERWs/Mines and Caches) are approximately 70 % VOIEDs and 30 % Command IEDs**, however this **cannot be confirmed** due to the lack of Post Blast Investigation (PBI) at many scenes.

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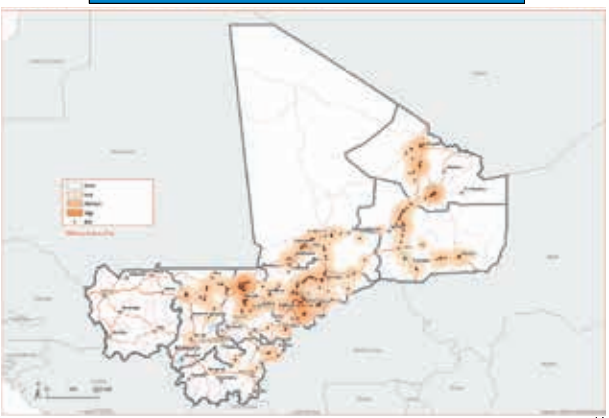
IEDs in Mali 2022 - 2023



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Updated 11FEB23

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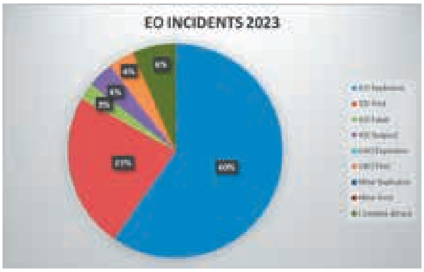
ANALYSIS OF EO THREATS IN MALI

IED/mine*

So far 2023	77
2022	227
2021	245



APR23
7

Updated 16APR23

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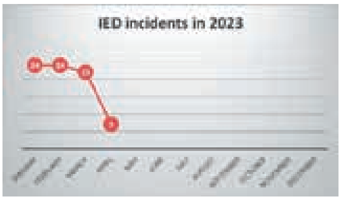
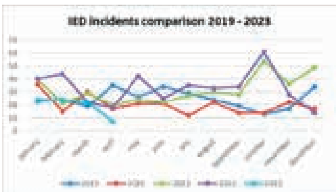
ANALYSIS OF EO THREATS IN MALI





Updated 16APR23

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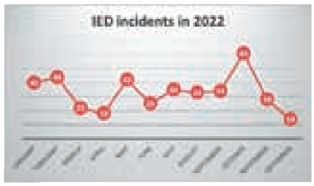

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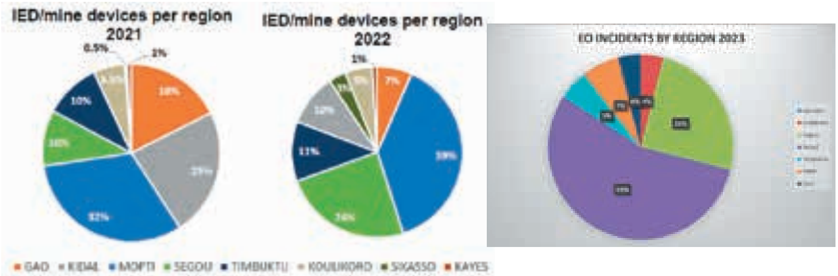
EO INCIDENTS IN MALI REGIONS



Updated 16APR23

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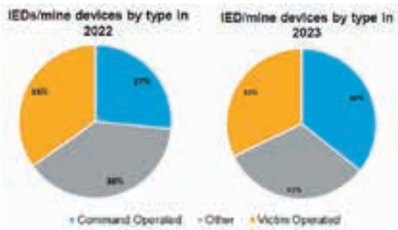
IEDs PER CATEGORY PER YEAR

Updated 16APR23 (source dated 31MAR23)



- In order - **COIED, VOIED & ERW(Mines)** are the **3 most commonly encountered Explosive Hazards** in Mali in **2023**.
- **VOIEDs are possesing significant threat in 2023 – but shift to COIEDs is visible.**
- **OTHER**: It is **assessed** that tasks falling into **OTHER (incl. ERWs/Mines and Caches) are approximately 70 % VOIEDs and 30 % COIEDs**, however this **cannot be confirmed** due to the lack of Post Blast Investigation (PBI) at many scenes.

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General assessments

HIGHLY LIKELY:
- MSRs will remain the most targeted entities, especially in the known threat boxes.
- The VOIED will remain the most used IED type.
- TAGs are improving their IDF accuracy and coordination of IDF attacks to support CxATKs which incl. IEDs.

LIKELY:
- CxATKs, SVBIED and POSSIBLY PBIED attacks will be used towards MDSF and IF, especially in retaliation for ongoing and past operations.
- TAGs place secondary IEDs.
- TAGs has the capability to execute accurate and coordinated IDF attack.

TRENDS:
- The use of conventional anti-personnel and anti-tank (anti-vehicle) mines.
- RCIED emplacement in hard-topped roads.
- Placing of RCIEDs in wrecked cars to initiate a CxATK.
- Use of multiple IEDs.
- Increasing weight of homemade explosive main charge (HME MC) – ANFO/ANS.
- Use of Unmanned Aircraft Systems (UAS).

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C-IED RECOMMENDATIONS

- According to the reported data, the most dangerous area in our MA (Mission Area) is the **MOPTI region with 39 % in 2022 and 55 % so far in 2023 of all EO incidents** within the MALI – these data are only from **one source** (MINUSMA) and are delayed.

- It is **unlikely** that the EO threat will be directly on the **MSR ELPHANT and DOLPHIN**, but it is **possible on the side roads** - minimizing the use of side roads, or **search for IED indicators or suspicious LP behaviors**.

- The typical weight of **HME** in a MC of the convoy targeted IED is approximately **10-30 kg** - for mitigation, **MRAP vehicles** are to be primarily used.

- The most used type of IEDs is the VOIED (Victim-Operated Improvised Explosive Device), followed by the **RCIED** (Radio-Controlled Improvised Explosive Device) – **ECM/CREW systems** and assets are to be used.

- By placing the **receiver of the RCIED at a greater distance** from the location of the, likely TAGs are trying to avoid interference from the ECM - detached RC wires reported in Mali are typically **8-10m long, but 70m long have also been detected** - Use **DOMINANCE TEAM** to seize the trigger point if RCIED indicators are detected.

- **AT mines** was used for IED MC – **treat** AT mines initially **as IED**.

- Use of Unmanned Aircraft Systems (UAS) - **treat** UAS initially **as IED**.

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EU TM MALI experience as J-3

LTC René Hečko

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AGENDA

1. EUTM MALI INFO
2. MALI EO THREAT ASSESMENT
3. **EOD JDs**
4. EOD EXPERTISE PROVIDED

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EOD JDs

PART 1 – ADMINISTRATIVE

Post Title:	EOD Coordination Cell Head (FULL EOD CAPABILITY)			**Post No:**	
Service:	A/N/F	**Grade:**	OF 3/4	**Status:**	CE

PART 2 – DUTIES

Post Description:	1. MFHQ EOD Coordination Cell Head. 2. Direct and coordinate all activities related to EOD / C-IED to the short term planning of the mission regarding future plans. 3. Provide the EOD inputs to Orders. 4. Provide EOD expertise and Explosive hazards related expertise. 5. Provide the MFHQ ICCW J2 explosive hazards analysis in Mission Area. 6. Develop and Coordinate response to explosive hazards in Mission Area.
Principal Duties:	1. Act as advisor to MI Cdr (or MFHQ staff branches and component staffs) on EOD / C-IED related activities. 2. Monitor EO threat situation in Mission Area. 1. Coordinate EOD support and C-IED support with other staff branches. 2. Produce EOD related reports and returns. 3. Support J3 with advice by developing, reviewing, and updating short and mid- term plans. 4. Cooperate with J2 and all FP Groups elements. 5. Advice FP Group Cdr on threat assessment. 6. Manage, coordinate, and assist to execution of EOD operations. 7. Manage, coordinate, and assist to reconnaissance, render safe and final disposal of explosive ordnance. 8. Manage, coordinate, and assist to EO disposals (including Ammo leftovers disposal). 9. Manage, coordinate, and assist in marking of hazardous zones and areas where explosive ordnance (EO) has been found.
Additional Duties:	1. Conduct Vehicle check training and other Explosive hazards related trainings as required. 2. Ammo Depot at the MFHQ inspection responsibility. 3. Any other tasks as directed by J3 Chief.

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EOD JDs

PART 1 – ADMINISTRATIVE

Post Title:	EOD Staff Officer (REDUCED EOD CAPABILITY)			**Post No:**	
Service:	A/N/F	**Grade:**	OF2/3	**Status:**	CE

PART 2 – DUTIES

Post Description:	1. MFHQ EOD Coordinator. 2. Drafting the EOD inputs to Orders. 3. Provide the MFHQ with analysis of explosive hazards.
Principal Duties:	1. Act as MFHQ EOD Coordinator. 2. Produce EOD related reports and returns. 3. Advice FP Group Cdr by EO threat assessment. 4. Coordinate execution of EOD operations. 5. Through/via EOD Teams coordinate the reconnaissance, render safe and final disposal of EO. 6. Through/via EOD Teams coordinate EO disposals. 7. Through/via EOD Teams coordinate marking of hazardous zones and areas where explosive ordnance (EO) has been found.
Additional Duties:	1. Monitor EO threat situation in Mission area. 2. Any other tasks as directed by J3 Chief.

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AGENDA

1. EUTM MALI INFO
2. MALI EO THREAT ASSESMENT
3. EOD JDs
4. **EOD EXPERTISE PROVIDED**

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EOD EXPERTISE

UAS / EOD ASSESSMENT

1) If UAS landed / grounded / crashed = **EXPLOSIVE HAZARD (EH)**
2) ACTIONS IAW C-IED procedures

TYPE	POSSIBLE PAYLOAD	HAZARD	SAFETY DISTANCE
		BLAST FRAGMENTATION HIGH TEMP and TOXIC (Li-Ion/Li-Pol baterry pack)	Minimal: 50 m Recommended: **100 m**
		BLAST FRAGMENTATION INCENDIARY (Fuel)	Minimal: **100 m** Recommended: 200 m

WORLD LIKELY / HIGHLY LIKELY

MALI POSSIBLY

3) C-IED 5Cs´ FIRST RESPONDER and **EOD** as RESPONDER = **INCREASED TIME**

CONCLUSION: If TREATED as EH(IED) = **ENHANCED FORCE PROTECTION** but depends on GROUND INHIBITION ASSETS availability and technical parameters.

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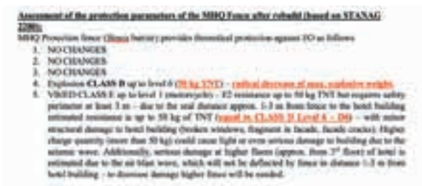
EOD EXPERTISE

HESCO BARRIER REMOVAL



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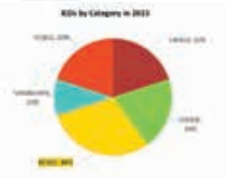
EOD EXPERTISE
IED/COMPLEX ATTACK RISK



- Small towns are forced crossing points-probability of suffering a reduction in speed is higher and increases the risk of suffering a complex attack.
- It is assessed as POSSIBLE that a complex attack would be carried out by VBIED activated by radio control system at the entrances and exits of the localities, adding SAF.
- The placing of (RC)IEDs in wrecked cars to initiate a Cx ATK is habitual TTP of KM. Recommended not to pass a wrecked car without a proper VP check
- The placing of RCIEDs in paved roads is POSSIBLE because the use of this TTP against IF in FEB23.
- The VOIED remains the most used IED type in MALI as these are the cheapest to produce and the easiest to emplace.
  However, VOIEDs do not discriminate between security forces and LP. Because of that it is UNLIKELY the use of this type against EUTM going out from the city.

EOD EXPERTISE
EOD RECOMMENDATIONS

SUMMARY from 01MAR16 to 10APR23:

- approx. 2088 EO incidents in MALI with confirmed RCIED incidents rate 4,4% (overall in country).
- 52 EO incidents in KOULIKORO (incl. BAMAKO) – 2 confirmed incidents with RCIED (approx. + 6 extra from category OTHER/UNKNOWN) – 7 years probability of RCIED = 15% (KKO).
- NO know neither confirmed EO incidents on MSR DOLPHIN & MSR ELEPHANT between BKO and KTC (Koulikoro city).

CONCLUSIONS:

- It is unlikely that the EO threat will be located directly on the MSR ELPHANT and/or MSR DOLPHIN, but their use is possible on the side roads - minimizing the use of side roads, or search for IED indicators or suspicious LP behaviors.
- The typical weight of main charge is approximately 10-30 kg (HME) - for mitigation MRAP vehicles are recommended to be used on side roads.
- Overally, The most used type of IEDs in MALI is the VOIED (Victim-Operated Improvised Explosive Device), followed by the COIED incl. RCIED – ECM/CREW systems (jammers) are to be used on side roads.
- If ECM/CREW systems are not available - Use DOMINANCE TEAM to seize the trigger point if RCIED indicators are detected.

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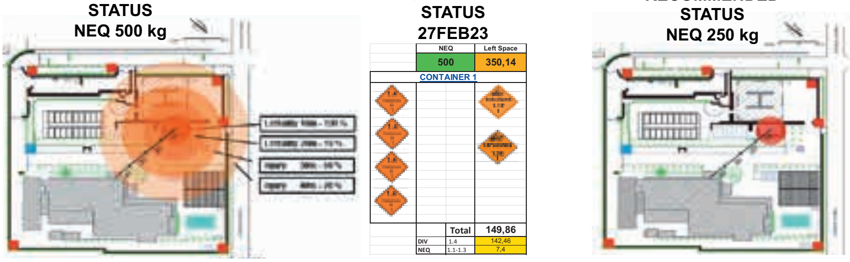
EOD EXPERTISE
MFHQ AMMO DEPOT NEQ Reduction

RECENT STATUS NEQ 500 kg

NEQ OCCUPANCY STATUS 27FEB23

RECOMMENDED STATUS NEQ 250 kg



1. RECOMMENDED **NEQ 250 kg**
2. 10 m separation recommended for constructions
3. SOP 03-600 MFHQ AMMO DEPOT UPDATED (Active 01MAR23) – NEQ REDUCED TO 250 kg

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Thank you for your attention.

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Experience EOD technician/team leader MINUSMA/ Experience of staff officer MINUSMA

2Lt Ian Dhooghe

MINUSMA Threat Mitigation Cell
MINUSMA U2/production/CIED

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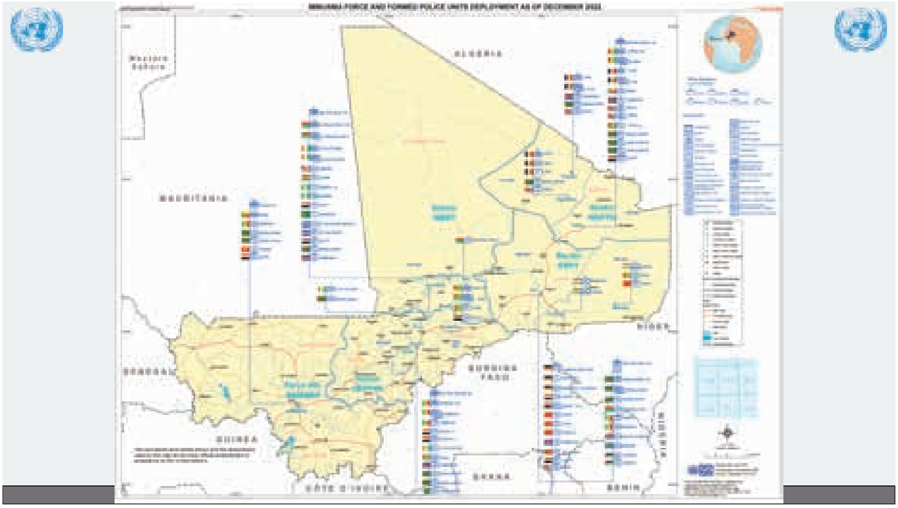
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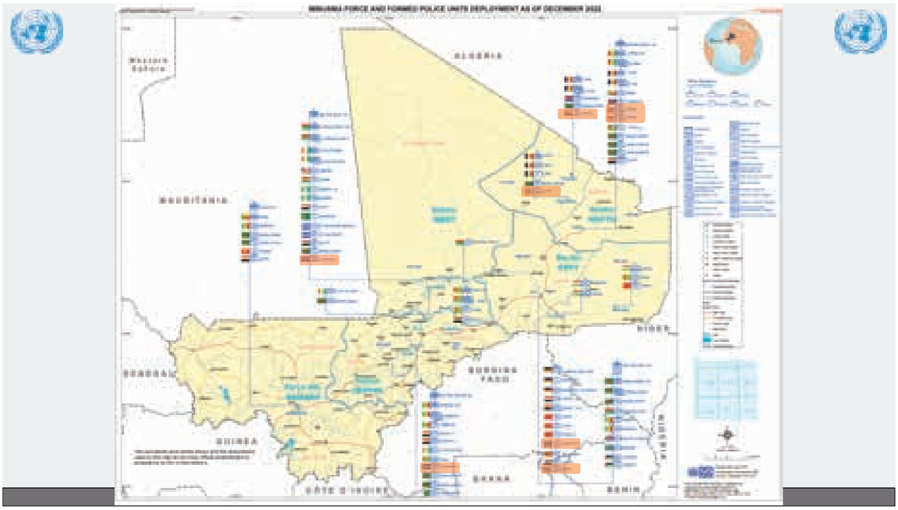
SENEGAL
GUINEA
BURKINA FASO
NIGER
GHANA
BENIN
CÔTE D'IVOIRE


ALGERIA
MAURITANIA
SENEGAL
GUINEA
BURKINA FASO
NIGER
GHANA
BENIN
CÔTE D'IVOIRE

U2 CIED Cell

CIED Analyst

- Weekly/monthly/yearly threat assessment of MSRs
- Monthly CIED threat assessment
- Roadbook for combat convoys
- SME for BOI (bureau of investigations)
- MSR threat analysis

IED Tech Analyst

- Collection of all IED events
- Analysis of trends in IED build ups
- Analysis of geolocation of IED
- Tactical analysis of IED emplacements
- Update SAGE database

MINUSMA Threat Mitigation Cell MSR Threat Assessment

June 2023

This monthly assessment provides the MSR multilayered threat overview based on IED 18-month historical overview baseline and a comprehensive analytical approach of the current TAG, CAG, IED and Political trends and dynamics. It is essential that all Sectors and operational forces pay strict adherence to the recommendations made in this document and apply the protective measures according the MSR threat level to protect lives and ensure successful operations.

Experience EOD technician/team leader MINUSMA/ Experience of staff officer MINUSMA

2Lt Ian Dhooghe

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EXECUTIVE SUMMARY

EXECUTIVE SUMMARY	INTRODUCTION	MODIF. MSRs	ROUTES OVERVIEW	PROT. MES / RECOMM.	THREAT LEVEL	UNCERTAINTY YARDSTICK	POC	ANNEXES

Executive Summary:

- Compared to April 23, there was a **21% decrease on IED incidents in May 23**. A total of **19 IED incidents** were reported to TMC Counter Improvised Explosive Device (CIED) Team, compared to 24 in April 23[1]. These 19 IED incidents are divided into the following types:
  - **11 Explosions / 6 Finds / 1 Complex ATK / 1 IDF**
- Sector Center (SC) remains the most targeted sector with 12 incidents. Jama'at Nasr al-Islam wal Muslimin (JNIM) maintains the use of IED as a common tool to target Military Defense and Security Forces (MDSF) and MINUSMA.
- Sector South of Mali (SoM) had 2 incidents.
- Sector North (SN) was involved in 4 incidents, three in one day on the GA-TE convoy.
- Sector West (SW) had 1 incidents.
- The moderate IED activity in South of Mali (SoM) remains present in the east side of the sector and will LIKELY be repeated in the coming months.

[1] *The number of incidents will always be adjusted when new reports are received (because of delayed reporting), reports until 03 Jun 23 are included*

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INTRODUCTION

EXECUTIVE SUMMARY	INTRODUCTION	MODIFICATIONS ON MSRs	ROUTES OVERVIEW	PROT. MES / RECOMM.	THREAT LEVEL	UNCERTAINTY YARDSTICK	POC	ANNEXES

Introduction:

This Threat Assessment for the Main Supply Routes (MSR) in Mali is to facilitate the planning and preparation process for logistics movements of MINUSMA elements, contractors, and partners, as well as to provide input for the emplacement of appropriate security measures for movements through different areas in Mali.

This assessment considers both the number of IED, DF and SAF related incidents that occurred in the last 18 months, and the qualitative security assessments created by U2 CIED cell in FHQ and is based on multiple comprehensive layers.

This Threat Assessment is not intended to specify the number or types of vehicles included in a framework operation. Furthermore, please note the recommendations are only recommendations and should be taken as such.

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MODIFICATIONS ON MSR

EXECUTIVE SUMMARY	INTRODUCTION	MODIFICATIONS ON MSRs	ROUTES OVERVIEW	PROT. MES / RECOMM.	THREAT LEVEL	UNCERTAINTY YARDSTICK	POC	ANNEXES

Last MSR Threat Level Changes

MSR Changes – **Increased**:

- HIGH to CRITICAL
  CAT-C, ELEPHANT-C, CROCODILE-B, GECKO, LION-A
- **MODERATE to HIGH**
  OCTOPUS-A, ELEPHANT-A, ELEPHANT-B, ELEPHANT-E, HIPPO
- **LOW to MODERATE**
  EAGLE
- **NEGLIGABLE to LOW**
  GORILLA

MSR Changes – **Decreased**:

- **CRITICAL to HIGH**
  RACOON-A
- **MODERATE to LOW**
  BUFFEL, JELLYFISH
- **LOW to NEGLIGABLE**
  ELEPHANT

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ROUTES OVERVIEW & THREAT LEVELS

EXECUTIVE SUMMARY	INTRODUCTION	MODIF. MSRs	OVERVIEW ROUTES	PROT. MES / RECOMM.	THREAT LEVEL	UNCERTAINTY YARDSTICK	POC	ANNEXES

Overview:

This table presents an overview of all the Threat Levels and the main threat type[1] for the MSRs assessed with a Threat Level equal or higher than LOW. The MSRs not contained in these tables are assessed with a negligible IED threat level (See Annex A).

[1]The Cx ATK threat refers also to the threat of SAF

MSR	Activity	Threat level	Sector	Route	Cercle	Main Threat – Possible
ELEPHANT C	↑↑	CRITICAL	Center	MOPTI	DOUENTZA	VOIED/RCIED – Cx ATK
LION A	↑↑	CRITICAL	Center	SEGOU	NIONO	VOIED/RCIED/CWIED – Cx ATK
MOOSE	=	CRITICAL	Center	BANKASS	MOPTI	VOIED/CWIED
SHARK	=	CRITICAL	Center	BANDIAGARA	OUO	VOIED/RCIED/Cx ATK
ELEPHANT B	↑↑	HIGH	Center	MOPTI	SEGOU	VOIED/RCIED - Cx ATK
ELEPHANT D	=	HIGH	Center	DOUENTZA	GOSSI	RCIED/VOIED/Cx ATK
LYNX	=	HIGH	Center	TENENKOU	MARKALA	VOIED/mine – RCIED
MOLE	=	HIGH	Center	MOPTI	KORO	VOIED/CWIED
KANGURU	=	MODERATE	Center	KOUTIALA	SIKASSO	VOIED/RCIED
LEMUR	=	MODERATE	Center	KOULA	TOROSO	VOIED/RCIED
OCTOPUS B	=	MODERATE	Center	DOUENTZA	DIONOUGA	VOIED/Cx ATK – (S)VBIED
PANTHER	=	MODERATE	Center	TIMBUCTU	TAOUDENI	VOIED/RCIED
BUFFEL	↓↓	LOW	Center	FANGASSO	BENENA	RCIED/VOIED
JELLYFISH	↓↓	LOW	Center	BANAMBA	SEGOU	VOIED

GECKO	↑↑	CRITICAL	SoM	NARA	DIDIENI	RCIED - VOIED
ELEPHANT A	↑↑	HIGH	SoM	BAMAO	SEGOU	VOIED/ RCIED
HIPPO	↑↑	HIGH	SoM	BAFOULABE	KITA	VOIED/ RCIED
COBRA	=	MODERATE	SoM	BAFOULABE	KENIEBA	VOIED – RCIED/(S)VBIED
EAGLE	↑↑	MODERATE	SoM	NIORO	KITA	RCIED - VOIED
FOX	=	MODERATE	SoM	TORODO	KIMBILA	RCIED - VOIED
IGUANA	=	MODERATE	SoM	KOULIKORO	BANAMBA	VOIED - RCIED
KOALA	=	MODERATE	SoM	BLA	KOURY	RCIED – VOIED
BABOON	=	LOW	SoM	NIORO	SANDARE	VOIED/mine – (S)VBIED
GORILLA	↑↑	LOW	SoM	BANAMBA	GOUMBOU	VOIED/mine – RCIED
IMPALA	=	LOW	SoM	SIKASSO	BOUGOUNI	VOIED/RCIED – (S)VBIED
LIZARD	=	LOW	SoM	DIEMA	NIORO	VOIED/ RCIED

CAT B	=	CRITICAL	East	GAO	ANSONGO	RCIED/VOIED – (S)VBIED
CAT C	↑↑	CRITICAL	East	ANSONGO	LABBEZANGA	VOIED/RCIED/Cx ATK
CROCODILE B	↑↑	CRITICAL	East	MENAKA	ANDERAMBOUKANE	VOIED/mine – RCIED
CROCODILE A	=	HIGH	East	ANSONGO	MENAKA	VOIED/RCIED – Cx ATK/(S)VBIED
ELEPHANT E	↑↑	HIGH	East	GOSSI	GAO	VOIED/RCIED/Cx ATK
CAT A	=	MODERATE	East	GAO	BOUREM	VOIED/RCIED – (S)VBIED
SCORPION	=	MODERATE	East	ANSONGO	TESSIT	VOIED/mine – RCIED
SQUIRREL	=	MODERATE	East	MENAKA	KIDAL	VOIED/mine – RCIED
ZEBRA A	=	MODERATE	East	GAO	ANEFIS	VOIED/mine/IDF - RCIED/Cx ATK/(S)VBIED
RHINO	=	LOW	East	BOUREM	TABANKORT	VOIED/mine – RCIED
URANUS	=	LOW	East	GAO	TALATAYE	VOIED/Cx ATK - RCIED

LION B	=	CRITICAL	West	SEGOU	NIAFUNKE	VOIED/RCIED/CWIED – Cx ATK
LION C	=	HIGH	West	NIAFUNKE	GOUNDAM	VOIED/RCIED – Cx ATK
LION C1	=	HIGH	West	GOUNDAM	TIMBUKTU	VOIED/mine – Cx ATK, RCIED
OCTOPUS A	↑↑	HIGH	West	DOUENTZA	TIMBUKTU	VOIED/Cx ATK – RCIED
RACOON A	↓↓	HIGH	West	TIMBUKTU	BAMBA	VOIED/mine/(S)VBIED – Cx ATK
RACOON B	=	LOW	West	BAMBA	BOUREM	VOIED/mine – Cx ATK/(S)VBIED

TIGER A	=	MODERATE	North	ANEFIS	KIDAL	VOIED/mines/RCIED – Cx ATK/(S)VBIED
TOPI	=	MODERATE	North	ANEFIS	KATAWATENE	VOIED/mines – Cx ATKs/SVBIED/IDF
ZEBRA C	=	MODERATE	North	AGUELHOK	TESSALIT	VOIED/mines – Cx ATK/SVBIED/IDF
ZEBRA B	=	LOW	North	KIDAL	AGUELHOK	(RA)VOIED/mines – IDF

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ROUTES OVERVIEW & THREAT LEVELS

EXECUTIVE SUMMARY	INTRODUCTION	MODIF. MSRs	ROUTES OVERVIEW	PROT. MES / RECOMM.	THREAT LEVEL	UNCERTAINTY YARDSTICK	POC	ANNEXES

Related Incidents:

This table details the number of IED/SAF related incidents over the last 18 months for each of the MSRs described above.

MSR	Threat level		2022												2023				
		Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May
CAT B	CRITICAL					1		1						1	3	2	3	4	2
CAT C	CRITICAL	1														3	2	2	3
CROCODILE B	CRITICAL													1		1		1	4
ELEPHANT C	CRITICAL	2	1	2	3		3		1		2	1	5					4	
GECKO	CRITICAL										2	1			1	1	3	3	1
LION A	CRITICAL						4		1		1				2	1	3	2	3
LION B	CRITICAL		1	1		2	2	1			3	2	2		3	6	2	3	
MOOSE	CRITICAL			1		1	1					1		1	2	7	1		2
SHARK	CRITICAL		1	1	3	1	1		1		2	1	1		2	3			
CROCODILE A	HIGH	2	1			1	2		1	1			1	1			3	2	
ELEPHANT A	HIGH														2		1		1
ELEPHANT B	HIGH									2	1				1			1	2
ELEPHANT D	HIGH	1			1	1	2	2	3	2	1		1					1	
ELEPHANT E	HIGH							1					1		2			3	
HIPPO	HIGH														1		1		2
LION C	HIGH	3	2		2		3										1	1	1
LION C1	HIGH		1		2	1							2		2		1	1	1
LYNX	HIGH														3	3			1
MOLE	HIGH	1		1	3				1						1			1	1
OCTOPUS A	HIGH	1	1		1	1		3		1	1		1				1		
RACOON A	HIGH	1		1				2			1			4	1	1			
CAT A	MODERATE	1																2	
COBRA	MODERATE															1	1		
EAGLE	MODERATE										1								1
FOX	MODERATE											1						1	1
IGUANA	MODERATE															1		2	
KANGURU	MODERATE														1	2			
KOALA	MODERATE									1	1	1							
LEMUR	MODERATE														1				
OCTOPUS B	MODERATE				1						1								1
PANTHER	MODERATE													1	1				
SCORPION	MODERATE														2				
SQUIRREL	MODERATE						2				1							1	1
TIGER A	MODERATE	3					1	1											
TOPI	MODERATE					1	1			1			1						
ZEBRA A	MODERATE	1	1	6		3			2	1	1								
ZEBRA C	MODERATE	1	1		1		1			1	1								

Table 1 – Number of Incidents – last 18 months

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PROTECTIVE MEASURES – RECOMMENDATIONS

EXECUTIVE SUMMARY | INTRODUCTION | MODIF. MSRs | ROUTES OVERVIEW | PROT. MES / RECOMM. | THREAT LEVEL | UNCERTAINTY YARDSTICK | POC | ANNEXES

The proposed protective measures, listed below in table 2, are a minimum standard but can always be more comprehensive.

Threat Level	Protective measures
CRITICAL	Escort is **recommended** to include an appropriate number of armored vehicles with heavy weapon systems, as well as an EOD team
HIGH	Escort is **recommended** to include at least 2 armored vehicles with heavy weapon systems, as well as an EOD team
MODERATE	Escort is **recommended** with small arm weapons and EOD QRF in stand-by
LOW	No escort **recommended** but convoys should consist of a minimum of three vehicles
NEGLIGIBLE	No escort **recommended**

Consideration should also be given to road conditions, considering seasonal and regional weather effects. The movement of vehicles is heavily affected during the different seasons in various parts of MALI. SLOW-GO areas and canalizing terrain make vehicles more vulnerable to attacks. In addition, the basic CIED awareness and principles must be trained and applied by all personnel:

- VP, including SLOW-GO areas (crossroads, sharp turns, chokepoints, steep slopes, loose soil, etc.) should be identified during the planning process and execution, and maneuver schemes prepared on the MSRs which are part of the itinerary.
- Drive off-road when possible and VP should be avoided or if not possible, VP checks should be done on each identified hotspot and in case of a suspicious point/location or noticed ground signs or suspicious activity.
- 5/25 m procedure needs to be executed for every stop.
- All equipment and personnel in vehicles should be strapped and secured.
- Personal Protective Equipment (PPE) needs to be worn (helmet, protective glasses, body armor).
- Patterns (time and space) should be avoided as much as possible: avoid starting convoys on the same time or day of the week, use different assembling areas and stop locations, as well as durations.
- Have a 360° situational awareness. Pay attention to the road but also the surroundings, nearby covers or observation points IOT detect anything suspicious (spotter, triggerman, markers, ground signs, etc.).
- Stay in the track of the vehicle in front. Minimizing the *footprint* of the convoy means less risk to strike a VOIED.
- It is recommended not to pass a wrecked car along the MSR without a proper VP check.
- Strapping in personnel and equipment correctly in the APC remains extremely important as larger main charges have been reported and suspected. Personnel being tossed around inside vehicles due to blasts leads to increased injuries. Also, loose equipment will become deadly projectiles inside vehicles when not secured properly.

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THREAT LEVEL – BACKGROUND

EXECUTIVE SUMMARY | INTRODUCTION | MODIF. MSRs | ROUTES OVERVIEW | PROT. MES / RECOMM | THREAT LEVEL | UNCERTAINTY YARDSTICK | POC | ANNEXES

Background information on the local assessment of the IED threat on MSR can be found in:

- **Monthly CIED Threat Assessment**
- **IED Warning Points**
- **MSR Threat Profiles**

Incidents that occurred IVO a major town, situated at the start or the end of an MSR will not automatically influence the threat assessment of that MSR. All depends on the assessment of the incident (target, operation conducted, relation to MSR).

To consider different threat levels along the MSR, some routes are subdivided into sections (from A to E).
This document links the threat levels to recommendations for protective measures (see table 5).
For unassessed routes, the sectors are advised to conduct reconnaissance patrols to determine the usability of these routes to increase flexibility.
Even on routes with a LOW threat level, single-vehicle movements are not recommended.
On following itineraries, MINUSMA troops should be prepared to provide additional security for the passing of the convoys: *MOPTI-GAO-KIDAL / DOUENTZA-TIMBUKTU / GAO-ANSONGO-MENAKA.*

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THREAT LEVEL - CALCULATION

EXECUTIVE SUMMARY	INTRODUCTION	MODIF. MSRs	ROUTES OVERVIEW	PROT. MES / RECOMM	THREAT LEVEL	UNCERTAINTY YARDSTICK	POC	ANNEXES

To determine the MSR threat level, U2 uses a multi-layered approach:

- IED/SAF 18 months historical overview/calculation* (see formula below)
- Comprehensive layers of IED, TAG, CAG and political monthly assessment

*Over a period of 18 months, the threat level assessment on the MSRs is based on a formula considering the place or the timeline when the events took place (and additionally checked with the most recent tactical layers).

The coefficients applied to the events are:

TIMING	COEFFICIENT	EVENTS RATIO
Last month	0.5	A
2-3 months	0.25	B
4-6 months	0.15	C
7-12 months	0.075	D
13-18 months	0.025	E

By applying the formula: **A*0,5 + B*0,25 + C*0,15 + D*0,075 + E*0,025** a factor X is obtained. This factor determines the threat level on the MSR as follows:

Threat Level	OUTCOME
CRITICAL	X ≥ 2.5
HIGH	1 ≤ X ≤ 2.5
MODERATE	0.25 ≤ X ≤ 1
LOW	0.01 ≤ X ≤ 0.25
NEGLIGIBLE	No registered IED-incidents on the MSR over the last 18 months

Note: Comprehensive Intelligence will always prevail on statistics

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UNCERTAIN YARDSTICK

EXECUTIVE SUMMARY	INTRODUCTION	MODIF. MSRs	ROUTES OVERVIEW	PROT. MES / RECOMM	THREAT LEVEL	UNCERTAINTY YARDSTICK	POC	ANNEXES

Probability	Description	Percentage
ALMOST CERTAIN	Almost guaranteed, the highest confidence possible, overwhelming evidence, beyond any reasonable doubt	> 90 %
HIGHLY PROBABLE, HIGHLY LIKELY	Highly probable, we are convinced, virtually certain, almost certain, high confidence, high likelihood	75 – 85 %
PROBABLE, LIKELY	Probable, we estimate, chances are good, high moderate confidence	55 – 70 %
REALISTIC POSSIBILITY	Even chance, moderate confidence, It is possible	25 – 50 %
IMPROBABLE, UNLIKELY	Probably not, not likely, improbable, we believe not, low confidence, possible but not likely	15– 25 %
REMOTE, HIGHLY UNLIKELY	Very low confidence, very low risk of occurrence, little chance of occurrence	< 10 %

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POINT OF CONTACT

EXECUTIVE SUMMARY	INTRODUCTION	MODIF. MSRs	ROUTES OVERVIEW	PROT. MES / RECOMM	THREAT LEVEL	UNCERTAINTY YARDSTICK	POC	ANNEXES

This MSR threat assessment is written by MINUSMA FHQ U2 Production CIED Analyst. The latest version can always be found on the U2 SharePoint:

Monthly MSR Threat Assessments

Questions or Remarks:

minusma-fhq-u2-prod-ciedanalyst@un.org or minusma-fhq-u3-Dchief@un.org

Content approved and released by:

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Annexes

EXECUTIVE SUMMARY	INTRODUCTION	MODIF. MSRs	ROUTES OVERVIEW	PROT. MES / RECOMM	THREAT LEVEL	UNCERTAINTY YARDSTICK	POC	ANNEXES

Annex A - MSR assessed as NEGLIGIBLE

ALIGATOR	=	NEGLIGABLE	SoM	KAYES	SAHEL	VOIED/mine – RCIED
ARMADILLO	=	NEGLIGABLE	SoM	YELIMANE	NIORO	VOIED/mine – RCIED
BAT	=	NEGLIGABLE	SoM	BAMAKO	NOUGA	VOIED/mine – RCIED
BEAR	=	NEGLIGABLE	SoM	KONIAKARY	YELIMANE	VOIED/mine – RCIED
BOA	=	NEGLIGABLE	SoM	DIAMOU	SIDIBELA	VOIED/mine – RCIED
CHEETAH	=	NEGLIGABLE	SoM	KENIEBA	KITA	VOIED/mine – RCIED
DONKEY	=	NEGLIGABLE	SoM	SANDARE	DIANCOUNTE	VOIED/mine – RCIED
DOVE	=	NEGLIGABLE	SoM	SIDIBELA	SANDARE	VOIED/mine – RCIED
ELEPHANT	↓↓	NEGLIGABLE	SoM	BAMAKO	GUINEA	VOIED – RCIED
FALCON	=	NEGLIGABLE	SoM	NIORO	GOUMBOU	VOIED/mine – RCIED
FROG	=	NEGLIGABLE	Center	DOUENTZA	MADOUGOU-DOGON	VOIED/mine – RCIED
GAIA	=	NEGLIGABLE	East	GAO	N'TILLIT	VOIED – RCIED/(S)VBIED
GIRAFFE	=	NEGLIGABLE	West	KEL MAHLA	DOUEKIRE	VOIED/mine – RCIED
GOOSE	=	NEGLIGABLE	SoM	KOLOKANI	BANAMBA	VOIED/mine – RCIED
HYENA	=	NEGLIGABLE	SoM	KOULIKORO	NYAMINA	VOIED/mine – RCIED
JAGUAR	=	NEGLIGABLE	SoM	FANA	DIOILA	VOIED/mine – RCIED
LEOPARD	=	NEGLIGABLE	SoM	SIKASSO	KADIOLO	VOIED/mine – RCIED
MONKEY	=	NEGLIGABLE	SoM	MANANKORO	BOUGOUNI	VOIED/mine – RCIED
NUMBAT	=	NEGLIGABLE	West	NIAFUNKE	KONNA	VOIED/mine – RCIED
OSTRICH	=	NEGLIGABLE	East	GOSSI	RHAROUS	VOIED/mine – (S)VBIED
PELICAN	=	NEGLIGABLE	North	TESSALIT	TINZAOUATINE	VOIED/mine – RCIED
PINGUIN	=	NEGLIGABLE	West	TAOUDENNI	AGAGAKTEM	VOIED/mine – RCIED
PYTHON	=	NEGLIGABLE	West	TAOUDENNI	ZEBRA D	VOIED/mine – RCIED
STORK	=	NEGLIGABLE	North	BOUGHESSA	ABEIBARA	VOIED/mine – RCIED
TIGER B	=	NEGLIGABLE	North	AGUELHOK	KIDAL	VOIED/mine – RCIED
TURTLE	=	NEGLIGABLE	North	TI-N-ESSAKO	ABEIBARA	VOIED/mine – RCIED
WOLVERINE	=	NEGLIGABLE	North	KIDAL	TINZAOUATINE	VOIED/mine – RCIED
ZEBRA D	=	NEGLIGABLE	North	INHALID	KATAWATENE	VOIED/mine – RCIED

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Annexes

EXECUTIVE SUMMARY	INTRODUCTION	MODIF. MSRs	ROUTES OVERVIEW	PROT. MES / RECOMM	THREAT LEVEL	UNCERTAINTY YARDSTICK	POC	ANNEXES

Annex B – List of Abbreviations

AOO	Area of Operation	LP	Local Population
APC	Armored Personnel Carrier	MDSF	Malian Defense and Security Forces
ATK	Attack	MINUSMA	Multidimensional Integrated Stabilization Mission in Mali
BANBAT	Bangladesh Battalion	MPV	Mine protected Vehicle
BENFPU	Beninese Force Protection Unit	MSR	Main Supply Route
BFABAT	Burkina Faso Battalion	MTF	Mobile Task force
BKN	Barkhane	NERBAT	Nigerian Battalion
CEXC	Combined Explosive Exploitation Cell	OP	Operation
CIED	Counter Improvised Explosive Device	PBIED	Person Borne Improvised Explosive Device
CIVBAT	Cote d'Ivorian Battalion	PPE	Personal Protective Equipment
CMA	Coordination des Mouvements de l'Azawad	PRAE	Presumed Radical Armed Elements
CWIED	Command Wire Improvised Explosive Device	PUT	Pickup Truck
Cx ATK	Complex Attack	RCIED	Radio Controlled Improvised Explosive Device
DF	Direct Fire	S&D	Search & Detect
ECM	Electronic Counter Measures	SAF	Small Arms Fire
EGY CCC	Egyptian	SC	Sector Center
FAMa	Forces Armées Maliennes (Malian Armed Forces)	SE	Sector East
FOA	Freedom of Action	SENBAT	Senegalese Battalion
FOM	Freedom of Movement	SN	Sector North
IAW	In Accordance With	SoM	South of Mali
ICVO	In Close Vicinity Of	SVBIED	Suicide Vehicle Borne Improvised Explosive Device
IDF	Indirect Fire	SW	Sector West
IED	Improvised Explosive Device	TAG	Terrorist Armed Group
IF	International Forces	TCHSOF CON	Chadian Special Operations Forces Convoy
IOT	In Order To	TOB	Temporary Operating Base
ISC	International Super Camp	TOGOBAT	Togolese Battalion
ISGS	Islamic State in the Greater Sahara	TTP	Tactics, Techniques and Procedures
ISSP	Islamic State in the Sahel Province	UAS	Unmanned Aircraft System
IVO	In Vicinity Of	VA	Vulnerable Area
JIT	Just In Time	VOIED	Victim Operated Improvised Explosive Device
JNIM	Jama'at Nusrat Al-Islam Wa Al-Muslimeen	VP	Vulnerable Point
KIA	Killed In Action	WIA	Wounded In Action
LKA CCC	Sri Lanka CCC		
LOC	Line of Communication		

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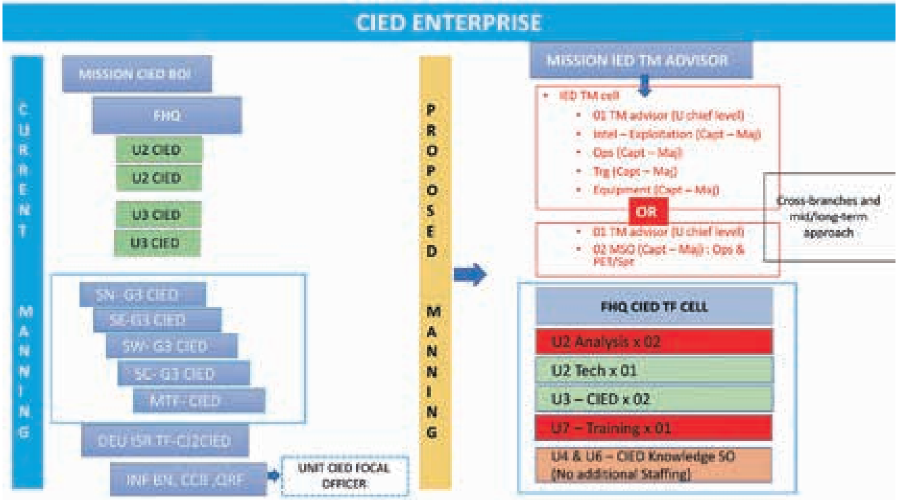
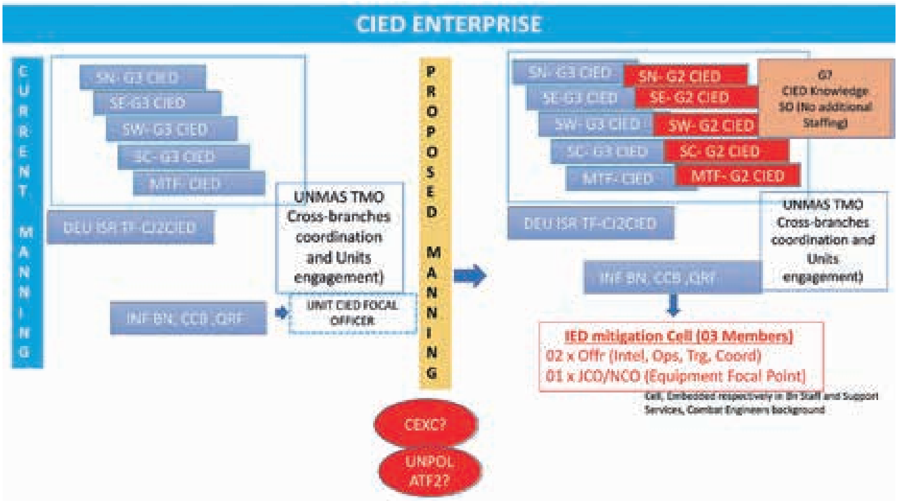
CIED ARCHITECTURE


CIED ENTERPRISE
CURRENT MANNING
MISSION CIED BOI
FHQ
U2 CIED
U2 CIED
U3 CIED
U3 CIED
SN- G3 CIED
SE-G3 CIED
SW- G3 CIED
SC- G3 CIED
MTF- CIED
DEU ISR TF-C|2CIED
INF BN, CCB ,QRF
UNIT CIED FOCAL OFFICER
PROPOSED MANNING
MISSION IED TM ADVISOR
IED TM cell
01 TM advisor (U chief level)
Intel – Exploitation (Capt – Maj)
Ops (Capt – Maj)
Trg (Capt – Maj)
Equipment (Capt – Maj)
OR
01 TM advisor (U chief level)
02 MSO (Capt – Maj) : Ops & PET/Spt
Cross-branches and mid/long-term approach
FHQ CIED TF CELL
U2 Analysis x 02
U2 Tech x 01
U3 – CIED x 02
U7 – Training x 01
U4 & U6 – CIED Knowledge SO (No additional Staffing)


CIED ENTERPRISE
CURRENT MANNING
SN- G3 CIED
SE-G3 CIED
SW- G3 CIED
SC- G3 CIED
MTF- CIED
DEU ISR TF-C|2CIED
UNMAS TMO Cross-branches coordination and Units engagement)
INF BN, CCB ,QRF
UNIT CIED FOCAL OFFICER
PROPOSED MANNING
SN- G3 CIED
SE-G3 CIED
SW- G3 CIED
SC- G3 CIED
MTF- CIED
SN- G2 CIED
SE- G2 CIED
SW- G2 CIED
SC- G2 CIED
MTF- G2 CIED
G7 CIED Knowledge SO (No additional Staffing)
DEU ISR TF-C|2CIED
UNMAS TMO Cross-branches coordination and Units engagement)
INF BN, CCB ,QRF
IED mitigation Cell (03 Members)
02 x Offr (Intel, Ops, Trg, Coord)
01 x JCO/NCO (Equipment Focal Point)
Cell, Embedded respectively in Bn Staff and Support Services, Combat Engineers background
CEXC?
UNPOL ATF2?

Annex 9

Experience EOD technician/team leader MINUSMA/ Experience of staff officer MINUSMA

2Lt Ian Dhooghe

IED Build-up in Mali

MINUSMA Force

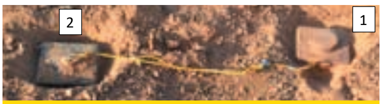
2. IED and TTP study IED Mines


Anti Tank Mine PRBM3

Single use

Anti vehicle Mine PT-Mi-Ba III

Double stacked Mine



The first (1) mine is placed on the tracks and a second (2) mine connected by detonating cord. Distance between the mines is approx 80 cm. Both mines will detonate at the same time.

Double use

TTP Mines:

- Spotter on look out for a target.
  - Mines are placed just before arrival of the target.
  - Main charge placed in advanced and initiating device placed just before arrival of the target.
- Location of mines on tracks.

Observations:

- TAG are using multiple mines to cause more damage to armored vehicles.

2. IED and TTP study IED Mines

The first (1) mine is placed on the tracks and two HME charges in a plastic canister (2 and 4) are connected by detonating cord (3). All charges will detonate at the same time. There is no electrical content.

Two plastic canisters with HME buried without an initiating device.
The initiating device can be a mine, pressure plate or an RC device.

Non metal content components are harder to detect.

TTP Multiple charges:

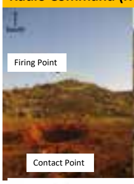
- Spotter on look out for a target.
  - Main charges are placed just before arrival of the target.
  - Main charge placed long in advanced and initiating device placed just before arrival of the target.
- Location VO initiating device on tracks.

Observations:

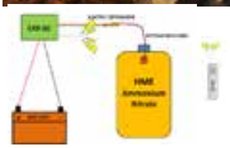
- TAG are using multiple mines to cause more damage to armored vehicles.
- The quantity of the main charge has become more important as protection measures from security forces raises.

2. IED and TTP study RC DEVICES

Radio Command (RC) IED 28FEB2018 DALLAH



RC transmitter and Mobile phone seized from trigger man



Highly Likely 2 channeled CX9-series transmitter.

Comment:
TAGs had prepared the area for the attack by identifying the damaged road surface and **pot holes** which can channel traffic and provide concealment for a device. The use of pot holes not only narrowed the route at the CP but also provided an **aiming marker** for the TAG trigger man. Effectively creating a VP on a straight section of road.

RCIED 4th veh

Build up:

- Firing Point on <u>Higher Ground</u>
- Escape Route
- Contact Point:
  Damaged Surface and Pot hole to burry IED
  Aiming Marker

TTP RCIED:

- RCIED placed on road, choke points.
- Spotter on the look out of for a target. Trigger man stands in line of sight:
  - Trigger position – IED – marker
- Placement IED probably by night

SIMULAR EVENT 09JUN18 DALLAH – RCIED- FAMa

Annex 9

Experience EOD technician/team leader MINUSMA/ Experience of staff officer MINUSMA

2Lt Ian Dhooghe

2. IED and TTP study RC DEVICES

Radio Command (RC) IED and Radio Activated (RA) VOIED

Improvised pressure plate

RC device CX9-2C

RCIED – car door opener Mor 120 MM HE

Main charge HME in a plastic canister (1) with a booster and detonating cord with the electrical detonator attached to it. A 12V battery (2) provides current for the pressure plate (PP). The RC device allows to activate the IED before arrival of the target. IED will explode when the target drives over the PP.

TTP RA VOIED:

- Spotter on the look out of a target. Trigger man gives a radio signal to the IED just before arrival of the target. The IED will detonate when the target drives over the PP

.

2. IED and TTP study RA VOIED

CACHE – TAMKOUTAT 17FEB18 – RA VOIED

RC device KL5000
RC device KL-K120LA.
Freq: 434 MHz

Pressure Plate with a Tire
Pressure 26kg

These components make it possible to install a RA – VOIED
The placement of the main charge HME can be done longer time before the attack, the pressure plate is only functional when the trigger man activates the RC device.

Motorcycle PP IED (tire)
RC DEVICE
HME ammonium nitrate

TTP RA - VOIED:

- IED placed on roads, choke points.
- Spotter on the look out of for a target. Trigger man stands in line of sight:
  - Trigger position – IED – marker

.

2. IED and TTP study CWIED

Command Wire IED - 7MAR18 - DIOURA

Device Construction and Method of Operation:
The device is comprised of an electric detonator, detonation cord and a HME main charge. A command wire allows the assailant to initiate the device from a safe location by using a power source such as a 12V MC battery or a 9V battery. The HME main charge was comprised of Ammonium Nitrate and Sugar (ANS).
This HME mixture was a first time seen in sector W, before in sector N and W.

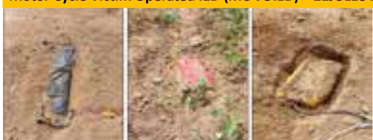
Similar case
18MAR18 TENENKOU
19MAR18 SIMBI FAMa
23MAR18 TENENKOU CIV
25AUG18 BOUNDJIGUIRE FAMa

Build up:
- Firing Point with view on road
  Escape Route
  Electrical cable hidden in ground
- Contact Point:
  Main charge buried on tracks, Aiming Marker

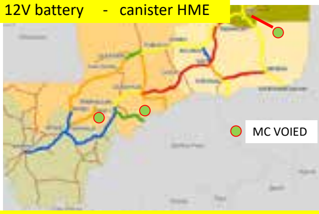
TTP CWIED:
- CWIED placed on roads, choke points,
- Spotter on the look out of for a target. Trigger man stands in line of sight:
  - Trigger position – IED – aiming marker
- Placement IED probably by night

2. IED and TTP study MC PPIED

Motor Cycle Victim Operated IED (MC VOIED) – 21JUL18 KORO



Tire PP - 12V battery - canister HME



Comments:
This type of IED was used in Sector N, KIDAL and appearing sporadically in sector W since 2017. Since April18 there are at least 5 incidents with MC VOIED.

IED Build up:
- Main charge buried in road
- Pressure plate (tire) on tracks
- Main charge HME
- Battery 12V in side of road

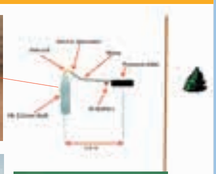
MCVOIED requires a specialized IED builder

22APR18 DIAFABRE - DJENNE
28APR18 NIONO
21JUL18 KORO
11AUG18 KORO
16AUG18 DJENNE

IED used as an asset in intercommunity conflicts

2. IED and TTP study PPIED

Pressure Plate IED (PPIED) – 24JUL18 TARNIKA ILOUK



PP High metal content

Comments:
Also on ZEBRA A VOIED appears again since 2017, when it was targeted with RCIED and VOIED. A high amount of same type 122 mm Shells were found in a cache KIDAL 28NOV2017. This PPIED was probably buried for a long time and did not function before it was discovered.

PPIED Build up:

- Main charge buried in road
- Pressure plate on tracks
- Main charge Artillery shell 122mm HE
- Battery 12V in side of road

TTP

IED placement at a channeling point

PP and main charge on tracks

PPIED requires a specialized IED builder

IED dysfunctional and left unattended since a longer time

Conventional munition found in caches

Likely target MINUSMA/BARKHANE

Incidents:

ZEBRA - A

24JUL18 TARNIKA ILOUK

08AUG18 TARNIKORE

2. IED and TTP study VOIED

Victim Operated IED (VOIED)

24APR2018 Pressure Plate BOOBY TRAP with a hand grenade (Source FAMa)

22APR2018 Pressure Plate with a Tire Connected to an arming wire (Source FAMa)

Comment:
22APR2018 Diafarabe IED found between DIAFARABE – FAMASSOULA.
The Main charge was buried in the road with a pressure plate. A long electrical cable leaves the option to choose the moment to arm the IED right before the target passes. When the target drives over the PP, it will detonate the main charge.

22APR18 DIAFARABE find

Motorcycle PPIED (MC PPIED)

Arming Wire

HME

TTP Command Wire - VOIED:

- IED placed on roads, choke points.
- Arming Device by command Wire, activation by PP
- Spotter on the look out of for a target. Trigger man stands in line of sight:
  - Trigger position – IED – marker

24APR18 KARA (DIAFARBE)

VOIED with hand grenade booby-trap

28APR18 DIABALY

VOIED with PP

3. CACHE 05APR2018 BAMAKO FIND/CACHE

HME

250 kg carrier explosives
AEL Company

Comments:

- Large quantity civilian explosives and HME at a civilian house
- No clear connection with TAG group
- Inventory:
  - 2300 electric detonator
  - 400 pyro detonator
  - 250 kg Carrier Explosives
  - 3 km detonating cord
  - 100 meters Safety Fuse-
  - 2 x 25 kg bags of ammonium nitrate;
  - 4000 kg of Urea (bag of 80kg).

On 05APR2018, a civilian was found seriously injured while handling explosive materials he was storing at his private home. Police found a large quantity of HME and civilian explosive materials. The suspect was likely linked to a civilian mine quarry, it remains uncertain about his terroristic intentions. There was enough explosives to execute a VBIED attack but no signs of other IED building material was found at the house.

Observations and assessment

Observations

- 648 IED related events were registered by U2 CIED in 2 years time
- 1268 casualties recorded, 413 Fatal
- An average of 3,2 casualties per event
- Significant shift towards SoM after the withdrawal of OP Barkhane.
- Encircling of the capital is ongoing and almost round
- IED concentrations in Segou, Mopti, Tessalit and TB2 region.
- MDSF have no capability to fulfill the full spectrum of the CIED process.

Assessment

- The availability of explosives in Mali, primarily AN and ATkM will highly likely maintain the trend in the use of IEDs and casualties. A shift to the SoM, combined with the significant flux of adversary forces from the neighboring countries is highly likely to be expected
- Probable likely is an evolution in the build of IEDs with more sensitive VO firing switches, such as motorcycle alarms.
- Improbable likely is an improvement on RCIED
- Highly likely will the use of armed UAVs be introduced shortly, due to a successful use within radical Islamic armed groups

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Current situation

- Withdrawal of all UN forces NLT 31 dec 2023
- The number of IEDs on MSRs has skyrocketed
- Withdrawal only possible by air

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Questions

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Table of Acronyms

AI . . . . Artificial Intelligence
ANN. . . . . Artificial Neural Network
ATP. . . . . Allied Technical Publication
AU. . . . . African Union
AUV . . . . Autonomous Underwater Vehicle
BASTA (project) . . . . Boost Applied munition detection through Smart data integration and AI workflows
CB. . . . . Chemical, Biological
CBRN. . . . . Chemical, Biological, Radiological and Nuclear
CBW. . . . . Chemical, Biological Weapon
C-IED. . . . . Countering the Improvised Explosive Ordnance
CISR . . . . Critical Infrastructure Security and Resilience
COE . . . . Centre of Excellence
COI. . . . . Community of Interest
CPAMs. . . . . Chemically Powered Artificial Muscles
CROMAC-CTDT . . . Croatian Mine Action Centre-Centre for Testing and Training
CT. . . . . Counter-Terrorism
D&T . . . . Demonstrations and Trials
DAT COE . . . . Defence Against Terrorism Centre of Excellence
DAT POW. . . . . Defence Against Terrorism Programme of Work
DEVCOM-ARL . . . . Developments Command - Army Research Laboratory
DL-GPR. . . . . Down-Looking GPR
DOTMLPFI. . . . . Doctrine, Organisation, Training, Materiel, Leadership, Personnel, Facility and Infrastructure
E&T . . . . Education and Training
EFE. . . . . Explosive Forced Entry

ENTEC. . . . . Euro-NATO Training Engineer Centre
EO. . . . . Explosive Ordnance
EOC . . . . Explosive Ordnance Clearance
EOD . . . . Explosive Ordnance Disposal
EOR . . . . Explosive Ordnance Reconnaissance
EP . . . . Environmental Protection
ERW . . . . Explosive Remnants of War
ESCD . . . . Emerging Security Challenges Division (NATO)
ETACS (project) . . . . EOD/IEDD VR Training and XR Combat Support Kit Project
EU TM MALI . . . . . . European Union Training Mission Mali
ETF. . . . . Education & Training Facility
FATAP . . . . Fight Against Terrorism Action Plan
FL-DL-GPR. . . . . Forward-Looking-Down-Looking GPR
FP . . . . Force Protection
FTF. . . . . Foreign Terrorist Fighters
GPR . . . . Ground Penetrating Radar
GPR-SAR. . . . . GPR-Synthetic Aperture Radar
HUD. . . . . Heads-Up Display
HVT . . . . High-Value Target
IED . . . . Improvised Explosive Device
IEDD . . . . Improvised Explosive Device Disposal
IR . . . . Infrared
IVAS . . . . Integrated Visual Augmentation System
ISAF . . . . International Security Assistance Force
JCBRN . . . . Joint Chemical, Biological, Radiological, Nuclear
LIDAR . . . . Light Detection and Ranging
LWIR . . . . Long Wave Infrared
MBES . . . . Multibeam Echosounder
MD . . . . Mediterranean Dialogue
MET . . . . Mobile Education and Training
MILENG WG . . . . . . NATO Military Engineering Working Group
MILMED COE . . . . . Military Medicine Centre of Excellence
MINUSMA . . . . United Nations Multidimensional Integrated Stabilization Mission in Mali
ML . . . . Machine Learning

MMR . . . . Minimum Military Requirements
MS. . . . . Military Search
NDPP . . . . NATO Defence Planning Process
NEQ . . . . Net Explosive Quantity
NGABS . . . . Next-Generation Advanced Bomb Suit
NRF . . . . NATO Response Force
NSJEC . . . . NATO Senior Joint Engineer Conference
PN. . . . . Partner Nation
POE . . . . Physical Operating Environment
POW. . . . . Programme of Work
PPE . . . . Personal Protective Equipment
RA. . . . . Requirements Authority
ROV . . . . Remotely Operated Vehicle
RSP . . . . Render Safe Procedure
RTK . . . . Real-Time Kinematics
SAF . . . . Small Arms Fire
SAR. . . . . Synthetic Aperture Radar
SBP . . . . Sub-Bottom Profiling
SME . . . . Subject Matter Expert
SMLB . . . . Senior Military Leaders Brief
SOPs . . . . Standard Operation Procedures
STANAG . . . . (NATO) Standardization Agreement
T.B.E. . . . . Tactical Body Extension
TNA . . . . Training Needs Analysis
TRLR . . . . Technology Readiness Level Report
TTP. . . . . Tactics, Techniques and Procedures
UAV . . . . Unmanned Aerial Vehicle
UNOCT . . . . United Nations Office of Counter-Terrorism
UNMEE. . . . . United Nations Mission in Ethiopia and Eritrea
UWB . . . . Ultra-Wideband (radar)
UXO . . . . Unexploded Ordnance
VX. . . . . a type of nerve agent
VR. . . . . Virtual Reality
WG . . . . Working Group
WLAN . . . . Wireless Local Area Network
XR. . . . . Extended Reality

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