NORTH ATLANTIC TREATY ORGANIZATION

SCIENCE AND TECHNOLOGY ORGANIZATION

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STO TECHNICAL REPORT **TR-IST-173**

Mission-Oriented Research for AI and Big Data for Military Decision Making

(Recherche thématique sur l'intelligence artificielle et les données massives pour la prise de décisions militaires)

This report summarizes the methodology used by the multi-domain IST-173 Specialist Team and presents its findings and recommendations for evolution of the theme moving forward.

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The NATO Science and Technology Organization

Science & Technology (S&T) in the NATO context is defined as the selective and rigorous generation and application of state-of-the-art, validated knowledge for defence and security purposes. S&T activities embrace scientific research, technology development, transition, application and field-testing, experimentation and a range of related scientific activities that include systems engineering, operational research and analysis, synthesis, integration and validation of knowledge derived through the scientific method.

In NATO, S&T is addressed using different business models, namely a collaborative business model where NATO provides a forum where NATO Nations and partner Nations elect to use their national resources to define, conduct and promote cooperative research and information exchange, and secondly an in-house delivery business model where S&T activities are conducted in a NATO dedicated executive body, having its own personnel, capabilities and infrastructure.

The mission of the NATO Science & Technology Organization (STO) is to help position the Nations' and NATO's S&T investments as a strategic enabler of the knowledge and technology advantage for the defence and security posture of NATO Nations and partner Nations, by conducting and promoting S&T activities that augment and leverage the capabilities and programmes of the Alliance, of the NATO Nations and the partner Nations, in support of NATO's objectives, and contributing to NATO's ability to enable and influence security and defence related capability development and threat mitigation in NATO Nations and partner Nations, in accordance with NATO policies.

The total spectrum of this collaborative effort is addressed by six Technical Panels who manage a wide range of scientific research activities, a Group specialising in modelling and simulation, plus a Committee dedicated to supporting the information management needs of the organization.

- AVT Applied Vehicle Technology Panel
- HFM Human Factors and Medicine Panel
- IST Information Systems Technology Panel
- NMSG NATO Modelling and Simulation Group
- SAS System Analysis and Studies Panel
- SCI Systems Concepts and Integration Panel
- SET Sensors and Electronics Technology Panel

These Panels and Group are the power-house of the collaborative model and are made up of national representatives as well as recognised world-class scientists, engineers and information specialists. In addition to providing critical technical oversight, they also provide a communication link to military users and other NATO bodies.

The scientific and technological work is carried out by Technical Teams, created under one or more of these eight bodies, for specific research activities which have a defined duration. These research activities can take a variety of forms, including Task Groups, Workshops, Symposia, Specialists' Meetings, Lecture Series and Technical Courses.

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List of Acronyms

AAP	Allied Administrative Publication
ACO	Allied Command Operations
ACT	Allied Command Transform
AIBDMDM	Artificial Intelligence, Big Data for Military Decision Making
AJP	Allied Joint Publication
CMRE	Centre for Maritime Research and Experimentation
CPoW	Collaborative Programme of Work
CoI	Community of Interest
CSO	Collaboration Support Office
EDT	Emerging Disruptive Technology
eMTEP	Electronic Military Training and Exercise Programme
HFM	Human Factors and Medicine Panel
HUMINT	Human Intelligence
IMINT	Imagery Intelligence
IST	Information Technology Panel
MCA	Main Capability Areas
MOR	Mission-Oriented Research
NATO	North Atlantic Treaty Organization
NAGSF	NATO Alliance Ground Surveillance Force
NCIA	NATO Communication and Information Agency
NIAG	NATO Industrial Advisory Group
NMSG	NATO Modelling and Simulation Group
OSINT	Open Source Intelligence
PfP	Partnership for Peace
R&D	Research and Development
SAS	Systems Analysis Studies Panel
SET	Sensors and Electronics Technology Panel
SIGINT	Signals Intelligence
ST	Specialist Team
S&T	Science and Technology
STB	NATO Science and Technology Board
STO	Science and Technology Organisation
ToE	Targets of Emphasis
UK	United Kingdom
US	United States

Preface

This report describes the efforts and results obtained by the first NATO multi-domain team, IST-173. The breadth of participants, including scientists from different panels and groups, as well as from NATO bodies and military stakeholders, academics, and industry generated a first Community of Interest for the theme AI and Big Data for Military Decision Making. The team proved in practice the feasibility of a new approach for STO, Mission-Oriented Research, to stimulate open dialogue, self-forming research collaborations and cross-panel activities. Moreover, this approach has been instrumental in the joint development of a first NATO S&T roadmap for 2 Main Capability Areas of Artificial Intelligence and Big Data for Military Decision Making, to address operational challenges that NATO faces in these areas. Due to the new organisation for (multi-domain teams with active participation of military stakeholders) and the application of this innovative approach, several lessons where identified that should support further operationalisation of the theme AI and Big Data for Military Decision Making.

Ana Isabel Barros, Francine Desharnais,
January 2020

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Mission-Oriented Research for AI and Big Data for Military Decision Making

(STO-TR-IST-173)

Executive Summary

The multi-domain IST-173 Specialist team goal was the development of a mission-oriented research roadmap for Artificial Intelligence and Big Data for Military Decision Making to address the grand challenges that NATO faces in these areas. The activity focused on the application of the mission-oriented research approach within the NATO Science & Technology Organisation (STO) to develop an initial research roadmap for two of the NATO Main Capability Areas (MCA: INFORM and COMMAND, CONTROL, CONSULT (C3)). The resulting roadmap leverages ongoing research, provides an overview of the current STO Collaborative Programme of Work (CPoW) in this area, and identifies key areas where new research is needed. As research and technology are constantly evolving, it will be essential to continue updating this roadmap, transforming it into a "living" STO co-creation (as it will be jointly updated by the STO community).

This report describes the methodology of the mission-oriented research design process, the lessons identified and learned during its application, as well as recommendations and guidelines on how to use and maintain the "living roadmap".

Recherche thématique sur l'intelligence artificielle et les données massives pour la prise de décisions militaires

(STO-TR-IST-173)

Synthèse

Le but de l'équipe spécialisée multidomaine IST-173 était d'établir une feuille de route de la recherche thématique sur l'intelligence artificielle et les données massives pour la prise de décisions militaires, afin de relever les immenses défis que l'OTAN rencontre dans ces domaines. L'activité s'est concentrée sur l'application de cette démarche de recherche thématique au sein de l'Organisation pour la science et la technologie (STO) de l'OTAN, afin d'élaborer une feuille de route de la recherche pour deux des domaines de capacité principale (MCA : INFORMER et COMMANDER, CONTRÔLER, CONSULTER (C3)). La feuille de route qui en résulte utilise les recherches en cours, donne une vue d'ensemble du programme des travaux collaboratifs de la STO (CPoW) en la matière et identifie les domaines clés qui nécessitent de nouvelles recherches. Étant donné que la recherche et la technologie évoluent constamment, il sera essentiel de continuer à mettre à jour cette feuille de route et de la transformer en une co-création « évolutive » de la STO (car elle sera mise à jour conjointement par la communauté de la STO).

Le présent rapport décrit la méthodologie du processus de conception de la recherche thématique, les enseignements identifiés et retenus pendant son application, ainsi que les recommandations et lignes directrices sur la manière d'utiliser et de mettre à jour la « feuille de route évolutive ».

MISSION-ORIENTED RESEARCH FOR AI AND BIG DATA FOR MILITARY DECISION MAKING

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1.0 INTRODUCTION

1.1 Background

During the NATO summit 2018, the strategic and military importance of AI was stressed by the political NATO leadership, and further emphasized the need to use it in support of both military and political decision making:

> *"Ensure that the Alliance has AI and Big Data supremacy for decision support by exploiting data and technology to its full potential across NATO and Nations to enhance both operational effectiveness and cost effectiveness."*

NATO STO started to focus on the theme AI and Big Data in 2017 and embraced this challenge by bringing together the community via the NATO IST-160 AI and Big Data for Military Decision Making specialist meeting in Bordeaux in 2018 [1].

As a follow up to this successful event, the Science and Technology Board endorsed the further stepwise development of an AI and Big Data for Military Decision Making (AIBDMDM) roadmap [2].

Following this recommendation, the STO Level 2 Chair Committee formed a tiger team to develop the way forward. Together with the IST activity (Ref. IST-173 [3]) a preparatory meeting took place in December 2018. As preparation for this work session, a mapping of the STO current and planned activities (about 70 activities) to the two Main Capabilities Areas of interest [4], was built [5]. This mapping clearly shows the interest of the scientific community for the theme and highlights the effort fragmentation. During the work session, the potential of the mission-oriented research approach proposed by IST-173 for the development of the desired roadmap was also explored. As a result, the IST-173 membership was expanded with panel representatives, stakeholders (ACT, CMRE, NCIA and others interested, like ACO, NIAG), and the mission-oriented approach was adopted.

The multi-domain team IST-173 was then faced with the challenge of using the mission-oriented research approach to develop a NATO S&T roadmap for Artificial Intelligence and Big Data for military decision making, to address the operational challenges that NATO faces in these areas.

1.2 Goal of Living Roadmap

The STO collaborative programme aims to create and exploit science and technology to advance the defence capabilities of Allies, partners, and NATO in support of the core tasks of collective defence, crisis

management and cooperative security. Recently the new STO strategy [6] stressed the importance of investments in four areas:

1) Enhancing the network of experts;
2) Intensifying strategic communications;
3) Improving the programmes of work; and
4) Promoting coherence of the Collaborative Programme of Work (CPoW).

Although the CPoW is well organized via its six panels and one group and yields a significant number of activities, there is a need to explore military capabilities that are lightly represented in CPoW and multi-disciplinary by nature (and hence cross-panel). This need was recognized by the Strategic Sub-Group (SSG) in January 2017 and as a result the concept of "Thematic Approach" was launched. The intent of such a thematic approach is two-fold:

- Building a community of interest in the theme area; and
- Strengthening the CPoW in the area by increasing cross-panel activities.

In order to operationalize this thematic approach, the STB decided during the Spring meeting 2017 [7] to start with the pilot theme AI and Big Data for Military Decision making by defining an approach that should:

- Have **impact** on and be **accepted** by military commanders;
- Require input from and promote **collaboration** between multiple (cross-panel) disciplines;
- Promote **engagement** with academia, military, and industry, e.g., "Multi-Domain"; and
- Lead to a **"flexible" S&T roadmap** to:
  - Provide guidelines;
  - Inspire and invite;
  - Identify possibilities for synergy;
  - Allow for linkages with other themes; and
  - Give room to both top-down and bottom-up activities.

The above defines the goal and the added value of a roadmap as it will enable NATO STO to:

- Create and access a community of interest which helps bringing awareness to other initiatives like Von Karman.
- Showcase STO research and its relevance to NATO operational needs.
- Frame a harmonized response to the challenges and opportunities from new technologies like Artificial Intelligence and Data Science creating more visibility and less duplication and inspiration for scientists.
- Stimulate cross-panel activities.

This report summarizes the methodology used by the IST-173 team in 2019 – 2020, presents the results, and produces recommendations for evolution of the theme moving forward.

2.0 METHODOLOGY

2.1 Introduction

In the early 18th century, the British government came to the realization that inability to properly determine the longitude of a ship's position was hampering its sea-dominance ambitions. There were ways to estimate longitude by measuring time difference between reference points, but this was a very inaccurate method to do at sea, and because of that, ship positioning was often imprecise in that time. In 1714, the British government established the 'Longitude Act', offering prize money for the first inventor that could build an instrument to reliably determine longitude at sea, and thus improve position assessment. This government-initiated incentive caused some of the UK's greatest engineers to take on the challenge, and led to the discovery of the marine chronometer by John Harrison in 1730, that, in combination with other instruments and lunar time table development, solved the longitude challenge. This was arguably the first example of 'Mission-Oriented Research' and showed that a well-stated and well organized mission can catalyze innovation and help solve some of the greatest technical or scientific challenges. Since then, we have seen many of these mission-style efforts, such as the Apollo moon mission, the Manhattan atomic bomb effort, the Delta works (*Deltawerken*) in the Netherlands, the Energy transition (*Energiewende*) in Germany and the development of the Concorde plane in the 60s.[1]

2.2 Mission-Oriented Research Approach Background

Mission-oriented Research is a type of 'objective-driven' innovation policy, in which the fulfilment of the objective (the '*mission*') is the leading driver for action. This contrasts with 'curiosity-driven innovation' where the interests of researchers or a technology push by providers steer the direction of innovation. Objective-driven research is aimed at solving a specific problem. Curiosity-driven innovation is open-ended and has no specific preconceived target (e.g., 'what can we do with this type of technology?'). Both types of innovation strategies are widespread through RD&I communities, but the recent adoption of a mission-oriented research policy by the European Union for its Horizon 2020 research programmes has generated a lot of new interest [8].

Mission-Oriented Research (MOR) is an innovation strategy that is specifically aimed at tackling large scale, complex societal challenges. MOR is typically centered around a **Grand Challenge**, a strategic objective of great societal importance that is difficult to solve, and that is often global in scale, such as 'Stop climate change', 'Establish space warfare superiority' or 'Create a disaster-resilient society'. Grand Challenges are often stated to gather wide support or funding and help mobilize research and innovation capacities. Grand Challenges usually do not have clear success criteria or evident solution paths.

In MOR, the Grand Challenge gives rise to **Missions**. A 'mission' is an innovation effort with a clearly defined success criterium. The mission has succeeded if the objective has been met, and achieving the mission contributes to solving the Grand Challenge. These missions will still be complex in nature and large in scale but represent a clear target for R&D partners to work on.

Where do the Mission statements come from? Missions are often defined by stakeholders, parties that have a direct benefit when the mission is solved. Because of the scale and risk of required funding and support needed, mission definition is often led by governments or public-private coalitions. US presidents famously launch innovation missions to bolster their position and catalyze the economy, such as Nixon's mission to find a cure for cancer. Mission statements can also come from joint efforts, such as crowdsourcing activities

[1] An interesting overview of past and current mission-oriented innovation efforts can be found in Ref. [9].

or open consultations. The European Union regularly holds consultation rounds in their research and innovation mission planning, sometimes open to key stakeholders in Members States, such as ministries, accredited advisory groups and research and technology organizations, sometimes open to the public. The famous 'Longitude Prize' in the UK nowadays holds open public polls to select innovation missions that should be backed by government funding.

Whatever format is chosen, the important element here is that the definition of mission objectives is a collective effort. Mazzucatu 2018 [10] notes that it is important to provide the necessary legitimacy and support to missions, which will greatly increase the chance of success.

Another important success criterium of innovation missions is the availability of clear intermediate goals and milestones. By definition, the mission objective does not prescribe a development pathway, just the desired end result ('the man on the moon'). The development path towards this objective is open, and often exploratory in nature. Different solution pathways can be investigated in parallel, and it perfectly acceptable to stop a certain development path if it proves to have less potential that previously foreseen. To ensure a strong push towards reaching the mission objective, it is crucial to set clear intermediate goals and milestones. **Intermediate goals** can take the shape of smaller missions, and form building blocks for the larger mission objective. Such smaller goals can be of any shape, including regulation, standardization or collaboration agreements. For instance, the German '*Energiewende*' (Energy transition mission) requires a lot of regulatory change and public engagement work. These are critical goals that need to be accomplished to let any technical innovation have its impact.

Clearly defined **milestones** are similarly important elements in the implementation and help establish critical timelines in the mission. By setting clear time-framed milestones, progression towards the mission objective can be assessed, and decisions can be made about the direction of development. Because of the importance of these milestones, their definition should be a collective effort, with a clear view of parties who are responsible to achieve the milestones and all underlying intermediate goals. As mission-oriented research can also function as a collective, multidisciplinary effort, **transparency** and **unity of vision and effort** is key, including the assessment of sub-goals and milestones. Such an open culture is necessary to take timely decisions regarding progress and prevent overall failure to meet the mission objective with all set requirements.

To some, mission-oriented research may seem similar to agile product development, with its flexible, inquisitive, iterative tactic. However, in normal product agile development, there is a clear product owner, and a clearly defined development team. In most mission-oriented research initiatives, there are many beneficiaries, and often society at large is the 'owner'. Also, the coalition of contributing partners during MOR is dynamic and potentially enormous in scale. For example, at the height of the US Apollo Space mission development, close to 20.000 contractors and half a million people were involved in various projects. Such a scale and variety of stakeholders requires a great amount **commitment and flexibility of partners**, and **pro-active management**. For most parties involved, being part of a mission-oriented innovation effort, means that specific organizational capabilities need to be developed that fit this way of working. Such capabilities could include dynamic financial resource allocation (being able to increase funding at short notice, if needed), and rapid formation of expertise.

In short, Mission-Oriented Research is about formulation of widely-accepted **Grand Challenges**, related **distinct innovation missions**, and from there building up solution pathways that lead to tangible results through specific projects (or, using a different vocabulary, sub-missions, or modules). The definition of projects can be facilitated by identifying specific **sectors** of interest, in order to focus the scope of activities. For example, in an effort to create a disaster-resilient city neighbourhood, one could focus on the professionals, the citizens,

protective technologies or ecology, or other sectors of interest. The different angles of interest help frame a sensible project. For example, Figure 1 shows the different sectors that were in view in a mission to create a carbon-neutral Manchester by 2038 [10].

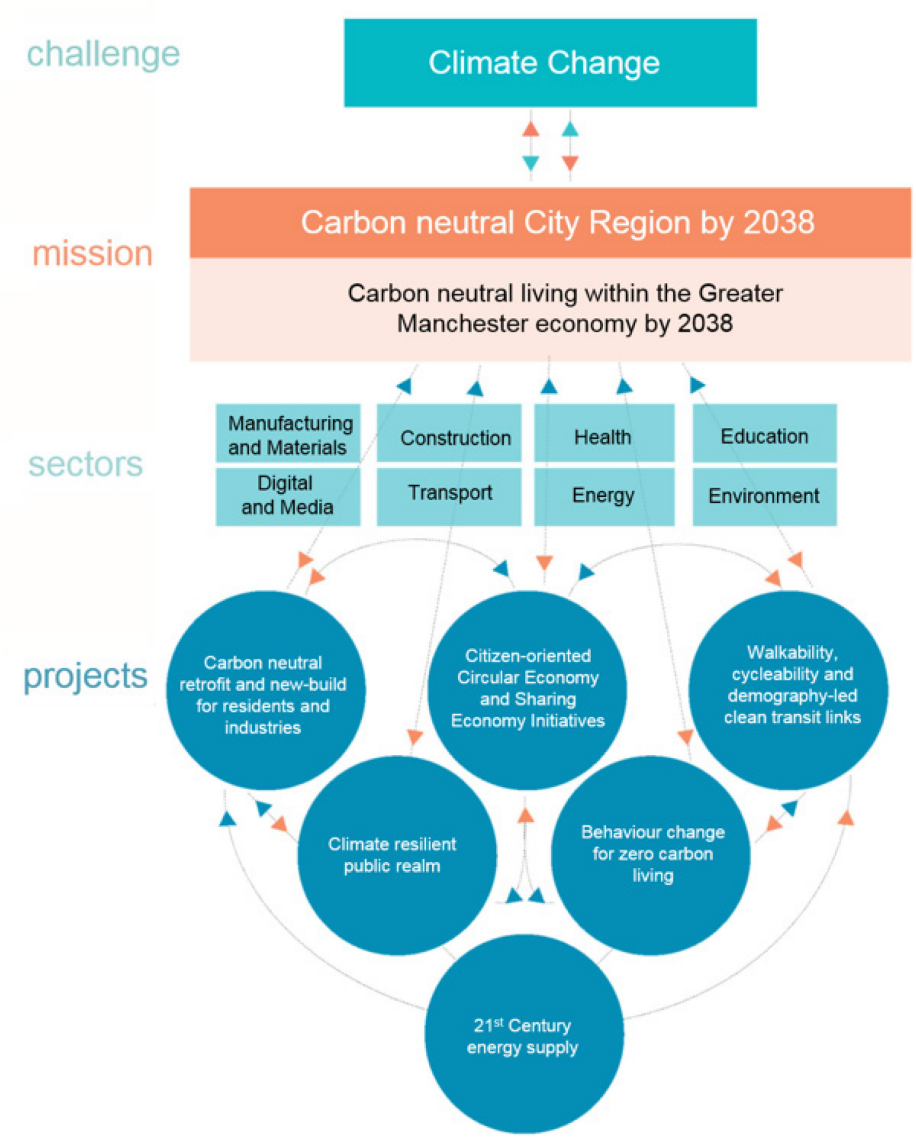

Figure 1: From Challenges to Missions Image: RTD-A.1 Based on Ref. [10].

Why is this approach suitable for innovation on **AI and Big Data for Military Decision Making**? AI and Big Data might be perceived as challenging developments, but they are not 'Grand Challenges' in itself. They are supporting technologies, and basically a 'means to an end'. By adopting a Mission-Oriented Research approach, stakeholders at NATO and Members States are stimulated to think about the larger picture: what is the Grand Challenge that presumably AI and Big Data will contribute to? And more precisely, what exact

innovation mission do we want to apply AI and Big Data technology to? A statement that 'AI will transform Military Decision Making' might not be inaccurate, but it does not provide any guidance nor incentive to innovation. MOR is about jointly defining an innovation objective and establishing a common commitment to fulfil that objective – be it through expertise, development capacity, funding, or strategic support.

2.3 Application of the Mission-Oriented Research Approach for Artificial Intelligence and Big Data for Military Decision Making

The application of the mission-oriented research approach to the theme started by the identification of a structure and common language to cluster the research activities. In order to strengthen the link to the military practice and potential stakeholders, the NATO Main Capability Areas (MCA), [4] (formerly Essential Operational Capabilities) were used as basic framework (Table 1).

Table 1: NATO Main Capability Areas.

MCA	Description
PREPARE	The capability to establish, prepare and sustain sufficient and effective presence at the right time, keeping sufficient flexibility to adapt to possible changes in the strategic environment.
INFORM	The capability to establish and maintain the situational awareness and level of knowledge required to allow commanders at all levels to make timely and informed decisions.
PROJECT	The capability to conduct strategic (re)deployment of both NATO and national headquarters' forces in support of Alliance missions.
ENGAGE	The capability to perform the tasks which contribute directly to the achievement of mission goals, including all abilities required to defeat adversaries.
COMMAND, CONTROL, CONSULT (C3)	The capability to exercise authority over and direct full spectrum of assigned and attached forces in the accomplishment of the mission.
SUSTAIN	The capability to plan and execute the timely logistical support of forces.
PROTECT	The capability to minimize the vulnerability of personnel, facilities, materiel and activities, whilst ensuring the Allies freedom of action and contributing to mission success.

The MCAs are also naturally linked to the NATO Staff branches and offices, for instance J2 has a natural link to INFORM, while J3, J5, J6 have a natural link to C3 and G4 to SUSTAIN [4].

Using this framework, the team took stock of current and upcoming NATO STO, ACT, NCIA and CMRE activities. Therefore representatives of the panels and group (panel executives) as well as representative of the NATO bodies (ACT, NCIA, CMRE) were asked to map the current and future activities using a pre-defined template that linked the activities to:

- The roadmap;
- The relevant Main Capability Area;

- The relevant military levels (technical, tactical, operational, strategic [11]); and
- The relevant domain warfare (information/cyber, land, maritime, air, space, multi-domain).

This effort has been captured in an Excel worksheet which showed that at the end of 2018, there were more than 70 activities in this area. Moreover, it showed that at that time, there were no activity addressing AI, Big data on the domain Space, and most of the research activities were multi-domain oriented. Further, the analysis also showed that:

- A large number of activities take place at technical level and operational levels, few at the strategic level.
- A concentration of activities on C3 and INFORM.

The outcome of this analysis was used as a starting point for the first formal meeting of IST-173 (March 2019), and as such the focus of the activity and roadmap development was on the MCAs INFORM and C3. This first meeting also showed the need to involve more military stakeholders in the process. Therefore, a questionnaire was developed to acquire input from both researchers, industry, and military to address the following three questions related to the MCAs as stated above:

1) Based on your own experience describe your ideas about challenges that NATO will encounter, now / in the near future.
2) Based on your own experience what is the single most important capability that NATO should focus on? Here you describe what you want to do with this capability. For example, you want a better and real time picture of the environment.
3) Which technology/technique/tool do you think will help develop the capability that you mentioned under 2?

During the first meeting in Germany in March 2019, multi-domain syndicates were formed to develop the S&T roadmap, as well as a research syndicate for development of common research activities. These syndicates were formed on the basis of NATO Main Capability Areas INFORM and C3 and based on the interests and background of participants. The work of the syndicates towards an S&T roadmap was facilitated via the Mission-Oriented Research approach. Each syndicate defined a grand challenge – an overarching objective towards which research should strive. A number of innovation missions were then outlined to help in achieving the grand challenge. Within each mission, sub-missions were defined with concrete goals and milestones (short-, medium-, and long-term). This process formed a large part of the meeting, with regular plenary presentations identifying overlaps and synergies between the two syndicates. This development was supported by the results of the questionnaires collected before the meeting as well as by the overview of current and planned activities in this area that was developed prior to the meeting.

During the first meeting, several Common Enabler Areas for the Main Capability Areas were identified. Some had a technology centric research focus and others were more focused on organizational research to support/enable the introduction of the technology within NATO and national defence organizations. With respect to the Technology area, two main topics were identified, and draft proposals for mission-oriented research were developed:

1) AI Infrastructure for NATO wide Development and Evaluation of AI technology; and
2) Orchestration and Scalability of AI driven Systems.

Similarly in terms of Organizational research the need to improve the understanding of Artificial Intelligence, Big Data and Data Science and educate leadership on current status of potential and drawbacks of AI, Big Data and Data Science for NATO was identified as well the need to increase the trust in AI. Moreover, a special session took place to create awareness on the legal, ethical, and philosophical challenges of AI and Big Data for NATO S&T.

In order to facilitate the embedding of the roadmap in the military practice an overview of the NATO electronic Military Training and Exercise Programme (eMTEP) and the relevant exercises for both Main Capability Areas was also developed. The awareness of upcoming exercises will enable an early engagement and the exploration of possibilities to test and demonstrate results for each of these MCAs can be demonstrated. The multi-disciplinarity of the team was also instrumental in the realization that there is a need for a "Centaur approach": leveraging AI and Data Science to enable NATO to fight and operate with machine speed and power while maintaining meaningful human control.

The results of the first meeting were summarized in a short presentation that was distributed to all the panels and group to stimulate discussion and increase awareness of the need for STO coordination of efforts. During the second meeting, held in Italy June 2019, the team built on the "Centaur approach" as identified during the first meeting. The identified challenges and missions in the Main Capability Areas INFORM and C3 that could be addressed by Artificial Intelligence and Data Science were refined and research gaps in these areas were identified and drafted. Also, during the three-day meeting a demonstration session was held to showcase cutting-edge "Working AI" solutions from Leonardo, TNO, CMRE, NCIA, and University of Trento for both MCA INFORM and C3.

As a key activity of the second workshop, NATO specialists (including a retired general) supported the work by drafting an AI-C3 innovation canvas for C3. The canvas took its inspiration from operational context to provide an architecture for the innovation mission. A similar canvas was eventually developed for MCA INFORM in view of its utility. See the Wiki S&T living roadmap [12] for further details.

2.4 Lessons Identified

The Mission-Oriented Research approach was used for the first time within a NATO context. Some of the lessons identified are listed below:

- The Mission-Oriented Research approach brought together scientific, military and industry communities. Developing/building a community (e.g., getting multi-discipline understanding, coordination, and alignment) requires time and effort. Commitment from National and NATO agency/bodies/panels/groups is essential to ensure multi-disciplinarity.
- Operational knowledge is extremely important and should be made available from the start and throughout, to provide guidance and operational insight to the scientists. In particular, the innovation canvas drafted by our NATO specialists was key in framing the S&T missions and identifying gaps. It would have been very beneficial to have this canvas developed at the front end of the theme activities.
- Thanks to the efforts of the organizers, attendance at the workshop was multidisciplinary and diversified, but not all panels were able to send representation. More panels, and more representatives from each panel would have been beneficial.
- Active support and promotion by STO are key in facilitating interactions with the panels, and in building the Community of Interest.

- Learning and improving the process of applying Mission-Oriented Research 'on the job' provided lots of insight but delayed the process. Working with two MCA syndicates enabled learning from each other. The time compression, however, limited the amount of cross-fertilizing between the syndicates.
- A lead was identified for the development of each MCA, Grand Challenge, and mission. This greatly facilitated the tracking of the documents, and the coherence from challenge to mission to TAPs.
- The MOR process is complex and requires much facilitation and guidance. Access to professional facilitators would have been helpful.
- There are currently no standard procedures for supporting and hosting Multi-domain activities as the majority of STO activities are mono-disciplinary. The CSO does not have an organizational structure in place for supporting such activities. The existing IT tools (e.g., Science Connect) can be adapted to support this type of activity, although tools like Wiki pages and more advanced queries on activities are still lacking. A lack of awareness of the STO mandate by some of the participants was noted. This occasionally challenged syndicates to reach a common understanding of workshop objectives.

3.0 RESULTS

3.1 Introduction

Related to the goals defined in Chapter I.2, IST-173 delivered the following:

1) A living roadmap in the form of a Wiki;
2) A mapping of current activities, identifications of S&T gaps, and initial set of TAPs to address some of the gaps; and
3) The kernel of a Community of Interest. Each deliverable is described in fuller detail below.

3.2 Living Roadmap

The primary product from this work is a NATO S&T "living roadmap" for AIBDMDM (Figure 2). This roadmap is in the shape of a wiki that can be easily corrected, augmented, and updated, based on the inputs from the Community of Interest. This roadmap is found on NATO *Science Connect* [12].

The roadmap focusses on two Main Capability Areas: INFORM, and C3 as well as a thread on "Common Enabler Areas" that are instrumental for all the Main Capability Areas. Each MCA uses an "innovation canvas" as a backdrop, i.e., an operationally inspired contextual diagram that described where Artificial Intelligence and Big Data may be most helpful. Each MCA also has (currently) one associated S&T Grand Challenge, and subservient innovation mission(s). Each mission includes a visionary statement, associated research goals, current related work, and S&T gaps. The missions link (in a wiki fashion) to existing work and TAPs in progress.

Annex A provides guidelines for further development of the Wiki. The Wiki also includes, as a reference document, the list of all current NATO activities that link to the roadmap.

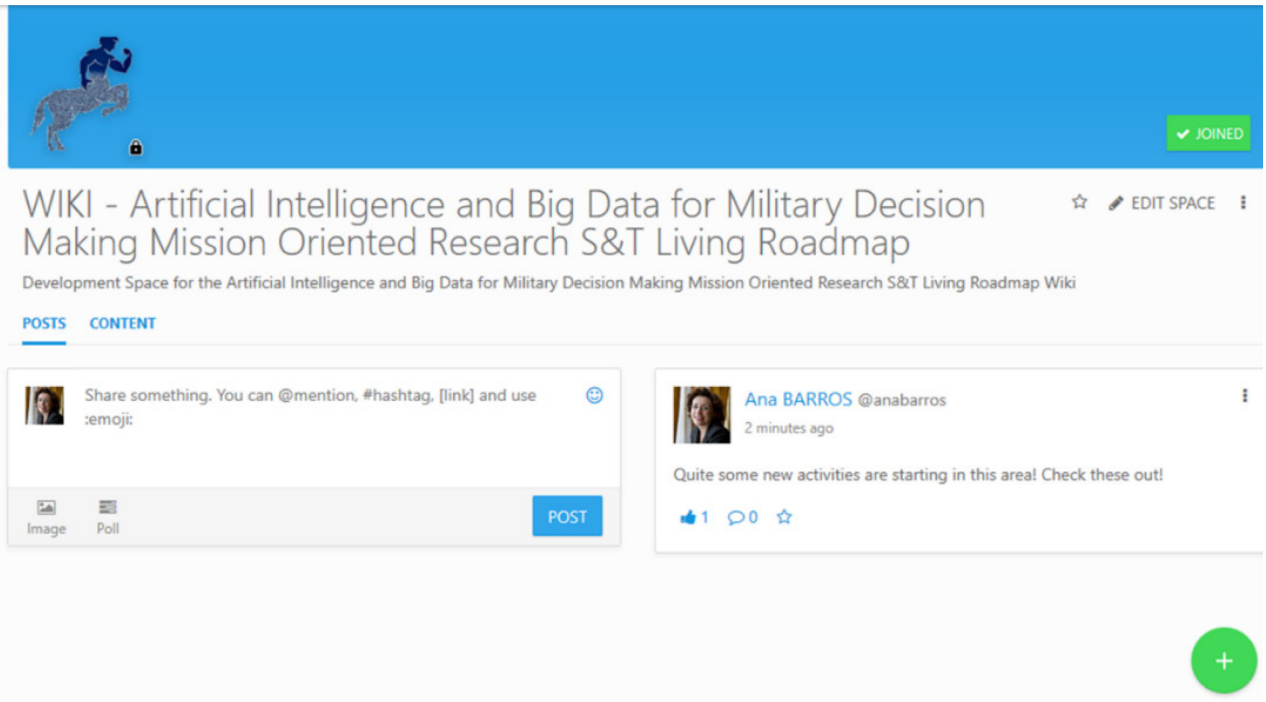

Figure 2: AIBDMDM Wiki – Screen Capture from Ref. [12].

3.3 Mapping of the Activities and Identified Gaps

The initial mapping of the STO activities developed at the end of 2018 [5] has been used in order to keep an overview of the research activities in this area. As the CPoW is quite dynamic, the maintenance of this mapping will require some effort, especially as at the moment little automation supports this process. As such, a simplified version of the original mapping has been created (which includes a hyperlink to the STO Activities database to accelerate consultation). It should be noted that new functionalities of the new STO Activities database enable queries in terms of the NATO S&T Targets of Emphasis (ToE) in particular those under the S&T Area of "Autonomy" (Artificial Intelligence), and S&T Area "Information Analysis & Decision Support" (Big Data & Long Processing and Analysis)[2]. It is also expected that in the future, new database functionalities will enable a query based on tags. Ideally, activities related to the theme should get such a tag in order to quickly produce an updated overview of all research activities in the area of AI and Big Data for Military Decision Making. A steady increase in the number of activities in this area is observed (from 70 up to 100 in one year) as well as an increase in the scope of activities (i.e., increase in activities in other Main Capabilities Areas, like Protect and Sustain).

The team identified gaps in the current CPoW, and an essential requirement for a NATO data infrastructure that allows for exploring and development of data, tools and capabilities that can take advantage of AI and/or Big data. The training of AI systems requires large amounts of annotated, labelled and validated data, computing resources, and SMEs for the specification of use cases and evaluations. At present, these resources are not commonly available to all NATO Nations. Therefore, the team has highlighted the urgency and need for an appropriate infrastructure during the fall NATO STO Science and Technology Board meeting of 2019.

[2] The 2017 NATO Science & Technology Priorities are clustered in 10 S&T Areas, each of these containing the so-called Targets of Emphasis that provide extra focus and orientation to these S&T Areas [13].

Some of the gaps identified with regards to the Common Enabler Areas "Technology" and "Organizational" (relevant to all of the Main Capability Areas) have already yielded new activities, while others are there to motivate and inspire the S&T community.

With regards to Common Technology Area, several methodology-based and infrastructure activities on machine learning are required and have already started:

- Develop an overall architecture for a NATO Machine Learning Ecosystem.
- Ensuring robustness and accountability in Machine Learning Systems.
- Coordinate and systematize the development and deployment of AI systems.
- Exploration of the potential of Unsupervised Machine Learning in the Military Domain.

Additional identified technology enabler gaps that are not yet addressed focus on determining the amount of labelled data required to solve a given machine learning problem, how to reduce the amount of labelled data required to build a machine learning model, how to counter AI bias, how to build trust in AI products (for instance by increasing the transparency and explainability of AI models) as well as how to increase the transferability of AI models between applications.

As for Common Organizational Areas the identified gaps concern the impact in military operations due to the introduction of AI and Big Data (also from ethical, moral and legal perspectives). In particular, there is an urgent need to increase the awareness of what Artificial Intelligence and Big Data Analysis is among military decision makers. Moreover, the desirable Centaur approach will require extra research into Human-Machine interaction and how to build trust in these technologies and in sharing data and resources. For these topics, some activities have just started or are in development. Other remaining identified research gaps in this area are:

- Collection and development of methodological best practices for the use of Artificial Intelligence within NATO;
- Human resource and cost implications of Artificial Intelligence introduction; and
- How to maintain military proficiency through the introduction of new AI technologies.

For the MCA INFORM, several gaps have been identified for each of the three defined missions. In some cases, these gaps have been quickly picked up and have resulted into activities. Below are some research gaps that have been identified (for more details, see the Wiki S&T living roadmap [12]):

- Potential of new methodologies and technical solutions to deal with trust in data sharing.
- Artificial Intelligence methods to improve automatic curation and data sanitation.
- Artificial Intelligence to support to the development of the Collection and Exploitation plan.
- Automated identification of information gaps and production of information requests.
- Automated search and discovery of data/information related to information and intelligence questions.
- Automated detection of circular reporting and/or data incest detection.
- AI for assessment of credibility and reliability of information and sources.
- AI Intelligence Devil advocate function to counter analyst's cognitive biases.
- Natural language processing methods for narrative detection.

For the MCA COMMAND, CONTROL, CONSULT (C3), several gaps were identified as they relate to finding the optimal balance in shared decision making between human and AI systems, and identifying the key issues related to Meaningful Human Control, a research thread that is already pursued by HFM and IST.

Below are some research gaps that have been identified (for more details, see the Wiki S&T living roadmap [12]):

- Machine understanding of operational environment metrics.
- Automated methods for the generation of Courses of Action (COA), and methods for Human-Machine co-creation of (master) COAs.
- Extended Situational Awareness in complex operational environments.
- COA Decision Criteria for military decision making.
- Identification of key issues and solutions for meaningful human control for C3.

The identification of these gaps has led to a new NMSG activity to explore the potential of Artificial Intelligence augmented immersive (using Virtual, Augmented and Mixed reality) Simulations and Data Science for Training and Decision Making support in complex environment (develop extended situational Awareness and support selection of best COAs).

3.4 Community of Interest

The work of IST-173 stimulated a NATO Community of Interest (COI). This initial COI is evidenced in the IST-173 membership and can be accessed through *Science Connect*. It is expected that the list of members will grow rapidly once the Wiki is fully operational, as it offers an easy access platform to post news and interaction.

3.5 Conclusions

IST-173 has already demonstrated many of the benefits of the multi-domain mission-oriented research approach. In particular, several TAPs have come out of the work to address operational needs, and most TAPs are either multidisciplinary in nature, or have been strengthened by being exposed and discussed in a multidisciplinary forum. There is also greater exposure, within this broad COI, of the previous and current work of other panels. This coordinated approach also greatly reduces the potential for duplication.

4.0 RECOMMENDATIONS

4.1 Introduction

IST-173 has revealed the potential of the multi-domain mission-oriented research approach, with results overarching the STO community, rather than stove-piped in groups and panels. However, this way of working is not a STO default, yet. This section contains recommendations related to Theme governance, to the application of the Mission-Oriented Research approach, and the living roadmap.

4.2 Governance

The implementation of a theme in practice requires an overarching governance that is aligned with the NATO S&T strategy, i.e., it must enhance collaboration and agility, reflect organizational diversity, and be rooted in the needs of our operational communities. Implementing the approach, and an initial roadmap for the AIBDMDM Theme, was a significant effort, and careful consideration must be given to the continuation of this effort for this theme, and the application of the methodology to other themes and or other Emerging Disruptive Technology (EDT), [14]. Moving forward, three options could be considered, each with its own governance, as well as a general recommendation.

4.2.1 Option 1: Full Development and Maintenance of a Living S&T Roadmap for AIBDMDM

Creation of a Theme-team to further implement and monitor the progress of the theme. This theme-team would consist of:

- A Cross-panel Theme Lead (who could be a Subject Matter expert and/or a CSO cross-panel member) and several theme experts, Points of Contact (or Champions) from each panel/group;
- The Theme Lead, with the support of the Champions and the CSO cross-panel structure, would provide scientific direction for the theme and Grand Challenges;
- The Champions, on a voluntary basis, would act as moderators for the Wiki;
- The new CSO cross-panel structure would support the coordination and deconfliction of activities across panels and groups, and ensure coherence across missions; and
- The theme progress would be reported to the STB by the Theme Lead.

This model would ensure continued engagement from all communities, including the panels, and compel the maintenance of a cross-panel/multi-domain approach.

This model would facilitate the approval of new activities of relevance to the AIBDMDM Theme (the new activities should be tagged with the reference to the theme to improve visibility). Ideally, TAPs aligned with the roadmap would be more easily approved. It would also be advisable for the Theme Lead to be informed of the related incoming TAPs and that, together with the TAP POC, linkages can be identified and secured at an early stage. As this is a living roadmap, insights from new approved activities would be used to amend the grand challenges or missions, if necessary.

The same model could be applied to all themes/EDTs.

4.2.2 Option 2: Simplified Cross-Panel Theme Coordination

It is acknowledged that building and maintaining a living roadmap would be a significant effort. While Champions may come forward naturally, there is a risk for panel/group fatigue, especially if applied to several themes or EDTs. A simplified model would limit the work to an effort of coordination and deconfliction of activities across panels by the new cross-panel CSO structure. While a surge team would still be required to define the initial roadmaps (such as IST-173 did for the AIBDMDM Theme), the new cross-panel CSO structure could bear the brunt of the coordination effort (Theme Lead).

In this option, an STB-Mentor would also be required to shepherd the development of the Theme. The Theme Lead would report to STB. No roadmap champions and/or contribution from the panels would be required once the roadmaps are developed.

It should be noted that the roadmaps would thus be developed once and remain static. While more limiting, this may be sufficient for transitory themes. Surge effort could be periodically considered to update the themes with longer-term relevance.

A minimalist variant of this option would be cross-panel coordination of activities by CSO, without the backdrop provided by the roadmaps. This would be a low effort, yet worthwhile effort to pursue.

4.2.3 Option 3: No Theme Coordination (*Status Quo* Option)

If the effort of maintaining the living S&T roadmap for AIBDMDM is assessed to be too large, the concept of co-development of living theme roadmaps could be abandoned altogether.

The Wiki developed for AIBDMDM can be used by the community, but no additional effort would be made to keep it updated, or to develop additional content. This report would then be the formal record of lessons learned to inform future similar endeavours.

4.2.4 General Recommendations for Theme AIBDMDM

A separate nomenclature should be adopted for overarching AIBDMDM Theme activities, such as Theme reviews, defining and maintaining grand challenges and innovation missions, organization of experiments, etc. For example: 'STO-AIMDM-RTGxxx', where xxx is an incremental number. A similar nomenclature should be adopted for all themes.

It should be noted that, from a technological point of view there will be some overlap with the Autonomy Theme since both heavily depend on the use of AI technologies. It is recommended that the Theme Leads promote the links between the two Themes, in order to ensure complementarity.

4.3 Methodology

Section 2.4 captures the main lessons identified through the application of the Mission-Oriented Research approach.

In view of the importance of aligning the roadmap with the needs and challenges of the Alliance, it is recommended to get earlier engagement with the operational community to better define the needs. Starting a theme with a broad stakeholder engagement session aside from a NATO meeting with high military representation would help this process. The AIBDMDM team was fortunate to have members of the intelligence community participating in the activity as well as access to retired NATO personnel, who were key in drawing the AI-C2 innovation canvas which became the underpinnings of the MCA C3 innovation missions. This successful process should be considered at the beginning of future themes.

Considering the effort required to build and maintain momentum in this cross-group/cross-panel activity, investing in professional support to facilitate meetings and community building should be considered by future themes. This includes leveraging 'modern' communication opportunities such as online videos to reach a broader and newer community of researchers.

We also recommend:

- The development of a Standing Operating Procedure (SOP), and supporting CSO structures and services, for STO multi-domain research.

- At the launch of a new theme and multi-domain activity some time should be reserved to describe STO, its goal and organization.

4.4 Living Roadmap

The Theme is called 'AI and BD for Military Decision Making'. The scope of the theme being very broad, it remains a challenge to fully explain and attract commitment from the various stakeholders. For future themes, it is recommended to carefully consider the scope of a Theme, narrow the scope as required to ensure each theme is distinct, and implement measures to stay within that scope.

If Option A (under Governance) is selected, support from Panel representatives and STB will be required to keep populating and realizing the living roadmap, to keep the content relevant and successfully exploited. The recommendation above related to governance, and the appointment of a Theme Lead and a supporting team would facilitate future success.

The roadmap should be extended to all NATO Main Capability Areas, if/when confident that enough resources can be committed to realize it.

4.5 Way Forward

In terms of the options presented under Governance (IV.2), the IST-173 team recommends that Option A (Full development and maintenance of living roadmaps by CSO) be selected specifically for the AIBDMDM Theme. While we acknowledge the effort that maintaining the roadmap will require, it is believed the effort to be of value, as it would best ensure the exploitation of the results achieved so far, and continued relevance to STO. It would also enable us to continue experimenting with the Wiki concept. It should be noted that the developed approach could be used for the new Emerging and Disruptive Technologies (EDTs) roadmap. Moreover, the results achieved so far can support the further development of the EDTs Artificial Intelligence, and Data Science. If STO wanted to apply the methodology to multiple themes and/or roadmap, however, Option B might be preferable in order to minimize the overall effort required.

Whichever option is selected by STB, active promotion of the STO multi-domain mindset should continue, as it was proven very successful in building this first instantiation of the AIBDMDM roadmap.

In the short term, the STB nomination of a follow-on AIBDMDM Theme Lead, and the formalization of a cross-cutting governance (as per any of the options listed above), should be viewed as priorities, to ensure the current momentum is not lost. This would also foster deeper roots for the budding AIBDMDM Community of Interest.

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Appendix 1: GUIDELINES WIKI

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This Appendix describes the layout of the Wiki Artificial Intelligence and Big Data for Military Decision-Making Mission-Oriented Research S&T Living Roadmap and templates for the development of Main Capability Areas Grand Challenges and associated missions.

1A.1 INTRODUCTION

Description of the Mission-oriented research approach to the STO theme Artificial Intelligence and Big Data for Military Decision Making and organization across the 7 *NATO Main Capability Areas* (MCA) and Common Enabler Areas.

1A.2 COMMON ENABLER AREAS

Description of the Common technological and organizational research areas that contribute to the realization of the Missions.

1A.3 GRAND CHALLENGES ASSOCIATED WITH MCAS

- A Grand Challenge should entail a desired state, or "where we want to go to". These Grand Challenges may be abstract in nature but must relate to tangible NATO (and nations) ambitions – and preferably link to existing strategic objectives.
- For each Grand Challenge, innovation missions[3] will be defined. Each mission details a concrete development ambition: a step beyond the current state. A mission is a part realization of the Grand Challenge. Missions jointly build up towards the Grand Challenge.
- Mission results are built up from joining results from activities. Mission-related activities can be built in parallel, sequentially, in complementary form, or even opposing form in case of pursuing various strategies. Mission plans are open and allow for change of strategy during the running time. Mission plans are comparable to roadmaps without a definite path to reach the endpoint.
- Also, there will be links to the MCA common technological areas of interest.

The Grand Challenge template is contained at the end of this Appendix.

[3] Note: When using the term 'missions' we imply 'innovation missions', not operational (military) missions.

1A.4 MCA GRAND CHALLENGE MISSIONS

When developing a mission associated with a challenge, it is important to keep in mind:

- What is the current situation: why there is a need for a change, the motivation for the mission.
- What we want to achieve, and where we want to end up and when?
- Who are the target users, what is the context of the innovation mission (use-case)?
- How to achieve the defined goals: what research do we need to get there and when?

The mission description should include information such as:

- Outline opportunities for innovation with military relevance;
- Describe concrete and clear end results that are measurable and time-bound (what can be expected and when);
- Define clear research paths to achieve end results;
- Be ambitious but also realistic in terms of research and innovation required; and
- Consider different disciplines (not stove piped) and explicit involvement of different parties like military NATO bodies, scientific bodies, and industry (for instance in military exercises, etc.).

See also the mission template at the end of this Appendix.

1A.5 MISSION TEMPLATE

MCA<name> Grand Challenge Name

Explain the trends/threats/opportunities in the world resulting in this Grand Challenge.

If possible, use a visionary statement as illustration as a point on the horizon towards which this challenge might head).

MCA<name> Mission <name>

Use a Subtitle, that illustrates what will be the end goal.

Visionary Statement

What we want to achieve, where we want to end up and when. Should provide insight into the future and how the mission results will be used within NATO.

Mission Rationale

What is the current situation: why there is a need for a change, the motivation for the mission.

From Realistic to Future

What are (from a military functional perspective) development steps to achieve the mission: what research do we need to perform to achieve it and when (within 5 years, between 5 – 10 years and more than 10 years). Think agile development: always have a minimal viable product. The table below can help mapping these developments in a timeline.

Core Functionalities at Short Term (Within 5 Years)	Core Functionalities at Medium Term (5 to 10 Years)	Core Functionalities at Long Term (More Than 10 Years)

What are (from a development perspective) necessary research elements that are near, medium, long term to fulfill the above identify steps? These elements should jointly build up to the desired functionalities in the table above. Think in terms of elements that can be developed independently but are mutually dependent to build up towards viable products. Think about technical modules, standards, processes, strategies, designs, etc. This is about decomposing the innovation mission into clearly defined parts that can be taken on by teams and inspire the creation of new research activities. The table below can help mapping these developments in a timeline.

Core Elements at Short Term (Within 5 Years)	Core Elements at Medium Term (5 to 10 Years)	Core Elements at Long Term (More Than 10 Years)

Include, where possible, concrete possibilities for data gathering, expert exchange, dissemination and exploitations (like panel activities, NATO exercises and other NATO events where results can be demonstrated).

Contributing Research Elements

Mapping of the current and past STO activities that will support this mission current STO activities (link to CSO database).

Identified Research Gaps

Identification of possible gaps where new activities should be developed.

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Mission-Oriented Research for AI and Big Data for Military Decision Making

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This report summarizes the methodology used by the multi-domain IST-173 Specialist Team and presents its findings and recommendations for evolution of the theme moving forward.

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14. Abstract

The impact and importance of AI and data science on military decision making has been recognized by STO and led to the launch in 2017 of the theme approach initiative on Artificial Intelligence (AI) and Big Data (BD) for Military Decision Making (AIBDMDM).

As part of this effort, the first multi-domain specialist team (including not only scientists from different panels/group but also military and industry representatives) IST-173 Mission Oriented Research for AI & BD for Military Decision Making was established to develop a "living roadmap" to support STO in bringing military AI and big data to its full potential. The team has identified the need for a "Centaur approach": leveraging AI and Data Science to enable NATO to fight and operate with machine speed and power while maintaining meaningful human control. This need has been operationalised using a mission oriented research approach that focused on the NATO Main Capabilities Areas, INFORM and COMMAND, CONTROL, CONSULT (C3) to develop a first version of such a "living" S&T roadmap in a wiki STO framework to enable easy access and adaptation. In particular, grand challenges that NATO faces in these areas were jointly identified, and research missions that leverage ongoing STO research were developed, with the aim to identify the key areas where new research is needed to inform Panel/Group efforts.

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