NORTH ATLANTIC TREATY ORGANIZATION

SCIENCE AND TECHNOLOGY ORGANIZATION

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STO TECHNICAL REPORT **TR-MSG-189**

AI Augmented Immersive Simulation in Training and DM Course of Actions Analysis

(Simulation immersive augmentée par l'IA dans le cadre de la formation et analyse du mode d'action de la prise de décisions)

Final Report of the Specialist Team MSG-189.

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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

5G	Fifth Generation of Mobile Technology
AAR	After Action Reviews
AI	Artificial Intelligence
APT	Advanced Persistent Threats
AR	Augmented Reality
AST	Application Security Testing
ATO	Air Tasking Order
BDAA	Big Data and Advanced Analytics
BERT	Bidirectional Encoder Representations from Transformers
BGs	Brigades
C2	Command & Control
CAST	Command and Staff Trainer
CAVE	Cave Automatic Virtual Environments
CAX	Computer Aided Exercises
CBT	Competency Based Training
CBT	Computer Based Training / Tested
CD&E	Concept Development and Experimentation
CE	Combat Estimate
CEMA	Cyber and Electromagnetic Activities
CGF	Computer Generated Force
CIVPOP	Civilian Population
CJIIM	Combined, Joint, Intra-government, intra-Agency, multinational
CMDB	Configuration Management Database
CoA	Course of Action
CONOPS	Concept of Operations (Operational Concept)
CONUSE	Concept of Use
COP	Common Operational Picture
COPD	Comprehensive Operation Planning Directive
CPX	Command Post Exercise
CS	Combat Support
CSP	Cloud Service Provider
CTC	Combat Training Centre
CVSS	Common Vulnerability Scoring System
D3	Data Driven Documents
DARPA	Defence Advanced Research Projects Agency
DDBM	Data driven Behaviour Modelling
DIS	Distributed Interactive Simulation
DM	Decision-Making
DVR	Desktop Virtual Reality
EBT	Evidence Based Training
EDT	Emerging Disruptive Technologies
EEG	Electroencephalogram
eMBB	Enhanced Mobile BroadBand
EMRELE	Embodied Mixed Reality Learning Environment

FPV	First Person View
FSTD	Flight Simulation Training Device
GANs	Generative Adversial Neural Networks
GNN	Graph Neural Networks
HLA	High Level Architecture
HMD	Head Mounted Display
IaaS	Infrastructure as a Service
IATA	International Air Transport Association
ICAO	International Civil Aviation Organization
IDS	Intrusion Detection System
IED	Improvised Explosive Device
IEEE	Institute of Electrical and Electronics Engineers
INFO OPS	Information Operations
IOT	In Order To
IoT	Internet of Things
IPB	Intelligence Preparation of the Battlefield
IPS	Intrusion Protection System
ISR	Intelligence, Surveillance and Reconnaissance
IVR	Immersive Virtual Reality
JFACC	Joint Forces Air Component Commanders
JTAC	Joint Terminal Attack Controller
KSAAs	Knowledges, Skills, Abilities, Attitudes
LED	Light Emitter Diode
LMS	Learning Management System
LVC	Live Virtual Constructive
M&S	Modelling & Simulation
MDMP	Military Decision-Making Process
MEDO	Méthode d'Elaboration d'une Decision Operationelle
MEL-MIL	Main Events List – Main Incidents List
ML	Machine Learning
mMTC	Massive Machine Type Communications
MPO	Method for Planning Operations
MR	Mission Rehearsal
MR	Mixed Reality
MRX	Mission Rehearsal Exercise
MSaaS	Modelling and Simulation as a Service
MTDS	Mission Training Distributed Simulation
NATO	North Atlantic Treaty Organization
NIST	National Institute of Standards and Technologies
NLP	Natural Language Processing
NMSG	NATO Modelling and Simulation Group
OE	Operational Estimate
OPP	Operational Planning Process
OWASP	Open Web Application Security Project

PaaS	Platform as a Service
POV	Point of View
PREE	Plan, Refine, Execute and Evaluate
QC	Quantum Computing
QKD	Quantum Keys Distribution
RBVM	Risk Based Vulnerability Management
RL	Reinforcement Learning
SA	Situational Awareness
SaaS	Software as a Service
SAF/CGF	Semi-Automated Forces / Computer Generated Forces
SAMM	Software Assurance Maturity Model
SDN	Software Defined Network
SDP	Software Defined Perimeter
SITFOR	Situational Forces
SME	Subject Matter Expert
SMPC	Secure Multi-Party Computing
SOA	Service Oriented Architecture
SSDLC	Secure Software Development Life-Cycle
STO	Scientific & Technology Organization
TaaS	Training as a Service
TAP	Technical Activity Proposal
TE	Tactical Estimate
TENA	Training Enabling Architecture
TFs	Tactical Forces
TPS	Tactical Planning System
TRL	Technology Readiness Level
TTPs	Tactic Techniques and Procedures
UAV	Unmanned Aerial Vehicle
UEBA	User and Entity Behaviour Analytics
URLLC	Ultra Reliable Low Latency Communications
VA	Vulnerability Assessment
VM	Vulnerability Management
VPN	Virtual Private Network
VPT	Vulnerability Prioritisation Technology
VR	Virtual Reality
xAI	Explained Artificial Intelligence
xR	Extended Reality
ZTN	Zero Trust Network
ZTNA	Zero Trust Network Access

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AI Augmented Immersive Simulation in Training and DM Course of Actions Analysis

(STO-TR-MSG-189)

Executive Summary

The rationale of the MSG-189 Specialist Team (ST) activities builds on the need to evaluate how to combine and integrate the new emergent disruptive technologies, which are changing the way we carry on our work and life, into the evolution of M&S techniques and related Simulation systems.

As part of the research's goals of the NATO STO NMSG, new architectures and advanced features for simulation systems have always been studied and defined. Just to mention a few: MSaaS (Modelling and Simulation as a Service) and MTDS (Mission Training Distributed Simulation) have been defined and their subsequent implementation has paved the way to a new generation of state-of-the-art simulation systems.

Furthermore, in recent years, the NATO STO Panels and related working groups have been addressing the issues and evolutions of the most advanced technologies: Artificial Intelligence (AI), Machine Learning (ML), management and analysis of large and heterogeneous amounts of information (Big Data), interaction between the real and the synthetic world through immersive devices (AR, VR, XR), wireless technologies (5G) and novel methods of delivering services through Cloud computing and Service Oriented Architectures.

It therefore seemed natural for NMSG to study the synergies between these research areas to outline characteristics and potential impact of such emerging and disruptive technologies for next-generation simulation systems.

The idea of defining a simulation system in which all the concepts indicated above were present in a holistic way is certainly challenging; for this reason, the working group focused its attention only on certain aspects for exploration:

- The MSG-189 outcome goal is to define an M&S Ecosystem described by a Reference Architecture. The important point to highlight in the Reference Architecture is the relationships among its building blocks and the products/services provided.
- The possibility of introducing in M&S new technologies as enablers to improve what already exists or to provide new solutions to solve problems that do not currently have a solution.
- The assumption that this M&S Ecosystem delivers "products" and "services" available on the network 24/7 according to the MSaaS over the "cloud" model.
- The functionalities and uses of the resulting system are concentrated on two specific areas: the Training of military personnel (including the Decision Makers) and the support for the Decision-Making Process of Commanders and their staff.
- Lastly, at this stage, MSG-189 ST is not trying to define a ready-to-use product (thus the level is more abstract), but rather to find a way (reference architecture) in which present or future products can be integrated together preserving as much as possible the integrity and basic functionalities of the resulting system.

It must be highlighted that the produced Reference Architecture of the framework has its main foundation on long standing and very important NMSG activities such as MSaaS and MTDS. MSG-189 ST activities build on those references to find new and innovative solutions that can enhance the use of a critical technology such as M&S. A "secure" design concept with a close look at the high resilience of the infrastructure to cyber threats (Secure by Design) is also a specific requirement to meet.

The resulting MSG-189 Ecosystem could be used not only as a training tool but above all as a valid support either in identifying the best CoA to be then implemented in "real" operations or in the subsequent phases of planning and defining the details of the operations to be performed (management of operating orders).

A final recommendation from MSG-189 ST suggests forming a follow-on working group (RTG) which, taking inspiration from what has been done in the group, can define a certain number of use cases in order to validate the choices made and demonstrate the validity of the reference architecture of the system and of the technologies listed.

Simulation immersive augmentée par l'IA dans le cadre de la formation et analyse du mode d'action de la prise de décisions

(STO-TR-MSG-189)

Synthèse

Les activités de l'équipe spécialisée (ST) du MSG-189 sont motivées par le besoin d'évaluer comment combiner et intégrer les technologies révolutionnaires émergentes, qui modifient notre manière de travailler et de vivre, dans l'évolution des techniques de M&S et des systèmes de simulation correspondants.

Dans le cadre des objectifs de recherche du NMSG de la STO de l'OTAN, les nouvelles architectures et les fonctionnalités avancées des systèmes de simulation ont toujours été étudiées et définies. Pour ne citer que quelques exemples : La MSaaS (modélisation et simulation en tant que service) et la MTDS (simulation répartie pour l'entraînement aux missions) ont été définies et leur application consécutive a ouvert la voie à une nouvelle génération de systèmes de simulation ultramodernes.

De plus, ces dernières années, les commissions et groupes de travail afférents de la STO de l'OTAN ont traité les questions et évolutions des technologies les plus perfectionnées : Intelligence artificielle (IA), apprentissage automatique (ML), gestion et analyse de grandes quantités d'informations hétérogènes (données massives), interaction entre le monde réel et de synthèse par le biais de dispositifs immersifs (AR, VR, XR), technologies sans fil (5G) et méthodes innovantes de prestation de services par l'informatique dans le cloud et les architectures orientées service.

Il a donc semblé naturel au NMSG d'étudier les synergies entre ces domaines de recherche pour décrire les caractéristiques et l'effet potentiel de ces technologies émergentes et révolutionnaires sur les systèmes de simulation de prochaine génération.

La définition d'un système de simulation dans lequel tous les concepts indiqués ci-dessus sont présents de manière globale est délicate, sans aucun doute. C'est pourquoi le groupe de travail a concentré son attention sur quelques aspects de qualification à étudier :

- Le but du MSG-189 est de définir un écosystème de M&S décrit par une architecture de référence. Le point de l'architecture de référence important à souligner est la relation entre ses éléments constitutifs et les produits/services fournis.
- La possibilité d'introduire dans la M&S de nouvelles technologies comme outils pour améliorer ce qui existe déjà ou fournir de nouvelles solutions pour la résolution des problèmes encore irrésolus.
- L'hypothèse que cet écosystème de M&S fournit des « produits » et « services » disponibles sur le réseau 24 h sur 24 et sept jours sur sept conformément au modèle de MSaaS dans le cloud.
- Les fonctionnalités et usages du système qui en résultent sont concentrés dans deux domaines particuliers : la formation du personnel militaire (incluant les décideurs) et le soutien au processus décisionnel des commandants et de leur état-major.

- Enfin, la ST MSG-189 n'essaie pas de définir à ce stade un produit prêt à l'emploi (par conséquent, le niveau est plus abstrait), mais de trouver selon quelles modalités (architecture de référence) les produits présents ou futurs peuvent être intégrés ensemble, en préservant autant que possible l'intégrité et les fonctionnalités de base du système qui en résulte.

Il faut souligner que l'architecture de référence produite repose principalement sur des activités très importantes que le NMSG mène de longue date, telles que la MSaaS et la MTDS. Les activités MSG-189 ST s'appuient sur ces références pour trouver de nouvelles solutions innovantes qui peuvent améliorer l'utilisation d'une technologie critique telle que M&S. Un concept de conception « sécurisée » avec un examen attentif d'une haute résilience de l'infrastructure aux cybermenaces (conception sécurisée) est également une exigence spécifique à respecter.

L'écosystème du MSG-189 qui en résulte pourrait servir non seulement d'outil de formation, mais surtout de support valable pour identifier le meilleur mode d'action à appliquer soit dans des opérations « réelles », soit dans les phases ultérieures de planification et de définition des détails des opérations à exécuter (gestion des ordres opérationnels).

Enfin, la ST MSG-189 recommande de former un groupe de travail (RTG) de suivi qui, s'inspirant de ce qui a été fait dans le groupe, puisse définir un certain nombre de cas d'utilisation afin de valider les choix effectués et démontrer la validité de l'architecture de référence du système et des technologies énumérées.

Chapter 1 – SCOPE AND AREA OF INTEREST

1.1 SCOPE

In recent years, a rapid development of the so-called "Disruptive Technologies," such as Artificial Intelligence (AI), Machine Learning (ML), management and processing of large amounts of data (Data Science and Big Data Analytics – BD) and immersive technologies (VR / AR / MR / XR), has been observed.

Various panels/group within the NATO STO have studied the possibilities offered by these new technologies; in particular, the NMSG working group is interested in studying new architectures and services for simulation systems that use them for future applications in the areas of military training and decision making. The NATO MSG-189 Specialists Team (ST) has taken on this challenge and performed a study to define such a simulation framework.

To start with, let's have a look at the objectives to be pursued, listed initially in the Technical Activity Proposal TAP [1] and then in the One Pager Document [2]:

- An overview of the state of the art of each of the enabling technologies (AI, BD, XR, etc.) aimed at defining the qualifying aspects that each of them can play in defining the proposed future simulation framework for training and decision-making support.
- The indication of the gaps, in the training and decision-making military fields, to which the proposed technologies can provide a valuable and viable solution.
- The definition of the system requirements of the simulation framework.
- The definition of the framework architecture.
- A survey on the possible SW tools to be used for the implementation of the framework and on the HW environment.
- The definition of the main functionalities.
- The definition of interfaces with other systems (for example C2 and decision panels).

The idea of defining a simulation system in which all the above concepts were present in an holistic way is certainly challenging and, in many aspects, goes beyond the objectives (and possibilities) of a Specialist Team.

So, the first task of the working group was defining in a more precise way the scope of the work and indicating the areas within which to address the group's study activities. The most important outcome of this was the decision to define a "Reference Architecture" upon which an MSG-189 Ecosystem (later often simply cited as System) would be built. This is an abstract form of architecture that provides a template solution for future concrete solution architectures (project architectures).

It has to be highlighted that the produced Reference Architecture of the framework has its main foundation on long standing and very important NMSG activities such as MSaaS (Modelling & Simulation as a Service) and MTDS (Mission Training Distributed Simulation). MSG-189 ST activities will build on those references to find new and innovative solutions that can enhance the use of a critical technology such as M&S.

A "secure" design concept with a close look at the high resilience of the infrastructure to cyber threats (Secure by Design) is also indicated as a specific requirement to be met. For this reason, this information has been presented in this first chapter.

1.2 AREA OF INTEREST

In particular, this chapter introduces the concepts of Military Training and Decision Making, highlights the importance of the Cyber Security aspects that such a System has to take into consideration and then defines the volume of interest for the MSG-189 ST activities. The in-depth study of the issues indicated and their integration into the Reference Architecture will be the subject of the following chapters.

The first part of the chapter is dedicated to the identification and description of the issues related to the Training, intended as essential and critical activity for all the professionals who work in military organisations, and to the Support for the Decision-Making process of commanders, their staff and personnel involved in missions.

Another topic outlined in the chapter is related to cyber security: the qualifying aspects of the architecture in relation to safety will be defined; the information provided must be the basis for the design of the framework and permeate all its features (secure by design).

In the final part of the chapter, the area of interest of the study is described, the dimensions of this area (Action, Expertise and Life Cycle) are defined and, for each of them, the levels to be considered are indicated and described.

Finally, we define the volume of interest within which the research activities of the MSG-189 ST will be carried out.

1.2.1 Military Training

Military training means definite but very different things to different people. At the level of a commander of a military unit, it means exercising troops in the field or sailors at sea so that they operate as an integrated, coordinated unit. At military personnel managers' level, it means preparing and certifying individuals across a full spectrum of occupational specialties that include cooks, dog handlers, tank turret technicians, radar technicians, and fighter pilots. At the level of developers and providers of major military systems, it means exercises performed in simulators or on the systems themselves. To all concerned, it means preparing individuals from a civilian society to perform as professional military personnel.

Military training is distinguished from other forms of training by its emphases on discipline, just-in-case preparation, and the training of collectives [3].

From the days of the medieval quintain and doubtless before, simulation has been prominent in conducting military training and assessing the readiness of individuals, crews, teams, and units to perform military operations. Today, simulation is as familiar to mud-weary soldiers participating in field exercises as it is to commanders manoeuvring corps of Computer-Generated Forces (CGF) sweeping across vast, electronic plains in our war colleges. It is supported by devices ranging from plastic mock-ups to laptop computers to full-motion aircraft simulators that cost more than the aircraft they simulate [3].

Some rough distinctions among models, simulators, and simulation are useful [3]:

- Models provide the underlying representation of inputs and outputs. They are the engines that control and determine the responses of simulators and simulations to users.
- Simulators are devices. They are intended to represent to the student other devices or phenomena likely to be encountered in the natural world and are used to produce simulations of the natural world.
- Simulations are the products of simulators and their underlying models. Thus, a simulation is a set of models and/or simulators representing operations or features of a system or an environment.

As technology evolves, military adoption will also follow to the extent that the value of the technology can demonstrate an improvement over current methods such as cost, safety, or speed. It must continually be forward thinking, innovative, and aggressive, both in understanding how warfare is evolving and in adapting training to meet those challenges.

What Is Training?

Training is one of the basic activities for any organisation; in particular, it has always represented one of the decisive factors for the success of the operations carried out for the armies of all ages.

Having well-trained military personnel is essential to be able to operate in the complex scenarios of modern warfare that require reactive skills and analysis capabilities that only trained individuals can have.

There are countless types of training ranging from individual theoretical training on specific topics to large theatre exercises involving thousands of people and vehicles in the complex and articulated operations in time and space.

It is therefore no coincidence that all the armies of the world invest huge resources in training. The evolution of training techniques and procedures must inevitably follow that of threats and at the same time the development of new operational concepts. The continuous updating of the training levels of military resources produced the famous motto: "Fight as you Train, Train as you Fight."

The U.S. military defines training as "instruction and applied exercises for acquiring and retaining Knowledge, Skills, Abilities, and Attitudes (KSAAs) necessary to complete specific tasks" [4].

Generally speaking, military training is divided into two broad categories: individual and collective. Individual training is exactly the training designed to develop individual skills. Collective training is designed to integrate trained individuals into a cohesive and effective team, either that team is a tank crew of four or an aircraft carrier crew of 5,000.

Training can be as small as an hour-long class for a four-person team on how to bandage a wound and as large as a multi-week joint exercise including tens of thousands of personnel and units from all services. The principal domains of training are: the **institutional domain**, which includes the various formal schools in each service; the **operational domain**, which includes training in units and on ships, whether at home station, deployed, or underway.

Another type of training is self-development: it is conducted by individuals to address the gaps they see in their own learning and (from a wider viewpoint) can be viewed as an education [4].

Simulation is the basis of the training and constitutes its essence; training-oriented simulation environments allow to train personnel in a safe, efficient, and economical way and to maintain training levels over time even for events that have a very low probability of occurring. Even simulation environments must, therefore, follow (and sometimes anticipate) the evolution of technologies and doctrines to best perform their tasks.

1.2.2 Decision Making of Commanders and Staff

Decision making has been defined and described in a myriad of ways, but basically it is a cognitive process by which some choice is made from a list of reasonable, potential options. The goal, of course, is to pick the "best" option from the available alternatives.

The typical complicating factor in decision making is uncertainty; that is, many aspects of the alternatives as well as the exact outcome of each prospective option may be unknown, unclear, or unpredictable [5].

Historically, a unit's success is directly related to the ability of the staff to execute the military decision-making process. Given the increased complexity of today's operational environment and the vast array of mission command systems and processes, integration and synchronisation of all activities associated with operations are increasingly difficult [6].

Military staff procedures have evolved since the late nineteenth century in an attempt to define a common process by which decisions are reached. While doctrine has been successful in providing a system for guiding the decision-making process, it has done little to address the uncertainty inherent in evaluating and selecting from potential courses of action. Complicating the situation is today's nearly unlimited access to vast quantities of information that may or may not need to be applied to a specific decision-making situation. Thus, while it would seem that more information is better, the fact is that having too much data can increase cognitive load and may result in overlooking other information that is more pertinent to the specific current circumstances. The challenge for the military intelligence analysis process is to enhance military decision making by providing timely, relevant, reliable information to commanders [5].

In the following we describe the different theories on the decision-making process and two viewpoints on how these theories are applied in the military domain are shown.

Theories on the Decision-Making Process

Describes relevant theory on (military) decision making to which support can be given:

- **Viewpoint 1:** technical/task-oriented (e.g., MDMP, OPP, etc.).
- **Viewpoint 2:** non-technical/skill-oriented (e.g., OODA, System 1 and 2, Cognitive biases).

Theoretical Approaches [7]

One may divide the many models in this field into two major currents and approaches:

- The **rational-philosophical current** relies on logic as its primary tool, i.e., calling for an analytical assessment, the best possible, of the strengths, weaknesses, opportunities, and risks. The rational current perceives the decision-making process as a logical analysis in order to identify the optimal alternative for action.
- The **cognitive-psychological current** relies on all cognitive processes of the human mind – analytical reasoning alongside intuition-based thought. This current sees the decision-making process as bringing the military leader to an awareness or sudden insight about the desired method of operation. The tools at work are cognitive, designed to create the natural conditions for the "eureka moment" while avoiding the pitfalls of human reasoning in general and reasoning under pressure in particular. As yet, neither current is fully grounded in comprehensively articulated theories, but research efforts are being invested in both.

1.2.2.1 Viewpoint 1

Mission planning has always been the major function of headquarters in the military decision-making process and has not always been carried out as efficiently as it should be.

In outline, the military planning process follows the steps summarised below, although this may vary across nations:

- Receipt of mission and mission analysis:
  - Briefing; and
  - Debriefing.
- COA development, analysis, comparison, and approval:
  - Wargaming for COA development;
  - COAA and comparison; and
  - Wargaming for Order enhancement.
- Orders production;
- Mission Rehearsal (MR); and
- Execution:
  - Assessment; and
  - Re-planning.

At the heart of any planning and execution process is the need to Plan, Refine, Execute and Evaluate (PREE) at both operational and tactical levels.

NATO and Nations have developed their military planning processes to support decision making at all levels of command. For example, the UK Army has developed three processes to support decision making, the US Army has one used at both the operational and tactical levels, and France has three that are used by their land forces.

The national processes are either at the operational or tactical level whereas the NATO process is used from strategic to operational levels of command. These are described in Table 1-1.

Table 1-1: Allied Military Decision-Making Processes.

Decision-Making Process	Nation	Utility
Operation Level		
Operational Estimate (OE)	UK	Operational (Campaign) Planning incorporating the Combined, Joint, Intra-government, intra-Agency, Multinational (CJIIM)
Comprehensive Operations Planning Directive (COPD)	NATO	Complex operational planning level incorporating the Combined, Joint, Intra-government, intra-Agency, Multinational (CJIIM)
Military Decision-Making Process (MDMP)	US	Operation and Tactical planning process
Operational Planning Process (OPP)	FR	Land Component Command with CJIIM context
Method for Planning Operations (MPO)	FR	Operational planning for national (unilateral) operations
Operational Planning Process (OPP)	CAN	Brigade Group level and above

Decision-Making Process	Nation	Utility
Tactical Level		
Tactical Estimate (TE)	UK	Planning for complex tactical problems, e.g., a brigade preparing for an intervention operation
Combat Estimate (CE)	UK	Short term tactical planning where the context of the mission is broadly understood and there is an emphasis on tempo of decision and action
Military Decision-Making Process (MDMP)	US	Operation and Tactical planning process
Méthode d'Elaboration d'une Decision Operationelle (MEDO)	FR	Tactical level used by Divisions, Tactical Forces (TFs) and Brigades (BGs)
Operational Planning Process (OPP)	CAN	The tactical or combat estimate – unit level and below

1.2.2.2 Viewpoint 2

Human decision making is a complex process with many factors that influence the process and its outcome. Although the theories on human decision making are evolving, there is a general distinction between two types of thinking related to decision making [8]. The first type (Type 1) is unconscious, rapid, automatic, intuitive, and heuristic-based using rules of thumbs and simplification based on previous experience – which is developed and honed through training.

The second type (Type 2) is conscious, slow, and deliberative and takes more mental effort [9].

Humans who make most decisions efficiently and effectively using the first rapid/intuitive type, are not always aware that they have applied that specific type. Humans have the tendency to perceive themselves as logical thinkers, which may explain the tendency to misjudge which type is being used and overestimate the frequency of applying Type 2. The use of Type 1, based on intuition, for decision making may be suitable in many situations especially when time is of the essence. However, it may also have negative effects caused for instance by cognitive biases, sleep deprivation or cognitive overload, focusing on a single minor event rather than the big picture, or when driven by emotion. When being unaware that a specific decision is made more on intuition instead of conscious reasoning using Type 2, these negative effects may be increased.

The following cognitive biases can be related to human decision making (both Type 1 and 2):

- Confirmation bias: the tendency to search for, interpret, focus on and remember information in a way that confirms one's preconceptions.
- Overconfidence bias – understanding the world:
  - Overestimation of one's actual performance;
  - Overplacement of one's performance relative to others; and
  - Overprecision in expressing unwarranted certainty in the accuracy of one's beliefs.
- Neglect of probability: illusion of certainty.
- Priming: the tendency to be influenced by what someone else has said to create preconceived idea.
- Status quo / default bias: the tendency to choose the default option over the other options.
- Loss aversion: the tendency to strongly prefer avoiding losses over acquiring gains.

- Availability heuristic: the tendency to assume that the examples which come to mind easily are also the most important or prevalent things.
- Survivorship bias: the tendency to study the survivors only (a non-representative sample).

The above facets of human decision making also apply to a military context. However, procedures and training offer a structured, formalised, and standardised approach typically aiming at the Type 2. Still the same disadvantage applies, and Type 2 decision making is more time consuming, cognitive biases still apply and personnel may still be unaware that (parts of) the decision and/or information filtering is actually conducted using a Type 1 approach. Decision support systems for military commanders have been suggested to overcome these vulnerabilities of human decision making, specifically in diverse and complex conflict situations with various technology and information in large quantities that need to be processed in real-time [10].

With the tendency of humans to perceive themselves as logical thinkers, combined with the current military training for a conscious Type 2 decision making approach, a pitfall may be to design a military decisions support system that solely focuses on Type 2 while pretending Type 1 does not exist. Type 1 still allows efficient and effective decision making and designing a system that utilises the advantages of this type of thinking and perhaps helps in recognising which type is applied and which cognitive biases are likely or even assist in going toward a desired most beneficiary state at certain moment may result in a better system and human-machine team. Some of these steps may be too far ahead but taking the human traits into consideration remains a necessity and first steps may be in revised training and/or training systems.

1.2.3 Cyber Security Aspects

Security aspects should be planned and addressed from the initial design phase, since it is much more difficult to address security (considering all perspectives and aspects) once deployment and implementation have occurred or even just started.

In addition, since the system architecture is likely to be based on a distributed and decentralised model – a service-oriented system (i.e., MSaaS) where the execution will be provided on distributed computing resources, based on a web/cloud-centric environment – cyber security aspects must be carefully considered.

There are numerous issues including but not limited to network, endpoint security, authentication, and access control topics to be considered when implementing a distributed simulation system. Traditional cyber security requirements and best practices provide guideline for the measures to be taken to ensure the confidentiality, integrity, and availability of the data. Just to list some examples:

- Access should be managed in order to ensure that only authorised clients can access or manipulate data, administrative privileges should be minimised, and administrative accounts should be only used when they are required.
- Authentication and encryption technologies to restrict who can access the server and to protect information transmitted should be periodically examined in order to determine the necessary security requirements.
- Appropriate security management practices are essential to operating and maintaining a secure environment: security practices include the identification of information system assets and the development, documentation, and implementation of policies, standards, procedures, and guidelines that help to ensure the confidentiality, integrity, and availability of system resources.

To ensure the security of the system and the supporting the entire infrastructure, the following practices are the standard reference for cyber security “as is” implementation (examples):

- Server and clients hardening;

- Configuration/change control and management;
- Risk assessment and management to identify potential weaknesses and vulnerabilities – (also performing regular tests);
- Patch and upgrade the operating system;
- Standardised software configurations tested and secured;
- Communication channels secured;
- Identification of contingency planning and continuity of operations – measures;
- Implementation of security monitoring solutions (e.g., log management, endpoint security, network security, etc.); and
- Definition and implementation of a Secure Software Development Life Cycle (SSDLC) to coordinate all the processes related to the creation of the software components.

In summary, the security of the infrastructure should be continuously maintained by configuring, protecting, and analysing log files and configuration, frequently backing up critical information, establishing and following procedures for recovering from compromise, testing, and applying patches in a timely manner, and testing security periodically.

In addition, there will be further cybersecurity aspects to consider as a result of increasing technological innovation and available computational resources and algorithms.

1.2.4 Volume of Interest for MSG-189

The spirit of the proposal lies precisely in offering an environment that is part of an ecosystem that follows the user from the beginning of his/her career to the stage of maximum experience without the need to continuously 'learn' the (new and different) system. This learning effort is very often in contrast with the real object of the IT tool, which should instead facilitate the work experience. Moreover, if you are an experienced user you can still have access to the lower level of information (e.g., to be able to brush-up, revision, getting technical information on a specific asset, etc.).

1.2.4.1 Action Dimension (Levels of Warfare/Operation)

In the light of the concepts described in previous paragraph, the dimension of "Action," related to the specific activity the user is doing, has been defined.

For the NMSG-189 the activity can be:

- **Training** to carry out a job at any level of intervention required (from the use of a piece of equipment to the development of a sophisticated action strategy);
- To **make a decision** either to elaborate a plan or in the course of action, as well as to be able to rehearse and analyse a mission.

Table 1-2 depicts a schematic representation of this concept.

Table 1-2: Training and Decision-Making Levels.

Technical	*Logistical*	*Tactical*	*Operational*	*Strategic*
Product/Service level		*Decision-Making level*		

Table 1-3 gives the meaning of each of the terms.

Table 1-3: Training and Decision-Making Levels Definitions.

	DEFINITION
Strategic	*The Strategic level is about high-level (national, international and theatre) policy-making and support, and relates directly to the outcome of a given conflict activity (e.g., war or emergency) as a whole* [11].
Operational	*The Operational level concerns the use of forces in a theatre of operations (civil or military) to gain an advantage over adverse conditions and thus achieve strategic objectives through the design, organisation and conduct of campaigns/major operations by making maximum use of the resilience of the environment of operation* [11].
Tactical	*The Tactical level converts the potential to act into success by means of decisions and actions that create gains within the zone of intervention. Tactics deal with the details of pursuing commitments and are highly sensitive to the changing environment of the field of action. Activities at the tactical level are the ways of achieving the objectives established at the operational level* [11].
Logistical	*Relating to the process of planning and organising to make sure that resources are in the places where they are needed, so that an activity or process happens effectively.*
Technical	*Relating to all those processes that allow resources to be available at full efficiency.*

1.2.4.2 Expertise Dimension (Theoretical, Procedural, Mission-Related, Strategic)

The "Expertise" dimension is linked to the level of training the trainee must reach. There is a certain relation between the level reached and the moment of training because, in general, theoretical training is done at the beginning of a training course while more complex experience, such as training to carry out a mission, is reserved for a person who already has more experience.

However, it is not uncommon that, for the same specific situation, the training may be better done after or at the same time as acquiring a certain degree of experience in the field.

To maintain a sequence while avoiding over-detailing the complexity of a training course, a sequential increase in education is provided in Table 1-4 and, for each level of development, the results in terms of maturity are addressed.

Table 1-4: The Expertise Dimension.

Training					
Theoretical	*Procedural*	*Mission Single*	*Mission Team*	*Mission Collective*	*Strategic*
Knowledge	*Skill*	*Competences*			

1.2.4.3 Life Cycle (Smart Acquisition, Support)

Modelling and Simulation (M&S) is a cross-domain and cross-lifecycle technology, i.e., it can play a role in a wide number of fields during the whole product/service existence.

In particular, it can be used to verify the effectiveness of a solution, explore new solutions if the current ones are not completely satisfactory and promote smart acquisition to decide which is the best choice to improve a solution for a defined or evolving requirement.

Table 1-5 describes a standard life cycle of a product/service where every step can be supported by some form of M&S related technology.

Table 1-5: Life Cycle.

Emergent requirements	Call for information-participation	System requirements definition	Contract definition	Initial design	System design	System integration	System qualification	Production, installation and commission	In field support and service
Acquisition		Contract		Development			Production		Support

This is a very large field and to limit its activity, the NMSG-189 will consider the steps concerning training and decision support. However, it is also advisable to add the CD&E process where reflections on gaps and new requirements induced by new real needs are often observed and better-defined during exercises.

In this respect the NATO CD&E study depicted in Figure 1-1 has performed specific work.

This process is located at any point in the operational life of the product/service when the actual activities are performed (Figure 1-2). It is at these times that limitations or shortcomings may be encountered or that a decision is made to improve some of the system's features, perhaps even defining new operational or usage concepts.

The extent of the study and thus the architecture comprising the intended functions, are summarised in Figure 1-3 where the area in light brown is the actual scope.

For example, a training activity for a maintenance technician who is starting his training course falls under the intersection of theoretical training, support, and logistics, while a high-level commander discussing a possible improvement of his equipment falls under strategic training, intelligent acquisition and strategic action.

Conversely, a pilot testing a new aircraft during the development phase does not fall within the area of interest of this study

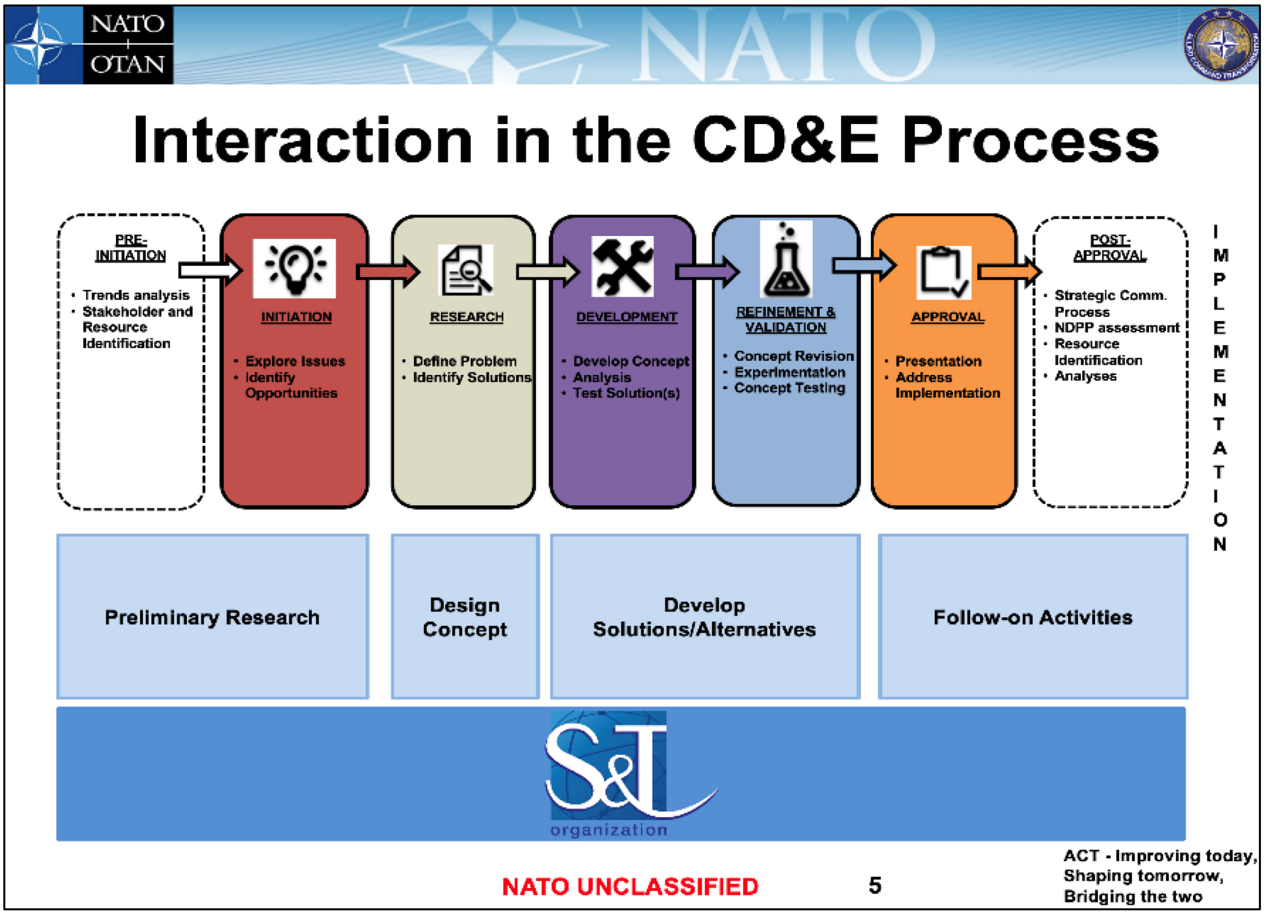

Figure 1-1: CD&E Process.

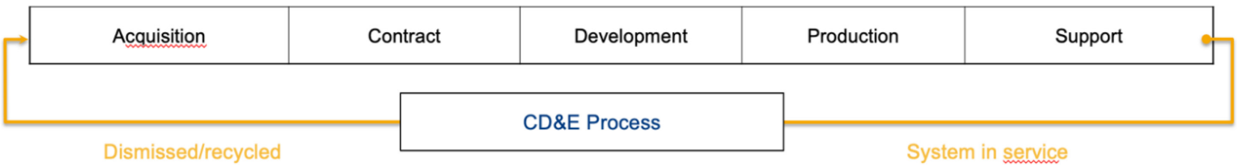

Figure 1-2: CD&E Process into the Life Cycle.

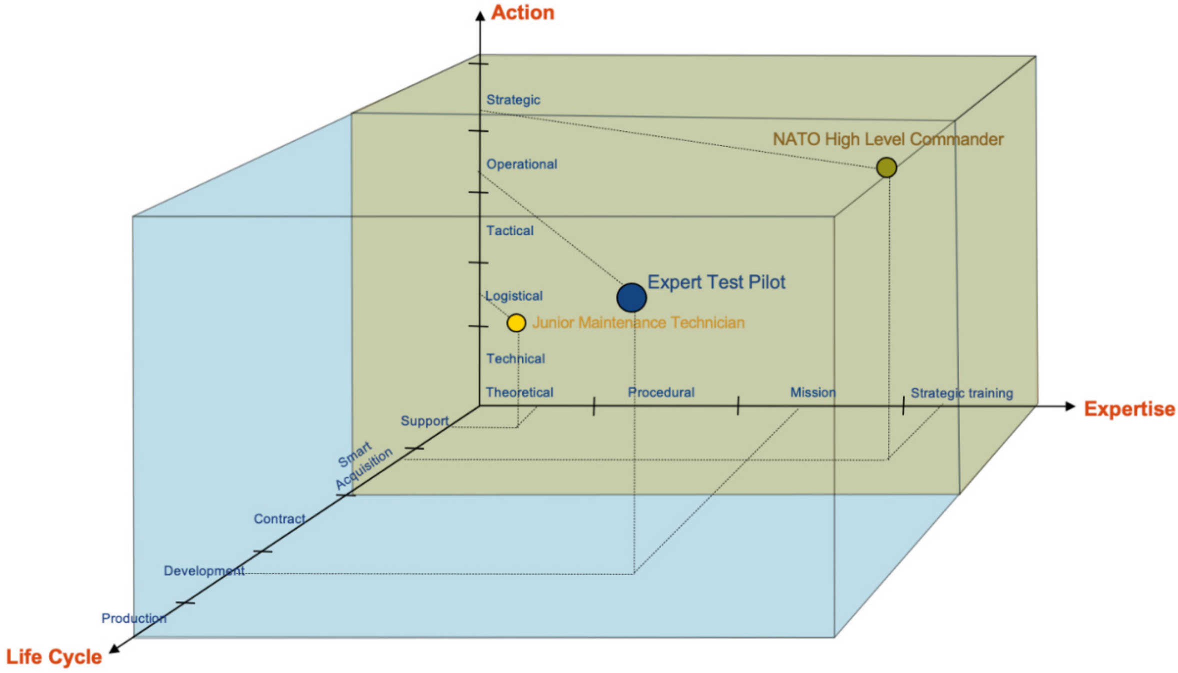

Figure 1-3: Volume of Interest for MSG-189.

1.3 REPORT FORMAT

This report is divided into:

- An Executive Summary that outlines the rationale of the ST, the main topics addressed, and activities carried out during the 1-year period of activities and the resulting conclusions and recommendations.
- The main body of the report that provides:
  - A chapter describing the Scope and Area of Interest of the MSG-189 ST activities;
  - A survey of state of the art of disruptive technologies that can be used to build the NMSG-189 Ecosystem;
  - A survey of state of the art related to Cyber Security Technologies;
  - An analysis of potential gaps in the field of military training and decision-making support domain;
  - A collection of requirements (legacy and new ones) to define the new System;
  - A definition of a Reference Architecture on which System would be built;
  - A list of products and services delivered by the System; and
  - Summary and Recommendations.
- A table of acronyms.
- References to the cited literature, report, standards, and websites.

Chapter 2 – BASIC TECHNOLOGIES AND STATE OF THE ART

2.1 INTRODUCTION

The Emerging Disruptive Technologies (EDTs) [12] are part of the technologies considered in this MSG-189 Specialist Team study for a future simulation system for training, decision making and CD&E support. However, based on national studies and SME proposals, other technologies have been included as well in the assessments.

Certain EDT technologies are considered fundamental for the study, for some it can be assumed that they are used in the definition of some ancillary and service functions of the proposed simulation system (e.g., cyber, communication, security, etc.), while others have little or no relevance for the system.

Artificial Intelligence (AI) and Big Data (BD) are among those disruptive technologies that will have a profound impact on the defence sector and will transform capability development and warfare itself in the long run. AI can be considered as an enabler and a force multiplier and its application in the military domain will certainly results in strategic advantages on the battlefield (e.g., remote-sensing, situational awareness, and a compressed decision-making loop).

The listed technological areas do not include (at least explicitly) all the technologies that are of interest to the simulation system. The field is too broad, and resources are limited. Technological areas such as:

- Immersive Technologies and Human Enhancement;
- Enhanced Communications and network Architecture;

and the technologies related to them, will also be treated in the document to complete the set of technologies that can be used in the system.

The following paragraphs discuss and review relevant technologies and their potential value in more detail. Chapter 7 will present a “holistic” view on how these technologies may be integrated and combined into a future system that leverages and exploits the advantages and new possibilities they bring to the table.

2.2 ARTIFICIAL INTELLIGENCE

2.2.1 Definition

The branch of computer science devoted to developing data processing systems that perform functions normally associated with human intelligence, such as reasoning, learning, and self-improvement [13].

Artificial Intelligence (AI) refers to the ability of machines to perform tasks that normally require human intelligence – for example, recognising patterns, learning from experience, drawing conclusions, making predictions, or taking action – whether digitally or as the smart software behind autonomous physical systems [14].

2.2.2 Current State and Use

Artificial Intelligence in Defence and Security

Artificial Intelligence (AI) emulates aspects of human cognition such as perception, reasoning, planning, and learning.

AI is able to autonomously perform tasks such as planning, understanding language, recognising objects and sounds, learning, and problem solving.

AI has been identified as the biggest technological challenge facing Alliance nations, with some calling it the most important technology ever invented.

AI has the potential of causing the biggest disruption in how we approach defence since the nuclear weapons age.

China's 2017 Next Generation AI Development Plan [15] describes AI as a strategic technology that has become a focus of international competition. China will seek to develop a core AI industry worth over $22 billion by 2020 and plans to firmly seize the strategic initiative and reach world-leading levels of AI investment by 2030. AI is at the central front in China and US struggle in military and economic leadership.

While lagging behind China and US, Russia is actively pursuing military AI applications. In 2018, Russia released a 10-point AI agenda for the development of military AI that include the establishment of an AI and Big Data consortium, a fund for Analytical Algorithm and Programs, a state-backed AI training and education program, a dedicated AI Laboratory, a National Centre for AI and created an equivalent to DARPA. Russia plans to create a robot unit consisting of robot weapons and soldiers by 2025.

NATO is developing its AI Strategy for Defence and Security along six principles that are: lawfulness, responsibility, and accountability, explainability and traceability, reliability, governability and human control, and bias mitigation.

Over the next 20 years, AI is expected to play a significant disruptive force through its effects on:

- Exploitation of increased digitalisation and the resulting availability of (very) large data sets, including publicly available data for system training and development;
- Widespread deployment and use in cyber-physical systems;
- Novel areas of application, driven by greater investment in and wider adoption of AI techniques;
- Decision making and optimal control (e.g., power systems, investment, etc.);
- Computation, such as advances in everywhere/edge computing, ubiquitous sensors, database design, developmental tools, cloud computing, new algorithmic approaches and using AI to bootstrap the development of AI; and
- Development of advanced large data analysis tools and computer vision.

Artificial Intelligence will transform warfare by providing the capability:

- To quickly synthesize complex, diverse, and evolving situations;
- To identify weak signals buried in data that might significantly influence the course of operations;
- To enable the necessary operational superiority by enabling commanders to focus on decision making;
- To improve our capacity to anticipate adversary's behaviour and optimise the response; and
- To augment training, resource management, maintenance, etc.

A Brief History of AI

Since its beginnings in the mid-1950s, AI has moved through three development cycles (Figure 2-1).

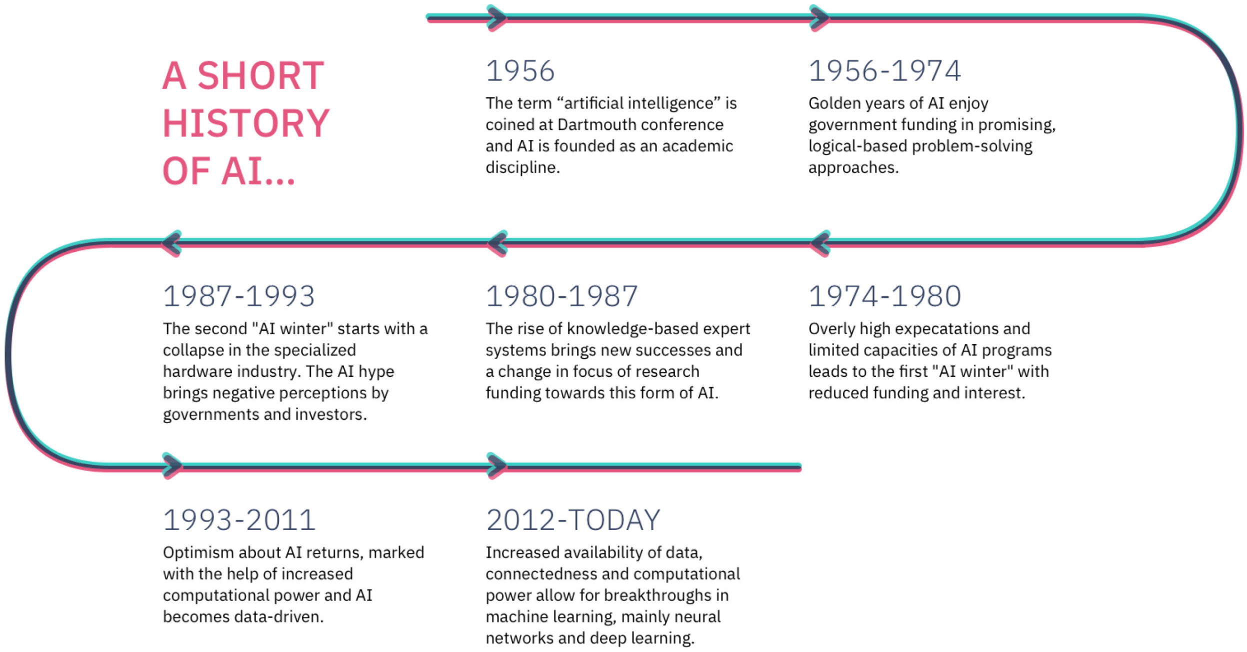

Figure 2-1: History of AI Development [16].

The initial period focused on rules-based approaches (decision trees, Boolean and fuzzy logic), e.g., expert systems.

The second cycle focused on the development and application of statistical methods (i.e., supervised, unsupervised and reinforcement learning). Such machine learning methods have been highly successful and underlie everything from e-mail spam filtering to internet web searches.

The third cycle of development focuses on the use of bio-inspired learning methods (neural networks, deep learning), with considerable success in the areas of sensing and perception.

AI Building Blocks

AI development and use reflect the environment in which it is conceived and developed (Figure 2-2). It will unconsciously embed the values, culture, beliefs of the society creating it and its policies and regulations. In an international context, it will have to be compliant with international laws and policies and agreed upon rules of engagement. Very specific issues are related to datasets which could either be collected or synthesized such as ownership, availability, security, biases. It is generally admitted that there will always be biases in datasets and that it is critical to know them in order for the decision maker to interpret the results accordingly. This is why it will be so critical to verify and validate that the AI is behaving and performing the way an end user wishes it to behave specifically in an interoperability context.

Platforms on which the AI is intended to be integrated drive requirements such as the architecture, standards, connectivity, and computing power.

Explainability of AI-enabled systems is still an area of active research. This will help in mitigating biases, increase trust and human-machine cooperation efficiency.

AI-enabled systems are vulnerable to intentional data corruption, all components must be properly secured.

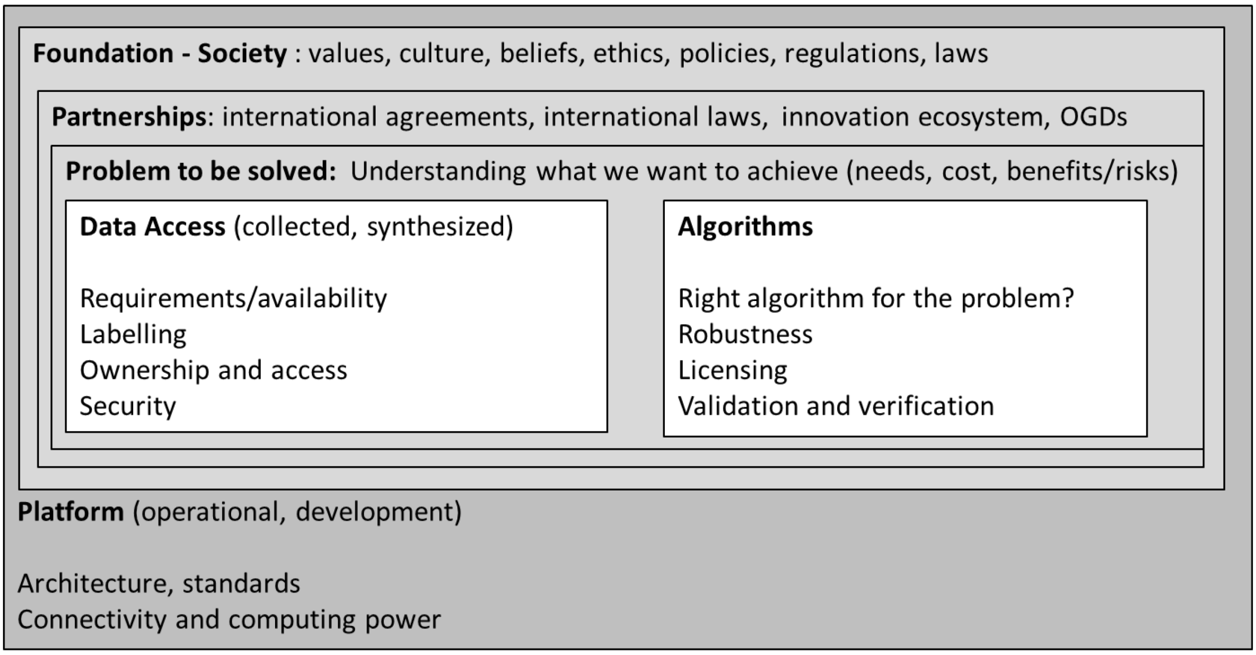

Figure 2-2: AI Building Blocks.

State of the Art

While major strides are continuing to be made in deep-learning methods, new research areas are being developed, including neuromorphic computing, which attempts to more accurately emulate the neural structure and operation of the human brain, and adversarial machine learning which seeks to understand how to confuse AI systems.

Another promising area is that of probabilistic computing, designed to deal with uncertainty, ambiguity, and contradiction in the natural world.

Research in these areas includes new machine and deep-learning methods focusing on the use of smaller training sets and explainability.

Another major area of R&D will be the development of new machine and deep-learning algorithms based on quantum information science and quantum computers.

Continued R&D into new and more general-purpose algorithms will be critical in maintaining the current momentum behind AI research and moving AI beyond its current practical limitations.

As of today, AI development is still at the level of what is called Narrow or Weak AI, meaning that it works in a limited context to perform specific, well-defined tasks. General or Strong AI defining an AI that can interpret its environment such that it can pick and choose what to learn the same way human would is a domain of active research but still decade away (Figure 2-3).

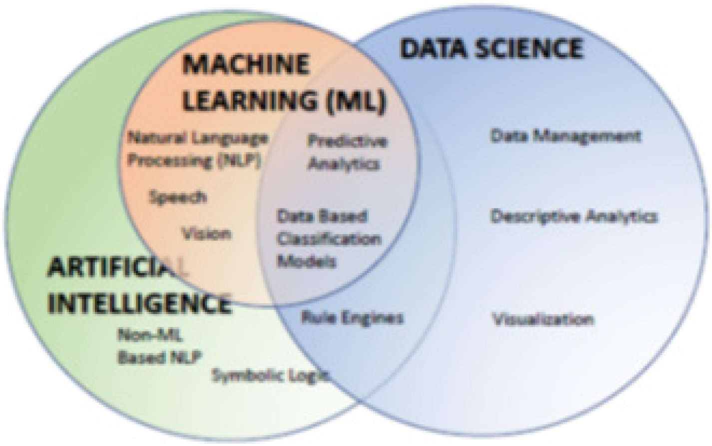

Figure 2-3: The Relationship Between AI, ML and Data Science [17].

Datasets

R&D opportunities exist to substantially expand the analysis of large data sets, including those associated with sensor data processing, fusion, and analysis.

Indeed, the expected continued rapid explosion in digitised data will make the use of AI (and its derivatives) even more useful and a practical necessity for Big Data and Advanced Analytics (BDAA). To put this in context, in 2020 the world is expected to produce 44 trillion gigabytes of digital data, with an annual growth rate expected to be approximately 60% [18]. Without AI, individuals and organisations will be challenged to turn this data glut into actionable knowledge.

This reliance on large quantities of data is both a strength and a weakness of AI. Data quality, in particular, is a critical issue, both for assessment and training. Reliance on large curated and filtered (training) datasets is an essential element of many AI algorithms and a significant contributor to the fragile nature of many AI applications. Research is being conducted on the development of more adaptable and efficient machine learning algorithms that will require less labelled data and are capable of making inferences with sparse or contradictory data while making them easier to train, more resilient to unpredictable real-world conditions and generalizable to new environments. In a similar vein, research is being conducted into the use of deceptive data and adversarial attack, whereby the injection of malicious data could be used to manipulate or provide an assessment of an AI system. As AI systems become ubiquitous and underpin decision making in complex systems-of-systems, the need to develop appropriate countermeasures and algorithmic resilience will be essential.

Development of symbiotic AI (i.e., humancentric), whereby humans and cognitive machines work together as trusted partners in a complex hybrid system, is a significant research challenge. Fundamental R&D is necessary to improve the understanding of human speech, extraction of semantic information inherent in a wide variety of media and responding to non-verbal aspects of communication. Such capabilities will also allow a more natural interaction and partnership but will also necessitate the integration of analogues to human perception in the physical (e.g., vision) and human domains (e.g., emotions), along with the development of machine common sense (i.e., the embedding of a priori knowledge. This will also necessitate the development of systems capable of asking questions, speculating, proposing multiple options, enhanced learning and explaining clearly the decision or deliberative process. As noted by DARPA [19]:

> *Enabling computing systems with such human-like intelligence is now of critical importance because the tempo of military operations in emerging domains exceeds that at which unaided humans can orient, understand, and act.*

Such human-machine symbiosis provides a more robust and potentially more effective construct leveraging the strengths of both human and machine.

Opportunities

Technologies related to AI are the basis of modern society. The use of AI in communications, commerce, banking, and medicine (just to name few sectors) have revolutionized the way we live, approach problems, and find solutions.

The TRLs related to these technologies are now at high levels (9) because the systems based on them are currently used in daily life (sometimes without we actually realize it).

In the military sphere, there exist, however, significant differences either in the geo-political domain or within the various armed forces and in various areas.

It is recognised that being an AI-enabled Armed Force will be a requirement for coalition deployment in the future (Figure 2-4).

AI technologies have been developed for the most part in the civil field; their use in the military field was borrowed from the corresponding civil applications.

Opportunities offered by AI and ML in the military domain include faster, automated analysis of data, speedier development of accurate models and simulations based on “training” systems vs manual modelling and programming.

- AI for Decision making: AI-enabled wargaming, AI-generated COAs, AI-enabled advisors (leveraging past operations and lessons learned);
- AI-enabled wargaming, AI-generated COAs, AI-enabled advisors (leveraging past operations and lessons learned);
- Predictive analysis, to be distinguished between short- and long-term predictions. While in the short term we generally look at the very local “neighbourhood” of an event, the long-term prediction implies opening the view to a more global context, which is way more complicated to handle. Tackling both short- and long-term would open new possibilities (thinking fast and slow, etc.),
- Pattern recognition, including video/audio/image analysis, object detection and tracking, video analytics. For example, AI & ML to interpret satellite imagery and generate 3D data for visualisation and planning. The system is trained by processing satellite images of known terrain data. An example of similar work is described in [20]. They process satellite imagery to generate and Unreal Engine environment. They expect to have a worldwide dataset by next year which they plan to charge $60k for, with 1-year support;
- Synthetic Data Generation, Generative Adversarial Neural Networks (GANs) (e.g., for data augmentation);
- Digital Twin (virtual/live synchronisation of environment, people, and equipment);
- Biometrics used to digitally identify a person’s identity by using the physical or behavioural human characteristic. It is crucial to identify the person correctly in order to give access to systems, data, devices and locations. Voice recognition, fingerprint, iris recognition, facial recognition, typing cadence recognition, retina scanning, are some of the techniques utilized in biometry. The advances in the deep learning have boosted also the performance of biometry applications. To prevent collateral damages and securing civilians, military applications of biometrics is a promising field.

Figure 2-4: AI Future Applications in Military Domain [21].

Gaps

The following items are indicative for areas where more research is required for:

- Explainable AI (trust);
- Lack of (validated) Training data;
- Poisoned data;
- Understanding and addressing Biases in Data;
- Computational Power;
- Adversarial Attack detection and countering;
- Reinforcement Learning (e.g., for learning tactical Decision Making);
- Decision Intelligence (augmenting data science with decision-theory);
- Knowledge Graphs (e.g., for Situational Awareness modelling);
- Hybrid AI (uniting symbol/sub-symbolic approaches);
- AI for decision making:
    - Behaviour Trees for decision making [22];

- AI in a wider sense (inputs, enablers for decision making):
  - Sensor fusion, and detection of suspicious activities with AI from multi-sensory data feed;
  - Speech recognition and synthesis;
  - AI-based 3d rendering and simulation modelling;
  - Rapid terrain generation;
- Generative Adversarial Neural Networks (GAN) for automatic generation of new data/scenarios and Graph Neural Networks (GNN) useful for learning the behaviour of complex systems.

2.2.3 Machine Learning

Definition

Machine Learning (ML) is the process by which computer algorithms can improve automatically through experience and by the use of data. ML algorithms build a model based on sample data, known as "training data," in order to make predictions or decisions without being explicitly programmed to do so [23].

Machine learning algorithms can be categorised into the following classes:

- **Supervised Learning:** algorithms that can apply what has been learned in the past to new data using labelled examples to predict future events. Starting with a known training dataset, the learning algorithm infers a function that enables predicting output based on provided input values.

- **Unsupervised Learning:** a learning approach that does not require the presence of labelled data. It studies how systems can infer a function to describe a hidden structure from unlabelled data. The algorithm does not figure out the right output, but it explores the data and can draw inferences from datasets to describe hidden structures from unlabelled data. It has a high potential to increase the performance of the current supervised learning tasks thanks to the increase in data scale. Nevertheless, good concepts should be proposed in the training procedure.

- **Semi-Supervised Learning:** fall somewhere in between supervised and unsupervised learning in that both labelled and unlabelled data is used for training – typically a small amount of labelled data and a large amount of unlabelled data. The systems that use this method are able to considerably improve learning accuracy.

- **Reinforcement Learning:** is a learning method that interacts with its environment by producing actions and discovers errors or rewards. Trial and error search and delayed reward are the most relevant characteristics of reinforcement learning. This method allows machines and software agents to automatically determine the ideal behaviour within a specific context in order to maximise its performance.

The above main classes have many subclasses which are not discussed all here. One example though is weak supervised learning which is a variant that deals with data that contains noisy labels such as the hashtags of Twitter or Instagram or with processing of unlabelled data and create labels from it.

Current State and Use

Examples of the above learning types are:

- Unsupervised Learning: Example contains the pre-training of BERT in NLP tasks [24], the training for optical flow tasks [25] and the training for 3D Pose Estimation tasks [26].

- Semi-Supervised Learning: a learning that combines a small amount of labelled data and huge amount of unlabelled data. Therefore, it is between supervised and unsupervised learning.
- Weak Supervised Learning: a learning from a data that contains noisy labels such as the hashtags of Twitter or Instagram or processing unlabelled data and create labels from it. Example: IG65M [27] dataset for action recognition.
- Reinforcement Learning: utilized in robot controls and computer-generated forces which can be utilized in military simulation applications. It can be utilized to control UAVs and autonomous vehicles.

2.2.3.1 Deep Learning

Definition

Deep learning is a class of machine learning algorithms that uses multiple layers to progressively extract higher level features from the raw input. These layers are usually represented within neural networks and the term “deep” refers to the number of layers through which the data is transformed [28].

- Deep Learning on Graph Networks: Graph-based techniques are required in order to model the physics system (e.g., learn molecular fingerprints, predict the protein interface, and classify diseases). Learning from unstructured data such as texts and images, reasoning on structures such as the sentence dependency tree and the scene graph of images are important research subjects that also require graphical reasoning models.
  - In many realistic settings, data is organised in irregular data structures (Figure 2-5). Machine learning techniques should be tailored to capture these irregularities. Mainly there are two main motivations in this field: 1) Estimating the information about missing nodes; and 2) Estimating the information about a completely new network, when we learn about other networks. The applications are possibly ubiquitous, but as an example we may consider information flowing from a war-zone as a potential application to predict unknown information based on the intelligence obtained.

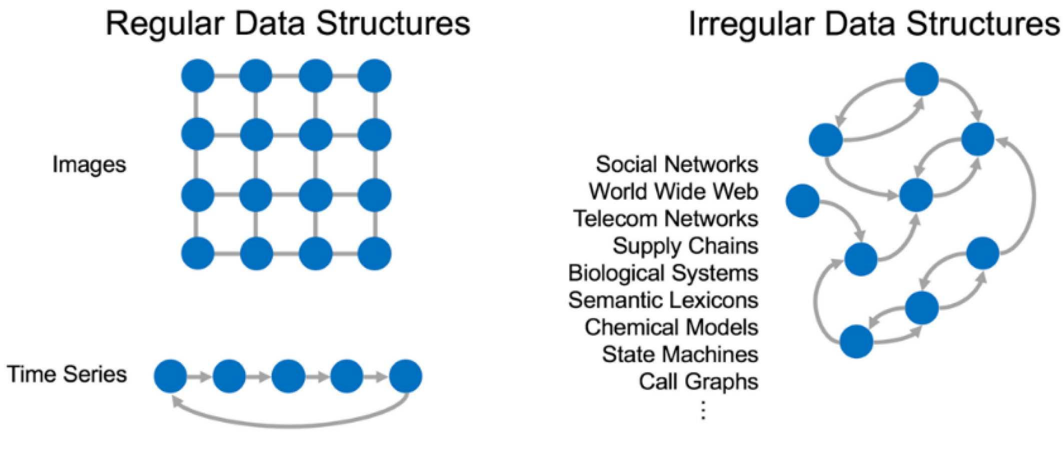

Figure 2-5: Regular and Irregular Data Structures [29].

In recent years, adversarial attacks have become one of the cornerstones in the analysis of machine learning applications. Adversarial attack can be defined as misguiding neural networks with small perturbations. An adversarial example is demonstrated in Figure 2-6. Although a neural network can classify correctly the panda image with 57.7% confidence, a perturbation on the image can make the neural network classify almost the same image as gibbon with 99.3%.

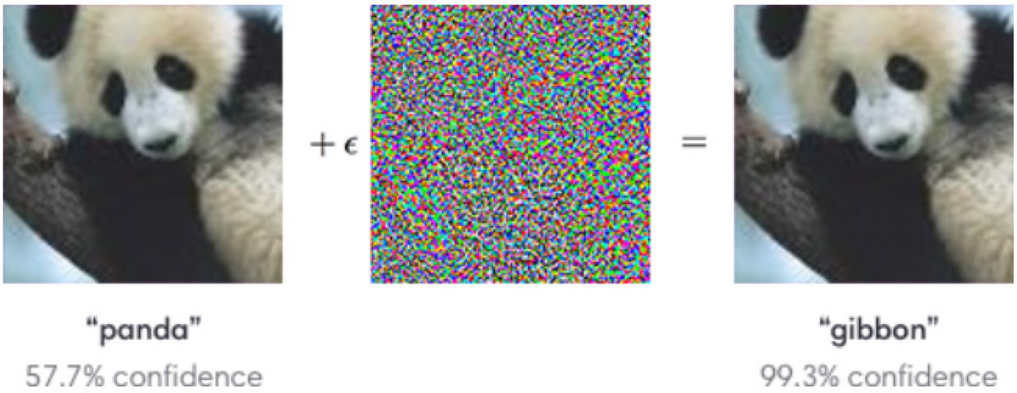

Figure 2-6: DL – An Example of Adversarial Attack.

Because of problems such as adversarial attack, the concept of explainable AI (XAI) has increased in popularity. In military applications, decreasing the number of false alarms is of paramount importance. Therefore, explainable AI focuses on the rationale behind the neural network and characterises the weakness and strengths of it. This concept tries to make the neural network more understandable for the end user by utilising techniques of human-machine interaction. The demonstration for XAI is shown in Figure 2-7.

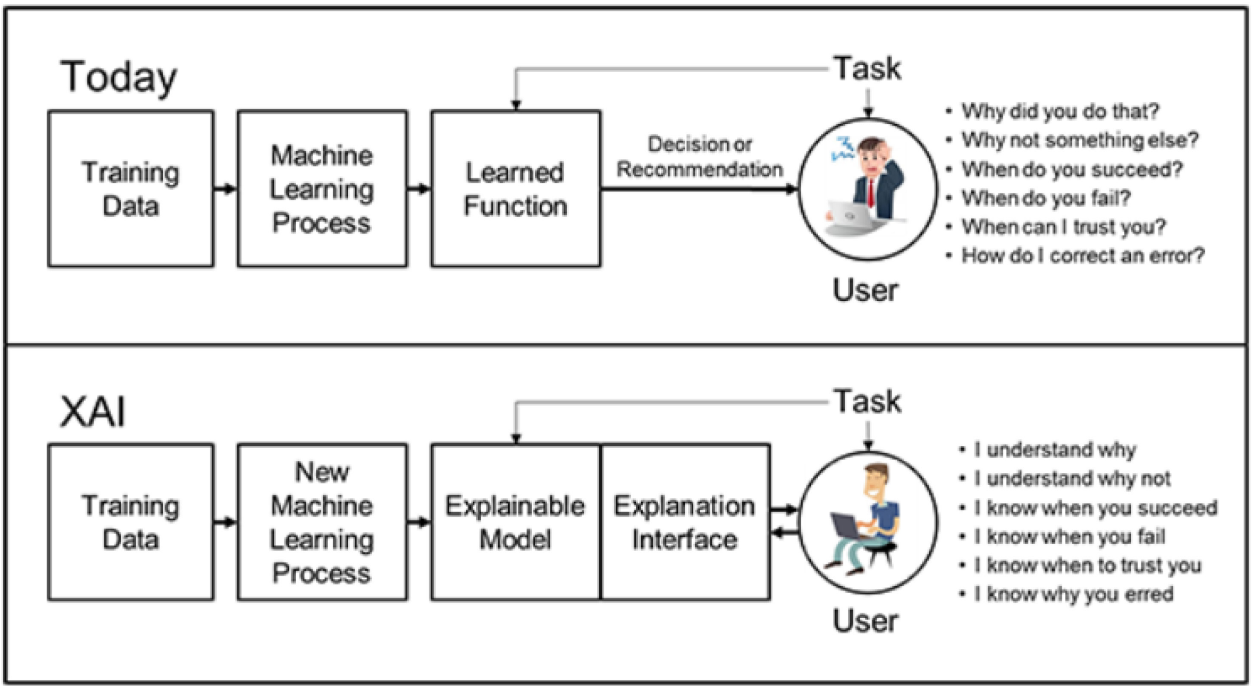

Figure 2-7: Explainable AI Concept.

2.2.4 Constructive Entities Based on AI (aka Semi-Autonomous Forces)

Definition

Constructive entities based on AI are a modern subclass of Computer-Generated Forces (CGF) that can be broadly defined as follows: "A generic term used to refer to computer representations of entities in simulations which attempts to model human behaviour sufficiently so that the forces will take some actions automatically (without requiring man-in-the-loop interaction)" [30].

A constructive entity must fulfil at least the following main requirements:

- Realism, to generate physical models and appearances of objects that comply with real-world observations;
- Autonomous operation, to ensure reactive and deliberate action, without human intervention; and
- Reconfigurability, in terms of flexible architecture, capable of being adapted to different simulation contexts, as well as being integrated with other simulation tools and assets.

As a general principle, it is expected that such entities are designed to mimic human behaviour by means of AI-based solutions, shifting from a deterministic finite-state approach to stochastic-based inference.

CGF offer support in different application areas; examples can include automated opposing forces (training and exercise), closed simulation systems (defence planning), Decision Support Tools (operations), and virtual environments (acquisition and procurement).

Current State and Use

Constructive entities are designed to support training, experimentation, and exercises. They are normally used for training, both in constructive and virtual systems. The most recent developments have seen also an increasing integration with live environments.

This technology provides building blocks when, as is normally the case, more than one entity (friend or foe) is required to be deployed in the simulated scenario, but it is not desired or not possible to delegate this task to human operators either for performance reasons (e.g., sufficiently skilled personnel not available) or for economic reasons.

In addition to representing entities such as platforms (ships, aircraft, land vehicles, etc.) or individual human characters, SAF/CGF systems can also be natural event generators (earthquakes, fires, floods, etc.), exploiting also interfaces with integrated human-in-the-loop simulators.

As far as agent modelling is concerned, the literature reports an increasing capability of algorithms to learn and infer human behaviours with good generalization capabilities, especially in terms of motion patterns and events generation. In particular, elements like sociality, communication and interaction with other agents, environmental sensing, description, and situational awareness, are among the most sought after features of an AI-based entity modelling tool. Two main modelling concepts are:

1) Learning from experience like reinforcement-based learning which doesn't use explicit data; and
2) A concept such as Data-Driven Behaviour Modelling (DDBM) [31] which uses example data, e.g., from exercises to mimic behaviour.

Behaviour models controlling units' behaviour in a realistic way with AI, however, need different types of world models than the currently available 3D world models normally used in simulators. Features of the environment, such as obstacle overlays or avenues of approach maps, are required rather than pure 3D representations in order to properly be able to reason and act in the 3D environment.

Opportunities

An important feature of the technology used in AI-based constructive entity modelling, when supported by behaviour triggered by AI algorithms, is that it adds significant realism to both training and what-if decision support sessions.

In these contexts, "realistic" means decreasing the predictability of stereotypical behaviour that leads people to think they can always respond in the same way to solve a given situation, while real-world threats are unpredictable (and even take advantage of predictability).

Realism is therefore fundamental to quality training, maximising the capability of the technology used, the ability to recognise and react to threat exposure. Realism also tests the effectiveness of countermeasures taken appropriately. Therefore, the current trend is to move from customised behaviour scripts to sophisticated AI software, as a tailored behavioural environment that also takes into account the dynamics of the various actors in the scenario.

Gaps

The opportunity presented above is, at the same time, the feature most in demand where effective implementation is not yet in place. Actually, one of the most complex things to achieve, is the contextual integration of SAF/GFC within the scenario. Constructive forces must be able to be dependent on the specific context in which they are used (virtual/constructive, live/constructive, live/virtual/constructive).

On the other hand, the behaviour of the single entities must be adequate: both realistic (i.e., without too many stereotyped forced behaviours) and appropriate/useful for the specific exercise or event avoiding any over- or under-sophisticated behaviour (e.g., in the case of basic instruction avoiding complicated information or, in a complex scenario to be exercised too simplified challenges). Therefore, the system must be "Learner-aware" (adaptation based on training needs/requirements) and "Exercise-aware" (adaptation based on constraints and conditions).

In practice, since it is normal for specific contexts of use not to be known in advance, they cannot be programmed in advance.

Maximum flexibility and adaptation at run-time are needed.

Without these features (flexibility and adaptation), the use of constructive forces will be relegated to a secondary role, still requiring the presence of human operators to represent the enemy or adverse operating conditions in a realistic manner.

In addition, looking at the literature on human behaviour analysis and pedestrian dynamics, most of the research has been currently conducted focusing on individuals, acting in the scene as single entities that sense the presence of the surrounding elements. The goal, however, is mostly to avoid collisions and ensure a smooth completion of the individual's action. This is indeed a very strong limitation, as sociality is discarded in most of its aspects. In fact, when dealing with crowds, or more in general with groups sharing similar goals (in terms of destination points, but also as mission objectives), the goals themselves can be considered as driving forces motivating the group, which could impact the outcome of the action. It is therefore necessary to enrich the AI-based models with additional awareness modules, which go beyond the adoption of so-called attention modules, and instead incorporate additional features, which are goal oriented and more affine to the perception and awareness.

2.3 BIG DATA AND ADVANCED ANALYTICS (BDAA)

2.3.1 Big Data

Definition

Big Data describes data that presents significant volume, velocity, variety, veracity, and visualisation challenges. Increased digitalisation, a proliferation of new sensors, new communication modes, the internet-of-things and virtualisation of socio-cognitive spaces (e.g., social media) have contributed significantly to the development of Big Data. [14].

Advanced (Data) Analytics describes advanced analytical methods for making sense of and visualising large volumes of information. These techniques span a wide range of methods drawn from research areas across the data and decision sciences, including artificial intelligence, optimisation, Modelling and Simulation (M&S), human factors engineering and operational research [14].

Current State and Use

BDAA (Big Data and Advanced Analytics) is a direct outgrowth of our increasingly digital and virtual world, and the subsequent need to make sense of the resulting information deluge. In particular, analytics is the process of generating understanding (e.g., through mathematical analysis and visualisation) and providing insights into current system states (descriptive) or future system states (predictive).

The analyst is often faced with data having significant volume, velocity, variety, veracity, or visualisation challenges. Vast amounts of data available throughout the future physical, human or information battle-spaces will enable analytics to deliver insights and predictions, provide real-time decision support, and highlight early indicators of success and warnings of crises.

Increased use of predictive analytics and M&S will enable decision makers to exceed their cognitive limits while improving consideration, interdependencies, in-transparencies, and temporal dynamics.

In the end this will allow decision makers to better understand the potential impact of their decisions and adjust plans accordingly. Many aspects of BDAA are well developed and, while it is and will continue to be highly disruptive in nature, some have questioned whether it is truly an emergent technology at this time.

BDAA is understood to encompass four essential components:

1) Collection (sensors).
2) Communication.
3) Analysis.
4) Decision making.

The 5Vs (volume, velocity, variety, veracity, and visualisation) describe the essential challenge of BDAA: how to make sense of large amounts of nonhomogeneous data coming too fast, and of potentially dubious authenticity and accuracy. BDAA covers the human (social media, bioinformatics, etc.), physical (sensors) and information (cyber, analysis, etc.) domains.

BDAA is a foundational technology and, as such, understanding its projected development is a critical step in understanding other EDTs. From a technology watch perspective, BDAA will be enabled by S&T developments in a variety of areas, which include: exploitation of human signatures; modelling and simulation for social media; modular multi-sensor fusion engines; provision and discovery of M&S tools and services in the cloud; visual analytics; decision support and planning support with M&S in the battlefield; virtual mission areas; distributed ledger technologies (e.g., blockchain); cognitive sensing; compressive sensing; computational imaging; deep learning; electric-and magnetic-field sensing; photonic integrated circuits; sensing sources data fusion; swarm centric systems; and, wideband telecommunications

Sensors are a critical enabler of BDAA. Sensors provide the data in the physical domain, and increasingly in the human domain. Ubiquitous sensing or sensors everywhere will be significantly enabled by the growth of 5G communication and the Internet-Of-Things (IoT). The concept of sensors everywhere refers to the ability to detect and track any object or phenomenon from a distance by processing data acquired from high tech, low tech, active and passive sensors. Effectively everything will be a sensor, and every sensor will be networked. Military applications will be wide-ranging, including the development of a multi-domain common operating picture, large scale underwater sensor mesh networks, exploitation and weaponizing of social media, automated logistics planning, autonomous systems, and integrated soldier systems. While sensor technologies are expected to evolve to support greater precision and accuracy, the most disruptive development will be the combination of further miniaturisation, reduced costs, novel (3D/4D) manufacturing and the sheer volume and wide distribution of sensors in the military sphere. Advances in materials technology also promise future sensors at the molecular, nano or quantum scale.

Gaps

In some potential application areas for BDAA data availability is however a challenge: it will take too long or is perhaps too difficult to collect data from a sufficiently broad range of scenarios. Simulation may be used to generate data in those cases. Examples in the civilian world where data is generated through simulations are validation or training of algorithms for autonomously driving vehicles. Companies such as Tesla are using simulations to train their algorithms on potential accident situations that occur rarely in the real world and it thus challenging to collect actual data.

Decision-making support for military planning could also be considered an area where BD availability may be an issue and simulation can come to the aid.

Opportunities

Developments in BDAA S&T are driven by massive commercial investments, as well as the availability of publicly available training data sets and tools for algorithm development and testing. Many Alliance nations have made significant BDAA investments in both civilian and military environments.

NATO will, therefore, be able to leverage these investments, while extending, adapting, and integrating them into NATO processes and operations. Continued investment in enabling capabilities, R&D collaboration and common standards and policies for data collection, curation and management will be necessary to ensure the successful integration of BDAA into the Alliance enterprise and operations. Potential legal, commercial and IP issues may provide additional challenges to the successful use of BDAA in a NATO context. Such challenges include introducing unanticipated vulnerabilities, limited configuration control and a lack of explainability.

2.3.2 Social Media

Definition

The increased virtualisation of social and individual interactions has contributed dramatically to the availability of social and personal data. One aspect of this virtualisation, Social Media, refers to the full range of internet-based and mobile communications where users participate in online shared exchanges and contribute user-related content or participate in online communities of mutual interest [14].

Current Use

Its applications in defence and security include population surveillance, sentiment analysis, knowledge and information sharing, low-cost means to stay in touch with families and strategic communications. Social media content continuously grows with ever-increasing rate but struggles to deal with issues of veracity and value. DARPA, in particular, continues to explore the implications of social media in such areas as linguistic cues; patterns of information flow [19]; topic trend analysis; narrative structure analysis; sentiment detection and opinion mining; meme-tracking across communities; graph analytics/probabilistic reasoning; pattern detection; cultural narratives; inducing identities; modelling emergent communities; trust analytics; network dynamics modelling; automated content generation; bots in social media; and, crowd-sourcing. As social media reaches more corners of society, it increasingly enables significant and subtle influences on the expression of collective political and social power. The technology has already demonstrated the potential to alter the nature of political and social discourse leading to new, rapid, and decisive mobilisation of populations at the right place and the right time to achieve political and social objectives. Similarly, data collection in the social sphere allows an unprecedented understanding of human social behaviour and group dynamics.

BDAA is being enabled in no small measure by ubiquitous computing, which is computing anywhere, anytime and on any device. Integrated with military mobile networks and mission cloud computing, ubiquitous computing has the potential to provide real-time decision support to the individual soldier at all times and all places. Such mesh networks of connected devices will allow BLUE forces to leverage and exploit distributed data structures and cloud computing services. It also encompasses software-driven functionality, with the ability to process incoming data at the sensor before transmission, and exploits advances in encryption that will enable assured information transfer across a network.

Opportunities

Social media provides a free and continuously updated source of grassroots data, spontaneously generated by large user communities and rapidly reacting to any important event happening at the local or global level. As such, social media may be used to integrate 'official' sources of information, to achieve an early and more accurate understanding of widespread opinions and sentiments, but also to detect events that have a significant impact on the population at some time-space coordinates.

Social media should also be used as a way to trigger the attention of individuals and communities, drive opinions and stimulate discussions. This is both an opportunity and a threat, and in the last case should be carefully analysed and understood.

Gaps

The increasingly widespread and pervasive dissemination of social media and the use of the services made available in the most varied areas is a challenge for all organisations. The management of the cultural and anthropological changes that technologies related to social media are able to create or amplify will be an epochal challenge that in the coming decades will see public and private organisations engaged in the constant effort to control the new cultural and social pressures and prevent or contrast the resulting risks and improper use. It is also unthinkable that these institutions (governments, financial institutions, armed forces, etc.) can maintain their organisation and use current processes, methodologies, and tools; they too will be forced to evolve in order to integrate with the dictates proposed by social media, use their tools and deeply understand the mechanisms that regulate them. There are many aspects to take into consideration and the areas of application related to social media; among the most important are:

- Multi-language, multi-cultural natural language processing;
- Validation of social contents trustworthiness; and
- Real-time analysis of huge quantity of information.

2.3.3 Predictive Analysis

Definition

Predictive analysis refers to the capability of an autonomous system to predict future events, given one or more past observations [32].

According to the available literature, the predictive analysis process can be considered as a continuous learning mechanism, in which the past data is fed in the prediction model. Each prediction is assessed, and the acquired knowledge is then exploited to further refine the learned model.

As a first step, a basic set of data must be collected. This information, suitably filtered and pre-processed, constitutes the starting point to check whether it is possible to discover useful information that can be used to train an automatic system to make the predictions. The following step implies the creation of the model, which starts from the statistical information extracted from the data and constructs the learning model. Once the model is learned, the deployment phase takes place. It is at this point that the incoming data is processed in order to infer the next state of the system. This might include both regular and anomalous events, possibly indicating a quantitative metric to estimate the corresponding likelihood. Predictive analysis systems can work as single or multiple outputs. In the first case, the goal is to provide information about the most likely event, often based on majority voting. On the contrary, in case of multi-label approaches, the probability of a certain event being verified can be chosen among a number of candidates. This can contribute to making the overall approach more robust, by taking into account longer time series and constructing graph-like decision trees.

In predictive analysis, the analysis of the time series is particularly relevant. In fact, the whole architecture can be seen as circular, where the analysed data can indeed contribute to the refinement of the model. This is particularly useful if the initial training data is scarce or poorly labelled; this allows the model parameters to be tuned, verifying the initial hypotheses in a supervised or weakly supervised manner. A general-purpose representation of the steps described above is shown in Figure 2-8.

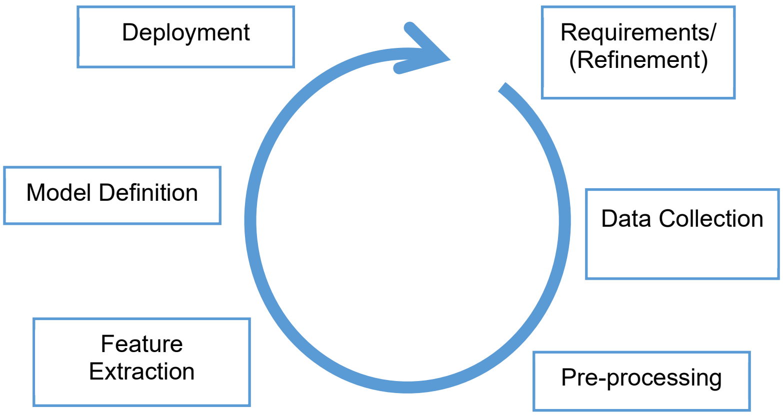

Figure 2-8: Predictive Analysis Cycle.

Current Use

Predictive analysis is currently adopted in a large number of application scenarios, and it benefits from the tools and algorithms studied and developed in various disciplines, including machine learning, artificial intelligence, data science, data mining, statistics. In particular, the objective of predictive analysis is to train a system to recognise and uncover patterns or behaviours within structured and unstructured data. While structured data generally deal with annotated and organised pieces of information, unstructured data mostly refer to streams or data flows, such as video streams, voice calls, which need to be processed to perform feature extraction.

Predictive analysis has seen a growing interest in research and industry especially in the field of maintenance, to assess the risk of failures of equipment and infrastructures.

Similarly, risk assessment has been adopted in other domains, including social and economic trends, as well as to monitor and make forecasts about the evolution of global phenomena like the COVID-19 pandemic. This is a clear example, where the combination of structured information (people's age, clinical records), has to be analysed in conjunction with unstructured information that models highly unpredictable and non-deterministic events, represented, for example, by the availability of medical supplies, the overall behaviour of people in respecting the contentions.

Opportunities

In the domain of modelling and simulation, predictive analysis can have multiple benefits. In fact, it can be considered as a valuable asset for addressing a diversified set of goals:

- With reference to the domain of industrial inspection and maintenance, it can serve as a tool to inform about the risk of damage to equipment and infrastructures, which might cause service interruptions or malfunctioning.
- In training sessions (driving, piloting), predictive analysis can be adopted in risk assessment, in the presence of potentially dangerous manoeuvres, wrong use of resources, inappropriate decisions that could lead to mission-critical failures.
- In military training, a predictive system could be adopted in the development of course of action, planning, assess situational awareness.

Gaps

While predictive analysis can be of great help in making forecasts about the evolution of a system and highlighting relevant events, one of the main limitations in its adoption is the availability of a sufficient amount of data, necessary to train a prediction model. In fact, although historical data is of great help and is a fundamental element in constructing a solid baseline for the automatic analysis, it often lacks a sufficient number of samples suitable for the detection of anomalous events. As an example, in professional equipment malfunctioning are rare events, occurring only in presence of non-adequate maintenance, and sometimes also due to human errors. Rare and anomalous events are precious sources of information, and this gap can be partially filled by the use of so-called digital twins, namely simulation models capable of resembling the behaviour of a real apparatus/equipment/software.

When talking about predictive analysis, it is assumed that the available database is secure, consistent, and its integrity is preserved. However, the procedures required for storing, transmitting, and processing information might suffer the presence of external security breaches at different levels, which could lead to data forging and manipulation. Such attacks could significantly hinder the performances of a prediction module.

2.3.4 Data Science

Definition

Data Science provides meaningful information by using various computational and statistical methods to analyse and extract knowledge from large amounts of data or otherwise complex, less structured data. On the basis of the results of the analysis, decisions can then be made on the interpretation of a phenomenon or on the behaviour to adopt in certain circumstances.

For this reason, data science is also called data-driven science and is based on a multidisciplinary approach linked to Big Data/Data Mining and machine learning, as well as to traditional fields of mathematics and statistics and information science [33].

Data Science should not be confused with Data Analytics. They are both used for the understanding of large amounts of data, but whereas analytics is mostly used to understand what happened to a certain phenomenon in the past, data science aims at developing models that can be used to assess and provide insight into *what may happen in the (more or less) near future*.

Current State and Use

Data Science is currently applied to extract usable knowledge from large volumes of data that are increasingly collected through different types of activities especially, but not only, through network interactions and the use of different types of sensors with digital output and thus easily stored and replicated. Through data science, these are prepared for subsequent analysis, advanced processing, and presentation of the results to recognise configurations/patterns, elaborate possible models for further analysis and comparisons and be able to extract information and conclusions at a higher level of abstraction than simple statistical analysis.

Data Science is a multidisciplinary approach not normally required in traditional data analysis as it requires considerable specialisation and highly experienced staff to achieve extremely sophisticated analyses. It requires computer skills, mathematical skills, statistical skills, artificial intelligence skills to highlight only the most important ones, which are then complemented by the domain skills needed for the specific field being examined. The different stages of a data science analysis include at least the following:

- Prepare data for specific types of processing: organising any cleaning and types of aggregation without this manipulation compromising the final result.
- Extract meaning from massive aggregations of data using predictive analytics and artificial intelligence (including machine learning and deep-learning methodologies).
- Use a wide range of tools and techniques to evaluate and prepare data – everything from SQL and data mining to data integration methods.
- Validate through scientifically designed tests and experiments the results obtained.
- Present as clearly as possible (through diagrams, charts, narratives, etc.) the meaning of the results based on that data to stakeholders (at different levels of knowledge and technical expertise) and to decision makers.

Opportunities

Through the collection of aggregated data from various agencies and sources (e.g., collection and analysis of “social” messaging), one is able to support various activities in both military and security fields. However, access to this data is often challenging.

One of the most promising applications is being able to predict and thus counter illegal activities or attacks that follow recurrent patterns. An example could be the operational methods of asymmetric forces in the territory or even the possibility of predicting the positioning of Improvised Explosive Devices (IED).

Another example of civilian, but also highly military, applications are electronic medical records, which allow an up-to-date analysis of the health status of a population and the possibility of identifying problems before they arise unexpectedly (see the recent decision of the US Defence Health Agency to use the medical records of military personnel to monitor the health status of troops).

The same kind of approach can be used for many logistical situations (arsenals, status of equipment and facilities).

This information may, for example, be vital in making informed decisions on mission readiness. It may also be important in recognising personnel for special training missions or monitoring the readiness of equipment or its obsolescence for certain missions or recognising its usability for other types of operations.

These examples can easily be transferred to the field of training.

All the study monitoring data, which are now beginning to be readily available because they are digital, can be used to help define which teaching strategies might be best for a given population of students or for a given subject.

They can help in understanding the difficulties of the individual student and as sources of suggestions on how to overcome these difficulties.

Gaps

Data Science is a young technology and must be treated with great caution.

For example, in the case of both statistics and data science, the basic principle must be correlation and not causation.

In practice, if two things appear to be correlated, this does not imply that one causes the other.

On the other hand, it is often possible to correlate two phenomena which are not related at all, but which appear to be related because the course of one is strikingly like the course of the other. This can cause dangerous misunderstandings and lead to rash conclusions.

Anomalous values should be detected and deleted, corrected and it should be made clear why they suffer this fate.

There are problems such as the choice of model for the regressions (based on response and predictor variables) which are not always easy to define if one does not find whether there is any functional relationship between the variables considered.

It is clear, therefore, that the experience of the data scientist has a considerable bearing on the quality of the results.

The distribution of data and information across different organisations without a single standard and its sheer volume has made otherwise valuable data inaccessible or lacking the necessary cross-validation. It is often difficult, if not impossible, to provide the necessary visibility (also in terms of aggregated representations from different points of view) to those who have to make important decisions in a tight timeframe. Other issues that not generally solved are related to security and privacy regulations (or lack thereof).

2.3.5 Data Visualisation

Definition

Data visualisation is a way for humans to transform the representation of data in order to better understand patterns and connections and to focus on important facts. Thanks to suitable visualisation tools, analysts and decision makers will be able to make sense of facts and patterns that even now are not essentially intelligible and are in essence only based on a specific narrative [34].

In a nutshell, data visualisation is about what humans are really good at (pattern recognition and interpreting results) that could be linked with what computers are really good at (data management, computation and statistics).

The importance of data at all levels and in all the fields of human activity has become so crucial as to lead to a real paradigm shift, from the 'information era' to the 'data era'. Massive amounts of data are generated every day by a large variety of sources concerning economy, media, society, industry, commerce, health, environment, and so on. Although those data have an unprecedented potential in terms of understanding and inference of complex trends, events, and situations, still technologies are needed to fully exploit such possibility, due to the difficult in distilling and suitably representing human-understandable clues out of unstructured corpora of data.

Data visualisation is a key issue in this domain. The possibility of representing heterogeneous data lying in hyper-dimensional spaces, in order to make evident their inter-relations and to allow navigating across multiple links has attracted big attention in the last decade.

In the simplest version, data visualisation can be achieved using multi-dimensional diagrams and graphs, where the objective is typically to reduce/project the space dimensions to achieve manageable and meaningful representations. More sophisticated applications can help with spotting correlations, implementing data fusion techniques, and introducing advanced 3D visualisation tools exploiting AR/VR technologies and immersive environments.

Current Use

Data visualisation is much more empowering than diagrams or graphs.

Among the most recent tools that are being used across a wide range of disciplines to help researchers visualise and extract meaning from large multi-dimensional datasets, the following can be mentioned:

- Cytoscape.
- DataWrapper.
- D3.js (Data-Driven Documents).
- FusionCharts.
- Highcharts.
- Plotly.
- QlikView.
- Sisense.
- Tableau.
- Watson Analytics.

Opportunities

Big Data should be used to increase the efficiency of information generation for decision making, but their interpretation, and therefore the production of meaning and evidence, often risks taking so much time that they become unusable. An end user is thus overwhelmed by the amount and type of data, which can also have significant interrelationships. The visualisation of data or information in general tries to transform what has been collected into a real "landscape." This can be enriched in various ways: for example, with other outline information that provides an interpretative context or metadata that may or may not be hidden for further study or simplification or provide “road signs” or even a useful “map” to avoid “getting lost” in particularly complex information areas.

M&S professionals can capitalise on these approaches. For instance, we can imagine situations in which data can be automatically analysed in real time and suitably presented to allow decision makers to reach a better understanding of complex environments and situations and take more informed decisions.

Also, large amounts of data from simulation scenarios could be merged with data from external sources or generated automatically for increasingly LVC-oriented scenarios, in order to build realistic scenarios or to infer the impact of a given event on the relevant generated data. Real-time exercises or experiments can also be seen and interacted with in a new kind of visualisation, perhaps even using Extended Reality tools where data visualisation can be superimposed on operational scenarios.

Gaps

As the availability of data grows, a graphic visualisation of the data to simplify its interpretation seems inevitable. As we have seen, there are many tools already available to assist in the interpretation of complex data sets by means of illustrations and visual diagrams of various kinds.

However, one must be aware that there are some problems that must always be kept in mind. For example, the end user may give too much credence to the credible representation of the images or have an over-simplification of the data, rather than understanding the exact nature of the underlying phenomenon.

These points can create great limitations, especially in the field of decision making. The presentation system should always be able to provide the elements necessary to understanding how the data was aggregated and how the system arrived at that visualisation.

2.4 IMMERSIVE TECHNOLOGY

Definition [35]

Immersion is the perception of being physically present in a synthetic environment (NSO terminology) [13].

Immersive Technology is an integration of virtual content with the physical environment in a way that allows the user to engage naturally with the blended reality. In an immersive experience, the user accepts virtual elements of their environment as part of the whole, potentially becoming less conscious that those elements are not part of physical reality.

Immersive technologies include:

- **Virtual Reality (VR):** a digital environment that replaces the user’s physical surroundings.
- **Augmented Reality (AR) :** a digital content that is superimposed over a live stream of the physical environment.
- **Mixed Reality (MR) :** an integration of virtual content and the real-world environment that enables interaction among elements of both.
- **Holography:** the creation of a 3D image in space that can be explored from all angles.
- **Telepresence:** a form of robotic remote control in which a human operator has a sense of being in another location. The user could, for example, guide the robot through a party or an office, stopping and chatting with people throughout the environment.

Even if not strictly related to immersive technologies, it is possible to consider also the following:

- **Digital twin**, a virtual replication of some real-world object that connects to the object for information so that it can display its current status.
- **FPV drone flight**, use of an Unmanned Aerial Vehicle (UAV) with a camera that wirelessly transmits video feed to goggles, a headset, a mobile device, or another display so that the user has a First-Person View (FPV) of the environment where the drone flies.

Supporting technologies for immersive experiences include AR, MR and VR headsets, 3D displays, 3D audio, gesture recognition, spatial sensing, speech recognition, haptics, drones, cameras, and omnidirectional treadmills.

According to the literature, there is a distinction between input and output devices. Input devices allow the user to communicate with the virtual environment, They can range from a simple joystick or keyboard to a glove allowing capturing finger movements or a tracker able to capture postures. Keyboard, mouse, trackball, and joystick represent desktop input devices that are easy to use, allowing the user to launch continuous and discrete commands or movements to the environment. Other input devices can be represented by tracking devices such as bend-sensing gloves that capture hand movements, postures and gestures, or pinch gloves that detect the finger movements, and trackers able to follow the user's movements in the physical world and translate them in the virtual environment. By contrast, output devices allow the user to see, hear, smell, or touch everything that happens in the virtual environment. As mentioned above, among the visual devices can be found a wide range of possibilities, from the simplest or least immersive kind (computer monitor) to the most immersive kind, such as VR glasses or helmets, or HMD or CAVE systems. Furthermore, auditory (speakers), as well as haptic output devices are able to stimulate body senses providing a more real virtual experience (for example, haptic devices can stimulate the sense of touch and force models in the user).

Current State and Use

The technology has been explored for several decades and is both maturing and becoming affordable due, to some extent, to commercial applications for entertainment, situational awareness, and training.

In fact, Immersive Technology has grown immensely in the past few decades and is continuing to progress. VR has even been described as the learning aid of the 21st century. Head Mounted Displays (HMD) allow users to get the full immersive experience. The technologies of VR and AR received a boost in attention when Mark Zuckerberg, founder/creator of Facebook, bought Oculus for 2 billion USD in 2014. Other massive corporations such as, Sony, Samsung, HTC, Varjo, are also making huge investments in VR/AR.

Although the most popular use of immersive technology comes in the world of videogames, in which the HMDs and other immersive devices have allowed individuals to experience the realm of videogames in an entirely new light (users are completely immersed in their favourite games), there are, currently, many researchers exploring the benefits and applications of virtual reality for educational purposes. However, there is little systemic work that currently exists regarding how researchers have applied immersive VR for higher education purposes using HMDs.

Particular mention must be made concerning studies of the "Dale's Cone of Experience" [36], which is a model that incorporates several theories related to instructional design and learning processes, and that shows that learners retain more information by what they "do" as opposed to what is "heard", "read," or "observed." Today, this "learning by doing" has become known as "experiential learning" or "action learning" and assumes a particular meaning when applied to Immersive VR/AR/MR technologies and justifies the extensive use of these concepts to improve the educational experience. In other word, doing training, using such technologies has demonstrated to be effective both in terms of memorization and learning:

Through perceptual-motor learning the subject operates on reality with perception and action, observes consequences and behaviour, he intervenes with his own action to modify them, observes the effects of his own action, and try to intervene in a continuous learning cycle. In repeating the cycles of perception and action, each operating on the result of the other, knowledge emerges while experiencing.

The cone is diagrammed and explained in Figure 2-9.

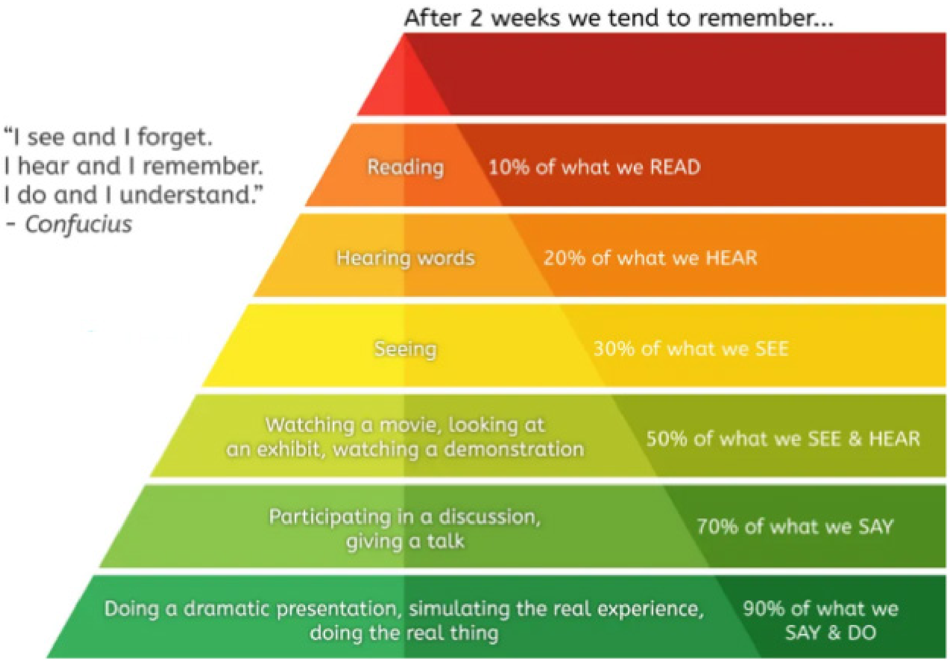

Figure 2-9: Dale's Cone of Experience Diagram.

Today, there are numerous virtual reality devices capable of providing different levels of immersion defined, in turn, by the level of user involvement in the immersive experience. In particular, three levels of immersion are recognisable:

- A first level consists of desktop devices – or Desktop Virtual Reality (DVR), in which the user interacts with a three-dimensional world generated on a computer screen. In this case, the user is not totally immersed in the virtual world and the interaction takes place through peripherals such as the mouse, keyboard, or joystick. Although the user experiences a sort of visual and auditory immersion, the sensory inputs from the real world that surround him are too strong, thus preventing him from fully immersing himself in the virtual experience. Examples of desktop virtual systems are video games and video simulations. These systems are used in the field of education as programs capable of stimulating the interest and attention of students towards the subject studied.
- A second level is defined by those devices capable of increasing the level of immersion thanks to the intensification of sensory stimuli from the virtual world or to the enhancement of the embodiment experience in virtual interaction. Full-domes are a great example of an enriched virtual environment. These devices are in fact displays with a wide field of view that surrounds the user, ensuring complete perceptual immersion and greater emotional transport. Embodied Mixed Reality Learning Environments (EMRELE), on the other hand, are environments that involve different sensory modalities including, of particular importance, the kinaesthetic senses: this type of system allows the user to interact directly with his own body with objects in the virtual environment. Systems such as

the Full-dome and EMRELE are devices used mainly in museum or collaborative learning contexts, in which several students participate together in the virtual experience, without being completely isolated from the real world and immersed in the virtual one.

- Finally, there are some devices, defined as Immersive Virtual Reality (IVR), capable of generating environments that perceptively surround the user and which are experienced as real. Unlike other devices, these systems have some features that can totally absorb the user in the virtual experience:
  - **First person navigation.** Numerous studies have in fact highlighted the benefits of self-centred navigation, compared to that in the third person, in terms of presence and immersion of the user in the virtual world.
  - **The dynamism of the scene.** Unlike systems in which the scene is fixed on a screen, in immersive virtual environments the scene is updated in a way that is congruent with the movement of the user's head, making the environment even more realistic; and
  - **Stereoscopic vision.** Immersive virtual reality systems create the illusion of depth, thus creating a flat image capable of giving a sense of perspective. Two examples of immersive devices are:
    - **Head Mounted Displays (HMD):** these viewers are worn by the user, who is perceptually isolated from the surrounding real world; they generate images with the characteristics listed above.
    - **Cave Automatic Virtual Environments (CAVE):** rooms in which three-dimensional images with which the subject can interact are projected onto the walls, ceiling and sometimes on the floor.

The development of these devices is mature enough for most of them while is only in its infancy for the remaining others.

Opportunities

The opportunities that may be offered by these new technologies are summarized in the following bullets outlining the most relevant application areas:

- **Training:** virtual reality, mixed reality, augmented reality but also Digital Twin (intended as the capability to digitally recreate the behaviours of equipment, instrument, and scenarios) are most useful for training. The training may be both operational and for maintenance purposes, and, more and more, it requires the use of the most sophisticated tools and technologies to meet the requirements of safety, security, reduction of pollutants, savings of energy resources, reduction of costs associated with training and so on. The combination of VR, AR and MR technologies can meet these stringent requirements while providing immersive scenarios that stimulate learning and memorization (Figure 2-10).
- **Situational Awareness:** has been recognised as a critical, yet often elusive, foundation for successful decision making across a broad range of situations, many of which involve the protection of human life and property, including law enforcement, aviation, air traffic control, ship navigation, health care, emergency response, military command and control operations, self-defence, and offshore oil and nuclear power plant management. Lacking or inadequate situation awareness has been identified as one of the primary factors in accidents attributed to human error. The formal definition of Situation Awareness is broken down into three segments: perception of the elements in the environment, comprehension of the situation, and projection of future status (Figure 2-11) [37].

- **Remote Support/Assistance:** uses both augmented and mixed reality to support and assist people during operational activity. Remote Support may be used extensively both for maintenance purposes both for providing auxiliary information and assisting people in any domain and during most of any activities that involve human knowledge sharing. Remote support may be delivered, for example, during maintenance activities to support inexperienced people to complete successfully their works or to help them during emergency activities. In addition, Remote Assistance can be evoked whenever there is a need to quickly find information about the activities to be carried out (Figure 2-12).
- **Surgery:** the use of AR techniques in surgery is a domain that deserves a separate discussion, since, while being part of remote assistance, aka telemedicine or telesurgery, it assumes a particular significance as in such conditions it is possible to think of organisations that remotely provide very specialised multimedia support considering that the object of the support is not an apparatus but a human (Figure 2-13).

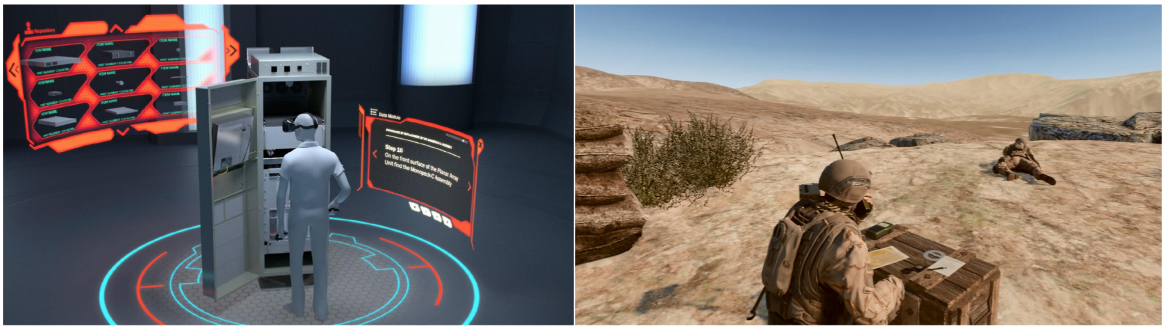

Figure 2-10: Maintenance and Operative Training Using VR Technology.

Figure 2-11: Situational Awareness in Operational Theatre.

Figure 2-12: Remote Support and Assistance with Augmented Reality.

Figure 2-13: Surgical Applications.

Gaps

Immersive technologies are still lacking in many areas even if Virtual Reality has reached a high degree of maturity in certain contexts, more so than Augmented or Mixed Reality. New solutions should be investigated to address:

- Accurate localisation (position, orientation, etc.) is minimally invasive (no markers, wires, etc.) and allows seamless integration in the real world. Computer vision-based systems seem to be a potential approach. A related problem is the seamless and dynamic matching of synthetic imagery and real world (AR, MR).
- Reducing/limiting cybersickness both during and after the immersive experience. This may include technical as well as procedural solutions [38].
- Improved immersiveness for all human senses (speech, haptic, smells, temperature, etc.); this would also include improved visuals that address both wearability (weight, comfort, wireless, hygiene, etc.) and quality (e.g., stereovision, depth of field, field of view, multifocal).
- Considering the training aspects, one additional element that could be of interest is the impact that solutions based on xR can have on the user, through the use of wearable sensors for a more quantitative evaluation (eye tracking, EEG, pulse, etc.).
- Electromyography is a way of controlling interfaces without gloves, mouse, and controllers as it taps in the muscles and electrical signals from the brain. It could be very useful in some types of simulations where an interface trying to replicate a real-world thing is very hard to do; (Brain-Computer Interface could be seen as an evolution of this technology).
- There seems to be a lack of common standards for xR technology (e.g., tracking sensors, displays, haptic, etc). This makes it hard to develop open vendor independent solutions.
- One other point is that the focus seems to be very much on first person 3D and VR. Command decisions are not going to be made using these tools, they need maps, icons, and COPs; a 3D view is just going to distract and get in the way of good decision making. So, for front line operators the 3D / VR drive is very valuable, but as you move up the command chain these are less relevant and the more abstracted the data is the easiest it is to digest. Coming up with techniques/technology to abstract the data to help create the COP would be very useful.

Recommendations

Continue monitoring and assessing the emerging technology areas that could augment human performance in various settings (training, decision-making).

2.4.1 Virtual Lab (CAVE)

Definition

The Virtual Laboratory is an interactive environment for creating and conducting simulated experiments: a playground for experimentation. It consists of domain-dependent simulation programs, experimental units called objects that encompass data files, tools that operate on these objects [39].

A CAVE (Cave Automatic Virtual Environment) is an immersive virtual reality environment where there is a possibility of an immersive visual experience (Figure 2-14).

Typically, a CAVE is a video theatre situated within a larger room in which the walls are made up of rear-projection screens, however flat panel displays are becoming more common. The floor can be a downward-projection screen, a bottom projected screen, or a flat panel display.

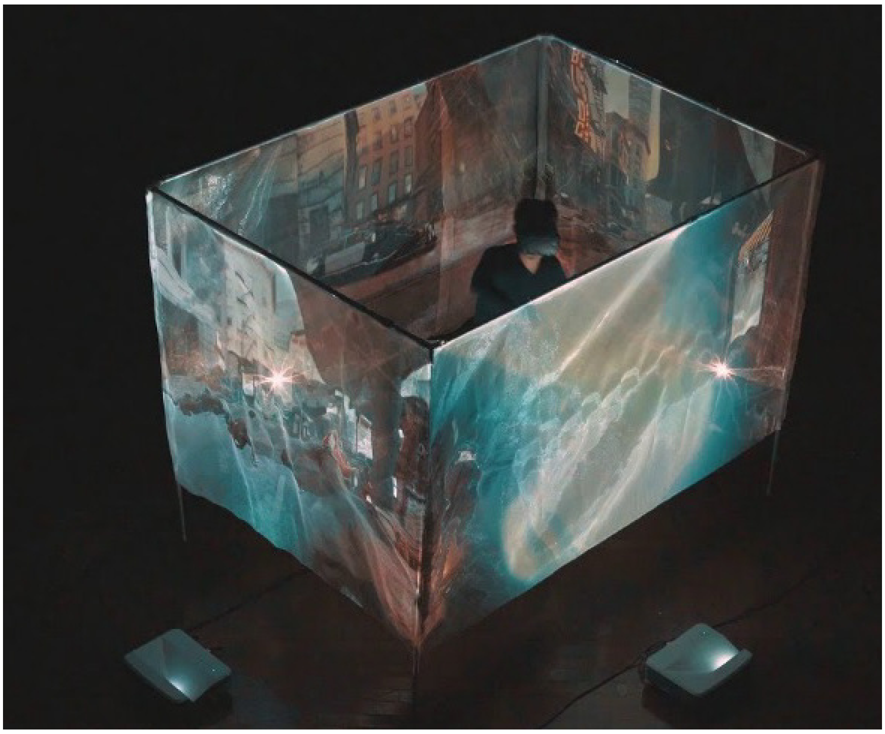

Figure 2-14: CAVE.

Current State and Use

CAVEs are used as part of the design of new platforms.

Opportunities

- Advantage: multiple persons can work in same CAVE and see each other, although only one controls the POV.
- LED walls may provide higher resolutions, higher light output and possibly lower cost and maintenance compared to projection-based systems.

Gaps

- Distortion of angled screens.
- Multifocal planes are not supported.
- Calibration cost/effort.

2.4.2 Display System (DOME)

Definition

The DOME is the complete system, including the combination of hardware and software, to visually represent the information in a data processing system.

The technological level of these systems can be as diverse as possible.

The DOME-system can allow a semi-full immersion but can reach up to VR systems where the field of view can be theoretically up to 360° spherical.

Current State and Use

Training systems using domes include airport tower simulation (air operations control), ship bridge simulations, forward air controller (JTAC) sims, etc.

Limitations include cost and large footprints.

Opportunities

- LED walls may provide higher resolutions, higher light output and possibly lower cost and maintenance compared to projection-based systems.

Gaps

- Limitations include high cost, large footprints, and lack of mobility.
- Point of View is locked to one sweet-spot. Use is therefore limited to objects at long distance. Multifocal planes are not supported.

2.4.3 2/3D Tactical Situation Display

Definition

To design, build and/or integrate the visualisation of the evolution of a synthetic environment using two or three-dimensional representations of environmental actors.

Current State and Use

3D sand table/displays, using LCD shutter glasses or polarized spectacles, have been investigated for many years. Real-world applications unknown.

Opportunities

- Combinations of real objects (movables) and/or maps with 3D overlays (augmented or mixed reality).
- 3D maps of the mission environment can improve SA, mission planning and debriefing. This could be used both at the Command Post as in the field with suitable tablets or mobile systems.

Gaps

- Point of View is locked to one sweet-spot. Multifocal planes are not supported.

2.5 WIRELESS CONNECTIVITY/5G

Definition [40]

5G refers to the fifth-generation cellular network technology, which has been evolving since 1980. 5G opens the floodgates to download rates of one gigabit per second, more than ten times what we are used to. A network where end-to-end latencies may be below 1 ms, data rates above 20 Gbit/s, data traffic above 50 exabytes/month, and connection densities of 1 million connections/squared kilometre allows thinking to scenarios belonging to science fiction up to few years ago.

In particular, Augmented, Virtual, and Immersive Reality systems, which should ideally be tetherless to allow free movement of users, will receive a boost from 5G network scenarios characterised by high data rate across a wide coverage area

Current State and Use

- Communication bandwidth and robustness of the wireless links between (high-res) displays and base-stations are challenging for current technology. Wired connections are in use to cope with this issue, so current systems often require wired connection between xR displays and base-stations also to compensate for computation and image generation processing power that cannot be available locally on the device itself.
- Electrical power needs can be significant when local/mobile computing is used for immersive hardware. Limited battery capacity and frequent recharging make systems less user friendly and acceptable.

Opportunities

To list some of the possible improvements and opportunities arising from the use of 5G networks, let’s have a look into three major use cases: enhanced Mobile Broadband (eMBB), massive Machine Type Communications (mMTC) and Ultra-Reliable Low Latency Communications (URLLC). Each of these scenarios brings a concrete advantage into the way Simulation can be exploited.

The eMBB foresees data-driven applications requiring high data rates across a wide coverage area. Examples are 4K/8K ultra-high-definition surveillance and reconnaissance video; cloud-based wargaming applications and related supporting tools such as Augmented Reality, Virtual Reality, naked-eye 3D visors that require wide bandwidth.

One potential benefit of high bandwidth low latency communications is that you can centralise the processing. The applications runs in the Cloud and clients connect with any web enabled device such as a laptop, mobile phone, or tablet to the cloud. All execution of the software is in the Cloud and the image is streamed to client. It could avoid the need to create software for different platforms and have heavy duty computing in the cloud with cheap lightweight, almost disposable tablets, headsets, etc. in the field.

The mMTC is expected to be mainly driven by IoT-like scenarios where there are large numbers of devices and sensors that intermittently transmit small amounts of traffic. This scenario is not too sensitive to bandwidth requirements, but it is extremely dependent on low consumptions and lifetime requirements. This feature could improve the way CTC (Combat Training Centre) use those devices to enrich the training environment.

The URLLC can enhance mission-critical communications, such as remote control of autonomous vehicles or providing extra remote computing power to AI-enhanced robots where ultra-low latency and high reliability are necessary because minimum delay and unreliability could bring about disastrous consequences.

There are many practical examples of applications in which 5G will make the difference. Other applications are entirely new and, in this case, 5G is their enabling technology.

The following list is merely indicative, and it is not intended to be exhaustive:

- **E-health applications:** in conjunction with the use of wearable devices worn by patients: secure and reliable data transmission in near-real time and rapid intervention in case of need.
- **Telemedicine:** reliable data transmission in near-real time, possibility of telesurgery through novel ++zero-latency" haptic interfaces that may also include part of the "Tactile Internet" environment, which is an evolution of the IoT, encompassing human-to-machine and machine-to-machine interaction and is characterised by extremely low latency in combination with high availability, reliability and security, as stated above.
- **Road transport: s**haring information in real time between connected cars and/or self-driving cars and autonomous context-aware vehicles; warnings about a problem ahead coming from roadside infrastructure allowing drivers to change routes quickly and to avoid car accidents; drones patrolling roads, detecting car accidents, and calling for ambulances.
- **Entertainment:** in a densely packed crowd at a sporting event, each spectator could use their personal device to view or immediately review a given event from different points of view. Two-way interactive electronic gaming can be enhanced with near immediate, high-capacity information in virtual or augmented reality.
- **Industry 4.0:** connected robots communicating with each other and with other machines; sensors embedded in products timely alerting service centres for servicing; sensors in connected products enabling new service-based businesses.
- **Retail:** thanks to 5G, customers may opt to enter their height and weight in an app and try on clothes from home through augmented reality technology. Smart shelves in supermarkets and hardware stores will be able to sense when a product is almost out of stock and automatically request a new shipment from the supply chain. 5G will also power retail deliveries.
- **Agriculture and farming:** growers will receive real-time data on fertilization and moisture levels, which would allow them to make adjustments that ensure maximum yield from each crop. Such data will be collected from a number of mechanisms that include sensors in the ground and drones overhead. Tractors and harvesters will evolve towards autonomous systems and smaller sensor equipped robots will be exploited to analyse field parameters. 5G could also help to track livestock.
- **Remote work:** currently, high-speed Internet is only available in dense urban areas and only over fibre-optic cable networks. 5G will widen the availability of high-speed Internet beyond these current limits and will enable full high-speed access even by mobile devices. People will be able to work wherever they want, even in a park. Thanks to 5G's low latency, the service sector will also have more opportunities to work remotely. Factory technicians could inspect and monitor system performance in real time from afar and health care professionals will be able to monitor their patients through wearable devices.

- **Real-time monitoring of processes:** will increase productivity and efficiency. Smart grids for energy, water, and gas represent an example where the data exchange through networking will optimise supply and demand, management of energy flows, and pricing.
- **Safety and security:** the pervasiveness of smart devices together with ubiquitous coverage will be employed to monitor critical infrastructures, metropolitan and hazardous isolated areas by sensors, microphones, and videos. Three technological keywords will have an essential impact in this context and will probably give the adequate answers: Big Data Analytics, Distributed Computing and Cybersecurity.
    - Cybersecurity translates to many different aspects: from computer to network security, from web to mobile system security, from critical infrastructure protection to social engineering.

Nevertheless, 5G shuffles the cards on the table: cybersecurity must be assured within critical environments where a huge number of connected devices exchanges data at high speed and with minimum latency.

The usage of widespread firewalls, antiviruses, and Intrusion Detection Systems (IDSs) slows down the processing power of the system and leads to delay in data transfer that cannot be accepted from the practical viewpoint in systems where the requirements are: responsiveness (real-time behaviour) of systems, timeliness of data being delivered, availability of any component of the system for use when needed and unacceptability of system outages.

A latency versus security issue can be envisaged. Whatever the examples and case studies, it should be emphasized that 5G has been conceived from its outset with the specific purpose of enabling solutions that create value for some Internet-connected industries (also referred to as “verticals”) such as automotive, healthcare, transport, and utilities. While it cannot be denied that former generations of wireless have delivered enormous socio-economic value, no mobile communication generation has ever set out with this fundamental goal as a stated priority.

Gaps

The Fifth Generation (5G) of mobile technology is emerging as a superior communication network, delivering increased speeds, coverage, and reliability. This innovative network is bringing about the reality of Internet-of-Things (IoT) as it is able to handle significantly more devices. However, as with any new technology, there are some disadvantages to be considered. Here are some of them:

- **Obstruction can impact connectivity:** the range of 5G connectivity is not great as the frequency waves are only able to travel a short distance. Added to this setback is the fact that 5G frequency is interrupted by physical obstructions such as trees, towers, walls, and buildings. The obstructions will either block, disrupt or absorb the high-frequency signals. To counter this setback, the telecom industry is extending existing cell towers to increase the broadcast distance.
- **Initial costs for rollout are high:** the costs related to the development of 5G infrastructure or adaptations to existing cellular infrastructure will be high. This amount will be further compounded by the ongoing maintenance costs needed to ensure the high-speed connectivity, and it’s likely the customers will bear the brunt of these big price tags. Cellular operators are looking to minimise these costs by exploring alternative options in the form of network sharing.
- **Battery drain on devices:** when it comes to cellular devices connected to 5G, it seems the batteries are not able to operate for a significant period of time. Battery technology needs to advance to allow for this enhanced connectivity, where a single charge will power a cell phone for a full day. Alongside depleted batteries, users are reporting that cell phones are getting increasingly hot when operating on 5G.

2.6 EVERYWHERE/UBIQUITOUS/CLOUD COMPUTING

Definition

A model for enabling ubiquitous, convenient, on-demand network access to a shared pool of configurable computing resources (e.g., networks, servers, storage, applications, and services) that can be rapidly provisioned and released with minimum management effort or service provider interaction [41].

The Cloud Model is composed of five essential characteristics, three service models and four deployment models:

- Characteristics: On-demand self-service; Broad network access; Resource pooling; Rapid elasticity; Measures service.
- Service Models: Software as a Service (SaaS); Platform as a Service (PaaS); Infrastructure as a Service (IaaS).
- Deployment Models: Private Cloud; Community Cloud; Public Cloud; Hybrid Cloud.

Current Use

- Distributed/Collaborative Simulation.
- M&S as a Service (MSaaS), MSG-136 [42], MSG-164 [43]), MSG-195.
- Training as a Service (TaaS).

Recent technical developments in cloud computing technology and Service-Oriented Architectures (SOA) offer opportunities to better and securely utilize M&S capabilities to satisfy these critical needs. M&S as a Service (MSaaS) is a concept that takes advantage of those developments, enabling an ecosystem that will supply and provide improved services to discover, compose and execute required simulation environments, using cloud-based computing or deployed to local computer systems or a hybrid of the two.

The NMSG has been developing the "Allied Framework for MSaaS" as the common approach in the NATO coalition towards a **federated MSaaS ecosystem** consisting of national and NATO MSaaS implementations, underpinned by a common technical reference architecture, common processes, and a common business model (Figure 2-15).

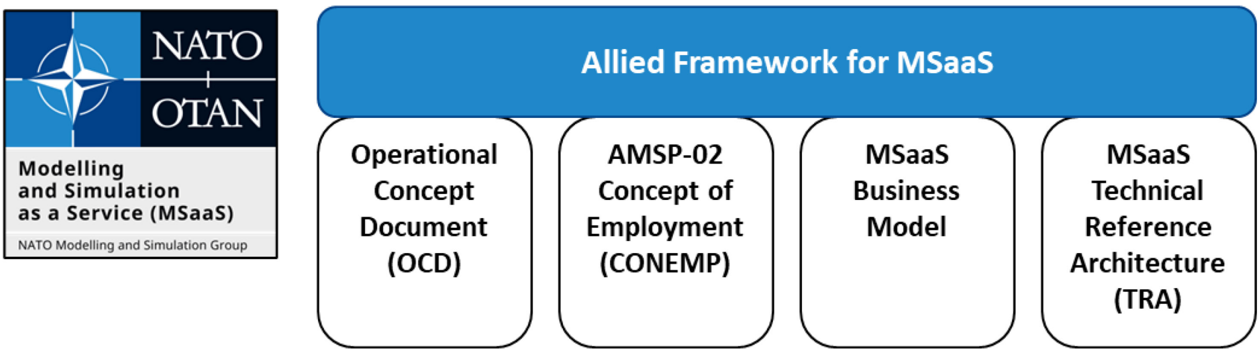

Figure 2-15: Documents Defining the Allied Framework for MSaaS (MSG-164).

The Allied Framework for MSaaS defines the blueprint for stakeholders to implement MSaaS. The specific solution architecture of MSaaS may be different for each implementation.

Opportunities

- Servitization (the concept of changing from a simple product offer to a combination of products and related services). Reduced local footprints, added flexibility and pay-per-use cost models.
- Integration with next generation computing technologies: quantum computing, neuromorphic computing, cognitive computing, swarm computing (aka collective intelligence).
- Digital Battlespace frameworks leveraging flexible cloud-based M&S and other services.

Gaps

- Environment Modelling and Interfacing.
- Networking Software Defined Network (SDN) and self-organising networks:
  - Aims to make networks configurable by software.
  - Manage the precious bandwidth adaptable according to the changing demand and circumstances.
  - To control the network in a centralised fashion.
  - To unify all available networking hardware (that comes in various brands and protocols) by designing and managing network via instructions.
  - Achieving network security via SDN is another emerging and promising field.
- Composability of (micro)services.
- New business models and cultural changes to adopt these.
- Security in the cloud solutions (technical and process-wise).

2.7 DISTRIBUTED AND COLLABORATIVE SIMULATION

Definition [44]

Distributed Simulation is the execution of simulation programs conducted (in real time) across a number of computers connected by mean of a proper network (local or wide). It is based on a series of standard protocols that ensure the interoperability among the actors of a SE (see DIS/HLA).

Collaborative Simulation is the ability to collaborate using networked simulation to achieve a specific goal. It can range from supporting engineers who collaborate on the design of a system to training people on a specific task.

Simulations can include Live, Virtual and Constructive elements.

- **Live:** A simulation involving human operators operating instrumented real systems.
- **Virtual:** A simulation involving human operators controlling simulated systems.
- **Constructive:** A simulation involving simulated control entities, including agents, operating simulated systems. Human operators make inputs to such simulations but are not directly involved in determining the outcomes.

Current Use

Live simulation includes real-world exercises, instrumented ranges.

Virtual simulation is used for task/procedure training and full mission simulation.

Constructive simulations are used for planning purposes and staff training as well as stimulation of Live or Virtual simulations.

Opportunities

Integrated LVC training offers solutions to provide more populated synthetic environments.

Gaps

Interoperability standards are incomplete, although good progress has been made.

Challenge with LVC is to offer valuable training for all players at the same time.

Live training is less suitable for any simulation that is non-real time. There are challenges to ensure safety of Live players in an LVC context.

2.7.1 MSaaS / TaaS

Definition [42], [43], [45]

Modelling and Simulation as a Service (MSaaS) is a means of providing on-demand services to customers through cloud networking technology by a Cloud Services Provider (CSP), allowing access to applications, functionality, and data of M&S (Modelling & Simulation) without the need to be the owner of the specific material that makes up the service.

The CSP, therefore, keeps the underlying infrastructure, the requirements and details of the platform and the software "hidden" to the customer both from a technological and also from an administrative point of view, as the end user is seen as a user of a service and not as the owner of a capability.

The CSP is therefore responsible for managing licenses, software updates, sizing the infrastructure according to the evolution of requirements, and is also responsible for providing the degree of service and the quality of service specified in the contractual agreements relating to the service level to be guaranteed.

The "service" approach, to access the modelling and simulation functions, offers advantages such as being able to offer it on demand (with an ever-wider range of applications and updated tools) and the possibility of being able to collect and sharing, within the group adhering to the service, data, models, resources, practices, other theoretical and operational knowledge. In practice, allowing a more effective exploitation of available resources.

By using service-oriented architectures and cloud computing to manage M&S repositories, this technology improves interoperability, composability, reusability and reduces the cost of M&S activities.

It also further improves simulation credibility and establishes sustainable and efficient management of M&S services through a single (cloud-based) repository.

MSaaS (Modelling and Simulation as a Service) is based on the concept of Software as a Service where the software are modules of M&S.

TaaS (Training as a Service) is a training technology also based on the concept of Software as a Service that can be coupled with the MSaaS whereas M&S is used to deliver a training. TaaS, in fact, is a specialisation of the MSaaS domain in the field of training that uses SaaS paradigm to deliver a new concept of training as service and no more as a product.

As a specialisation of MSaaS, it inherits all the properties and benefits of MSaaS.

Current Use

The use of simulation techniques and tools plays a strategically important role for any national and supranational Organisation.

In the national army domain as well as many other international Organisations (such as NATO), the simulation is used for different purposes: ranging from the realization of advanced and immersive training activities to the targeted development of the skills required in particular missions, up to decision support used in mission command and control activities.

It is useful to underline that recent development in the field of cloud computing and architectures such as Service-Oriented Architectures (SOAs) offer a relevant opportunity to exploit, effectively, the M&S paradigm according to the objectives and needs of several national organisations.

In Cloud Computing, the available IT resources are offered in the form of services that can be used through the network, in agreement with three different provisioning models, which depend on the type of resource provided: **infrastructures** (IaaS – Infrastructure as a Service), **processing platforms** (PaaS – Platform as a Service) and **software** (SaaS – Software as a Service).

The introduction of Cloud Computing and SOAs in the M&S domain allows us to define a new paradigm to support the development and delivery of distributed M&S applications, called Modelling and Simulation as a Service (M&S as a Service – MSaaS).

According to the MSaaS, a simulation is obtained through the selection and composition of M&S services available in the Cloud. In this way the creation of a simulation is obtained through the integration of components available on demand.

To intercept these needs, NATO has launched a research program, within NMSG (NATO Modelling and Simulation Group), to investigate how the most recent architectural approaches and the most innovative technologies can serve as a basis for building a strategic Modelling and Simulation services for countries' military activities of the Alliance from an MSaaS perspective.

The studies of the NMSG in this area were concretely carried out in distinct phases mainly through the activities of three working groups.

Initially, the NMSG-131 (Modelling and Simulation as a Service: New Concepts and Service-Oriented Architectures) [45] conducted a preliminary study on the opportunities offered by the Modelling and Simulation proposed in a service perspective.

Based on the results obtained, a subsequent working group, the NMSG-136 (MSaaS - Rapid deployment of interoperable and credible simulation environments) [42] focused its contribution more concretely on M&S as a Service (MSaaS) with the aim of identifying the technological and organisational bases for the construction of a permanent M&S ecosystem called Allied Framework for MSaaS.

Finally, the current work, still in progress, is conducted by NMSG-164 (Modelling and Simulation as a Service Phase 2) [43] and continues on the same line as MSG-136 with the main objective of increasing operating capacity in the MSaaS area.

Obviously, interest in these topics is high and, as previously said, several organisations and some European foundations are interested in such innovative solutions. In parallel, the EU Commission has taken pro-active steps to ensure that the EU builds upon its strategic autonomy through the presence of a strong, full spectrum and well-trained military force. To achieve such purposes, the EU Commission has sponsored the provision of scalable, on-demand services across geographically separated and varied customers/users and has made them possible in a cost-effective manner due to the availability of cloud services of the MSaaS (Modelling and Simulation as a Service).

In fact, the use of Modelling and Simulation (M&S) solutions is assuming an increasing role in the management of critical situations and in complex operational contexts (such as, for example, military ones, especially as regards planning, execution, and management training activities, as well as analysis and decision making) and the possibility of offering these technologies as services considerably increases their potential on the market. Depending on the needs, the role of the CSP and the cloud infrastructure itself can also be sold to the end customer, as is often the case, for example, for classified military training centres.

The simulation of complex and “Mission & Safety Critical” systems supporting the real systems themselves is increasingly acquiring a key role in the Defence market and its declination in the MSaaS environment opens up new perspectives for the implementation of interoperable solutions, federated and economic in the following areas:

- **Management of critical situations:** environmental disasters, terrorist attacks, military operations, etc., in which the exercise is performed using human operators, Constructive resources such as Computer-Generated Forces (CGF) and related interactions, simulated and real scenarios, in various configurations that can be partially or completely overlapped.
- **Engineering of complex systems** throughout the life cycle, from the design phase, in which the simulation is used to calculate and predict the behaviours of the system in relation to different conditions and scenarios, to the development and integration phase, where the simulation supports these activities stimulating the systems involved up to logistical support, in which a synthetic representation of the system and virtual and augmented reality technologies can improve the efficiency of maintenance activities.
- **Staff training on complex systems** focused on procedures, decisions, and strategies in relation to different scenarios, also in “virtual immersive” mode.
- **Concept Development and Experimentation:** the ability to conceive, design and study, in a simulated environment, the adoption of new operational concepts (CONOPS) and concepts for the use of existing resources or new acquisitions (CONUSE).
- **Innovative solutions** based on the cloud computing paradigm and Service-Oriented Architecture (SOA).

Moreover, MSaaS technology, combined with emerging technologies such as Virtual Reality, can greatly facilitate the development of solutions that minimise time and costs in the management of complex training systems, since in this context, virtual models can be enriched with simulation functions and made usable “on service”, even remotely. In fact, one of the most immediate repercussions and applications can be identified not only in the context of the Concept Development and Experimentation (CD&E) but also and above all in the context of training driving through an innovative service approach of the training itself (Training as a Services or simply TaaS).

In fact, Training as a Service (TaaS) is an approach that takes into account the influx of disruptions and disruptive technologies by providing a service that is of highest value to business and learners alike. TaaS is strictly related to MSaaS in so far as it uses the modelling and the simulations as a service to compose training exercise to be delivered as a service.

With proven and sustainable value, TaaS combines the benefits of a traditional shared services model with a flexible design, development, and delivery approach that keeps pace with today's cloud and SaaS software. TaaS is an ideal, cost-efficient solution for large, globally dispersed, tech-forward organisations.

Opportunities

The MSaaS concept has many positive effects in many domains of application but there is no doubt that the field in which the MSaaS paradigm finds its maximum diffusion and has the greatest opportunities is in the field of training in which it takes the name of TaaS.

When most professionals think about training, they imagine having to schedule regular time out of their work calendar to go to a classroom, run through the syllabus, and complete a certification within a set timeframe.

Yet, as technology expands and evolves, this traditional training model is increasingly outdated.

Choosing online training, in which lessons are performed using simulation results or are closely related to simulations, makes maintaining regular education easier for individuals. Online training and resources are up-to-date and available, enabling the training to be flexible, fast-moving, and adaptable in the face of a rapidly changing and expanding industry.

The benefits of online training include:

- **Saved time:** online training doesn't need to be scheduled, so doesn't interrupt work, or impact capacity.
- **Saved budget:** time and expense in travelling to courses is avoided.
- **Consistent training:** training managers know exactly what the course will contain for each student – anywhere in the world.
- **Ease of securing management:** buying Online training minimises barriers to training adoption such as lost time and resource.
- **Accessibility and flexibility:** Training can be taken 24/7, 7 days a week to suit individual requirements.
- **Certifications on demand:** There's no waiting around to enrol on scheduled classes.
- **Online access:** Courses and support materials can be accessed any time via any online device. This offers the additional benefit of resource availability to support on-site work.
- **Paced to suit the individual:** Training doesn't have to be completed in one sitting, and individuals can plan to their schedule.
- **70/20/10 development:** 70% of learning comes from real life experience, 20% comes via feedback from managers or supervisors and 10% comes via formal training. Online training supports the 70/20/10 development model, offering a consistently available point of reference, learning material, and support to help professionals while on-site and learning via practical experience.
- **Multilingual:** Online training can be made available in multiple languages to support student preferences.

One key requirement to meeting the above benefit is the use of a Learning Management System (LMS) to support and manage the program needs. A LMS is a peculiarity of a TaaS (Training as a Service) as it represents a way of organising courses in a rigorous manner by managing resources and users remotely, making sure that the provision of a service is carried out in a structured way and that, even by accessing remote resources, the user does not notice this as the LMS takes care of providing the training paths in a transparent way for the user itself.

Gaps

- Standards for Cloud-based applications (noting that MSG-164 Reference Architecture has made a significant effort);
- Security aspects;
- Limited network Bandwidth that may limit the power of simulations;
- Technology not yet fully mature;
- Business model not yet fully identified.

2.8 EVIDENCE-BASED TRAINING METHODOLOGY

Definition [46]

Evidence-Based Training (EBT) (sometimes referred as Competency-Based Training (CBT) whose acronym, however, is confusing because it is the same as Computer Based Training) has been supported by the International Civil Aviation Organization (ICAO), the International Air Transport Association (IATA) and by a group of airline industry experts. EBT is a new approach with the goal to increase the effectiveness of pilot training and meet the challenges of airline operations in the 21st Century.

EBT concerns training and assessment, characterised by developing and assessing the overall capability of a trainee across a range of competencies rather than by measuring the performance of individual events or manoeuvres.

In other words, EBT attempts to reduce the rate of aircraft accidents by strategically reviewing pilot training and evaluating flight crew based on evidence gathered during actual operational life. It is therefore based on real mistakes that have been made and data relating to flight safety. In this way the pilot is instructed according to knowledge of typical actual failures depending on the route and type of aircraft rather than being engaged in full-blown theoretical instruction.

Some definitions can be useful: [46]

- **EBT instructor.** A person, who has undergone a screening and selection process, successfully completed an approved course in delivering competency-based training and is subsequently authorized to conduct recurrent assessment and training within an approved EBT program.
- **EBT module.** A session or combination of sessions in a qualified Flight Simulation Training Device (FSTD) as part of the 3-year cycle of recurrent assessment and training.
- **EBT session.** A single defined period of training in a qualified FSTD that normally forms part of an EBT module.
- **EBT scenario.** Part of an EBT session encompassing one or more scenario elements, constructed to facilitate real-time assessment or training.
- **EBT scenario element.** Part of an EBT session designed to address a specific training topic.

EBT has an innovative approach in at least two main aspects:

1) The fact that there is evidence (or proof) i.e., what is inferred from the analysis of the data collected on safety and training.
2) The fact that there are basic operational competencies that are possessed by the expert(s) making up the course (potentially including the teacher). Operational competencies are all that is required to perform optimally.

The term 'resilience' is another key word used in EBT.

Resilience is the ability of a team to resolve unexpected events that fall outside standard operating procedures with an approach that enables positive results.

Current Use

It is currently mainly used in the field of civil aviation. The reason can best be summarised in this EASA statement from the ToR of "Evidence-based and competency-based training" [47]:

> *An analysis of fatal aircraft accidents worldwide for the period 2010 – 2011 shows that in more than 50 % of these accidents the actions of the flight crew were the primary causal factor (UK CAA, 2013). This analysis shows that flight crew handling skills were a factor in 14 % of the accidents whereas flight crew non-technical skills were a factor in more than twice as many (32 %). It is generally accepted that further improvements in flight safety require a comprehensive review of pilot training (IATA, 2013), and the accident statistics show that the emphasis of this training should be placed on developing the non-technical as well as technical pilot skills.*

Opportunities

The use of this approach in the military field looks promising. In particular, if it is blended with M&S and new disruptive technologies like the several times cited AI and BD.

Following the approach briefly presented above, it will be possible to collect evidence, both on the field and during exercises at all levels, in order to examine successes and errors, and to centralise this information in a formalised repository.

Gaps

The gap that this technology must fill is mainly about the professional trainees.

Lectures, professional development workshops, or a compulsory training course are conducted practically all the time.

There are countless lectures on new aspects of a given doctrine.

Unfortunately, all these transmissions of information do not always succeed in becoming real training tools for the audience because no good methodology has been defined for ensuring that this enormous mass of information is translated into "know-how."

Chapter 3 – CYBER SECURITY TECHNOLOGIES

Some technologies listed in this part of the document may have been already described in other sections. This chapter highlights specific features of these technologies that can be integrated into the cyber functionality of the environment and its infrastructures (communication networks, data repositories, etc.).

The introduction of "as a Service" models and cloud computing has changed the IT approach, enabling it to become more agile, introduce new business models, provide more services, and reduce costs.

On the other hand, such models have various implications from a security perspective, for example regarding data ownership, information security risks and potential regulatory compliance issues related to data treatment. Compared to previous models, this approach requires a much deeper knowledge of the data being processed remotely, in order to adopt measures that reflect the criticality of the data being protected.

Since a considerable part of data processing is performed remotely and data is decentralised, the very first aspect to be considered is how the data protection should be guaranteed, possibly by adopting various security countermeasures such as data encryption solutions (at rest, in transit, and in use), using secure channels to transmit commands and private sensible information, and implementing access management policies and authentication technical solutions.

In addition to the standard security technologies and requirements already listed in the previous paragraphs, there are various systems, tools and applications that could be used to enhance information and data protection in MSaaS environment, representing innovative solutions and security practices able to take the protection level of such systems to a higher level, while also taking into account the increase in cyber threats registered in recent years and that is predictable for the future. A list of such innovative technologies is presented and briefly explained below. The Cyber Security Requirements defined here address these issues.

3.1 QUANTUM COMPUTING

Definition [48]

Quantum computing is the use of quantum phenomena to perform computation. Computers that perform quantum computations are believed to be able to solve certain computational problems, substantially faster than classical computers. The application of such technology can be seriously disruptive for consolidated and standard algorithms such as encryption ones.

Current Use

Quantum computing systems today have not yet achieved enough scale and capability to exceed their classical counterparts for any applications or algorithms. It is still important to understand related use cases and field of applicability to drive future development and analysis.

Opportunities

Transformative innovation in quantum computing has driven the development of new systems and opportunities for innovative applications thanks to additional resources and computing capabilities. With the possible future migration of cryptographic and digital signature algorithms to quantum-safe replacements, there is an opportunity to significantly upgrade cryptography capability and utility: many quantum computing-based systems will potentially have properties beyond just encryption, such as new data analytics opportunities. In addition, quantum-safe algorithms will soon become useful replacements for existing asymmetric algorithms: in such terms, it is important to consider new cryptographic needs and standards and how they will change and evolve during the next years, to be sure to grant to the system a reliable communication and data protection resilient through time. It is surely better to evaluate future scenarios with adequate time to plan instead of reacting to forced technological changes driven by insecure communication channels or algorithms.

Besides using quantum computing in cryptographic applications, another area where applications are promising is the area of "quantum machine learning," which is the integration of quantum algorithms within machine learning programs.

Gaps

It is also important to underline that quantum computing systems and applications are developing well-ahead of quantum hardware. Algorithms and development environments are proliferating, creating the necessary future possibility to leverage the hardware as it emerges.

3.2 MACHINE IDENTITY MANAGEMENT

Definition [49]

Machine identity management process and tools focus on the management of trust in the identity of a machine interacting with other entities, such as applications, cloud services or gateways. Specifically, machine identity management handles the life cycle of credentials used by machines. Machines are being leveraged at an increased rate due to the growing trends, and traditional methods of identifying and managing machine identities has led to the proliferation of tools that do not scale.

Current Use

Machine identity management approaches handle the discovery and life cycle management of the credentials used by machines, which is something extremely relevant when dealing with virtual infrastructures, automated processes, or large distributed environments, as many cyber threats can seriously leverage an improper or insecure management of machine identities.

Opportunities

Machines, such as servers, cloud environments, and applications all require digital identities, especially in cloud-enabled environments. These digital identities will require appropriate security policies to be defined and managed in order to have control of all these entities. Machine identity management involves a wide set of technologies (i.e., Certificate management, SSH key management, etc,) that nowadays are still disconnected and treated separately, for complexity reasons, and only by certain specific technical areas.

Gaps

Machines used for integration and data exchange often have high-level credentials and weak policy settings in order to prevent any kind of malfunction while running and performing their tasks. Furthermore, it is difficult to understand an uncommon behaviour for a machine if no historic and statistical data is available for the analysis to be compared with.

3.3 ZERO TRUST SECURITY

Definition [50]

Zero Trust Network Access (ZTNA) creates an identity and context-based, logical-access boundary around an application or set of applications. The applications are hidden from discovery, and access is restricted via a trust broker to a set of predefined entities. The broker verifies the identity, context, and policy adherence of the specified participants before allowing access and prohibits lateral movement elsewhere in the network. This removes the application assets from public visibility and significantly reduces the surface area for attack.

Zero Trust Networks (ZTN) are designed to micro-segment network access, dynamically creating one-to-one network connections between the user and the resources they access: if compared to a standard VPN, this approach is able not only to establish a secure tunnel, as for a VPN, but also to validate and authorize access to the resources, leveraging network zone that are isolated and secured individually, reducing in the end the possibility for lateral movement or privilege escalation activities related to a potential cyber threat.

Current Use

ZTNA can have different technical approaches, but generally based on shared fundamental elements:

- Removing applications and services from direct visibility on the public internet.
- Implementation of least-privilege access for users to specific applications only after an assessment of the user identity, device identity and context has been carried out.
- Access independent of the user's physical location or the device's IP address, except where policy prohibits.
- Access policies are primarily based on user, device, and application identities.
- Access only to the specific application, not the entire network containing it.
- End-to-end encryption of network communications.
- Monitoring of the session for indications of unusual behaviours, such as user activity, session duration or bandwidth consumption.

Opportunities

ZTNA can enhance security of a system or application through reduction of its attack surface, as well as the additional difficulty for an attacker to perform standard actions such as lateral movement or privilege escalation once has gained access to the network.

Gaps

There are still some gaps to be addressed for the technology to be fully adopted, such as the following ones:

- Single point of failure for the trust broker.
- Potential latency for the users due to the trust broker.
- Administrator credentials are still a potential sensitive attack point.

3.4 USER AND ENTITY BEHAVIOUR ANALYTICS

Definition [51]

User and Entity Behaviour Analytics (UEBA) solutions aimed at the detection of uncommon events possibly leading to the discovery of security incidents or compromises. The most common use cases are threat detection and response, both for internal and external contexts.

UEBA solutions add an additional analysis capability to standard security technologies based on log analysis, such as IDS, IPS, etc. but need an analyst to set and determine rules and criteria for the event to be pointed out as significant.

Current Use

User and Entity Behaviour Analytics (UEBA) solutions use custom analytics to evaluate the activity of users and other entities (e.g., hosts, applications, network traffic and data repositories). They discover threats and potential incidents, commonly presented as activity that is anomalous to the standard profiles and behaviours of users and entities across time.

UEBA is now used to enhance detection capabilities for a wide variety of use cases, such as the following:

- Identification of internal threats / insider threats.
- Zero-day attacks.
- Detection of Advanced Persistent Threats (APT).
- Incident prioritisation.

Opportunities

Even if increasingly used, there is still room to grow in terms of capabilities and functionalities, due to the fact that the main approach is nowadays focused on the identification of anomalies (e.g., characteristics detected on less than 1% of the connections), but there is much to research and discover in terms of machine learning, which is a discipline that could be used in cooperation with UEBA, in order to discover, define and predict anomalous behaviours possibly affected by context related variables and historical data.

Gaps

UEBA needs to rely on a large amount of data in order to be effective and efficient: statistical comparison and behavioural analysis can be analysed through the availability of “standard” data based on common users, which often requires a large number of entities (users) and events (historical data).

3.5 ADVANCED MACHINE LEARNING TECHNIQUES FOR CYBER SECURITY DEFINITION

Section 2.2.1 and Section 2.2.1.1 described the main features of Machine learning and deep learning technologies.

The definitions provided and the areas of use indicated are of a general nature. In the following paragraphs, however, more detailed information is provided regarding these technologies in the field of cyber security.

Current Use

In the cyber security field, ML can be used for prediction based on knowledge and known properties acquired from the available data, in particular for threats and anomalies not detected by traditional systems (as can be for unknown malware and unknown indicators of compromise), but even to define algorithms needed to effectively detect such threats in future occurrences.

Opportunities

There are many variants of machine learning that are still to be investigated for adoption in cyber security field, mainly regarding threat prediction activities, advanced threat recognition and quick (or automated) decision-making, for example in response to an incident.

Deep learning is a variant of machine learning algorithms that use multiple layers to solve problems through extraction of knowledge from raw data and transforming it at every level. These layers incrementally obtain higher-level features from the raw data allowing the solution of complex problems with higher accuracy, fewer features, and less manual tuning. To achieve consistently good results, large quantities of labelled data are needed.

Decision Intelligence is a discipline aimed at understating and predicting cause-effects relations, to suggest effective decision-making through the representation of decision modelling graphs.

Gaps

Such ML variants represent nowadays a huge research field, and application for cyber threat prediction, prevention, detection, and response will certainly be one of the core elements that will enhance cyber security capabilities during the coming years. Nevertheless, real use of such disciplines is limited to the amount data actually available for artificial intelligence purposes: the already observed growing in terms of information observed and happening will also make a boost for the development and usage of these approaches in traditional cyber and information security activities.

3.6 VULNERABILITY PRIORITISATION TECHNOLOGY

Definition [52]

Vulnerability Prioritisation Technology (VPT) performs a comprehensive risk-based vulnerability analysis and remediation/mitigation process by focusing efforts on identifying and prioritising the vulnerabilities that pose the greatest risks to the contexts, by considering:

- Exploitability of a vulnerability.
- Asset or business criticality.
- Severity of a vulnerability.
- Compensating controls already adopted.

Current Use

Vulnerability Management (VM) is traditionally a foundational part of information security operations. However, organisations approach prioritising vulnerabilities according to a severity score, such as the Common Vulnerability Scoring System (CVSS), which results in a response to vulnerabilities that is based on a single metric. This metric-driven output is not frequently based on risk, as factors such as threat activity and asset context are not considered.

In order to progress a step further in the management of system and infrastructure vulnerabilities, Vulnerability Prioritisation Technologies (VPT) are being developed, in order to integrate assessment executed by Vulnerability Assessment (VA) tools, Configuration Management Databases (CMDB), Application Security Testing (AST), and cyber threat and vulnerability intelligence, to prioritise actions for vulnerability treatment, enabling an efficient risk-based vulnerability management process more comprehensive and effective than a process based only on a traditional scoring system.

Opportunities

Adoption of VPT can help reduce the attack surface, as well as cost reduction for the entire management of assessment and remediations related to the identification of a vulnerability, through the adoption of an iterative process based on risk (Risk-Based Vulnerability Management, RBVM) adaptive to the context and the overall threat landscape, thus changing over time.

Gaps

VPT related processes are resource-intensive and time consuming, requiring manual effort, maturity of threat intelligence capabilities and deep knowledge of business context for assets. This has impeded wider-scale adoption of the concept until now. VPT technologies leverage jointly machine-powered analytics and vulnerability intelligence in order to reduce the resource requirements of performing risk-based vulnerability management.

3.7 BLOCKCHAIN AND SMART CONTRACTS

Definition [53]

Blockchain is a shared, distributed ledger on which transactions are digitally recorded and linked together so that they provide the entire history or provenance of an asset. A transaction is added to the blockchain only after it has been validated using a consensus protocol, which ensures it is the only version of the truth. Each record is also encrypted to provide an extra layer of security. Blockchain is said to be "immutable" because the records cannot be changed and transparent because all participants to a trade have access to the same version of the truth.

Smart Contracts are lines of code that are stored on a blockchain and automatically execute when predetermined terms and conditions are met. At the most basic level, they are programs that run as they have been set up to run by the people who developed them. The benefits of smart contracts are most apparent in business collaborations, in which they are typically used to enforce some type of agreement so that all participants can be certain of the outcome without an intermediary's involvement.

Current Use

Secure communication and data storage is essential in military operations. Databases are the traditional means to store and maintain structured and related data. More recently, distributed ledger technologies (e.g., blockchain) have emerged and been used as the distributed, transparent, and permanent data management technology underlying the Bitcoin cryptocurrency. The increased use of blockchain technologies (along with AI-enabled defensive cyber-bots/agents, Quantum Key Distribution (QKD) and post-quantum encryption) will significantly increase the ability to ensure trusted communications and data storage.

Opportunities

Data security applications using blockchain can leverage decentralisation capabilities to offer alternative methods to establish data protection, with minimal reliance on centralised components. Such methods can enhance use cases involving chain of custody ensuring data integrity, as well as encryption to ensure all aspects of confidentiality, integrity, and availability and even transparency.

Common data security approaches that may benefit from a blockchain-based approach, such as key management and tokenisation, can all gain resilience, reliability, transparency, and trust due to blockchain's ability to decentralise these functions. This is in direct contrast to traditional approaches that would have the data stored in a central repository that typically doesn't require multiple parties to manipulate the data.

Gaps

Blockchain has the potential to increase resilience, reliability, transparency, and trust in a variety of common data security functions that rely on centralisation such as PKI, key management, and tokenisation. Blockchain applied to data security applications offers alternative methods that allow to gain further trust in data by ensuring integrity and availability. This can be enhanced further by layering in data protection techniques such as data encryption that could be done off-chain. Nevertheless, there is an absence of regulation or standards, meaning that adoption of the new technology can later drive the necessity for deep adjustments required by possible upcoming regulations and standards applicable to the field.

Chapter 4 – GAP ANALYSIS FOR SIMULATION BASED TRAINING AND DECISION MAKING

This chapter identifies some of the gaps between capabilities currently used in the military training and decision-making domains and capabilities that are foreseen as feasible when using new emerging technologies. Since the domain of training and decision making in combination with new emerging technologies is extremely large, a complete survey would be impossible to perform in this MSG-189 activity. Therefore only a few combinations are considered with the focus on AI and making these examples of a way of dealing with the more general problem.

The capabilities will be discussed based on use cases along the lines of the decision-making levels as described in Section 1.2.4.1. In this study it has been decided to focus on the **tactical decision-making** level also because there are not many models and simulators covering the operational level and close to zero at the strategic level. Most simulators and decision support tools currently used exist in the tactical domain and there is the most to be gained from using new emerging technologies in this domain.

4.1 THE TACTICAL LEVEL TRAINING DOMAIN

The tactical level can be divided into high tactical level (command level) and lower tactical level (front line / lower ranks). When these are combined with the three expertise/training dimensions as defined in Section 1.2.4.2 (theoretical, procedural, mission (leaving out strategic for reasons mentioned above)), the following six categories remain:

1. High tactical level (command level) training.
    - 1.1 Theoretical Training (knowledge).
    - 1.2 Procedural Training (skills such as man management, law, logistics, communications, etc.).
    - 1.3 Mission Training (Commander and Staff) competences such as battle management, red teaming, platform understanding, etc.).
2. Lower tactical level (front line / lower ranks training).
    - 2.1 Theoretical Training (knowledge).
    - 2.2 Procedural Training (skills such as weapon maintenance, safety checks, marksmanship, map reading, etc.).
    - 2.3 Mission Training (ranging from single to collective) which includes competences such as dogfighting, breach and clear, fire support and so on.

Since the number of cases that can be described in this report is limited, the following sections describe only a selection of the six categories above that, in our opinion, could most benefit from the use of emerging new technologies. These are for the high tactical level: theoretical training, procedural training, and mission training and for the lower tactical level mission training.

4.1.1 High Tactical Level (Command Level)

4.1.1.1 High Level Theoretical Training

There is little to no simulation training of more senior commanders (Figure 4-1). They take courses and they plan Courses of Action on paper but rarely get to see what the results of their plan would look like. They may get to do manual wargaming, which is very useful, but very rare, due to the time and cost of getting the people together to run those games. It also tends to be the more senior the commander the less opportunity they have to train. There is also peer pressure and an aversion to experimenting with new tactics as everything you do is very visible to the other players around you, so people take safe options and do not experiment, which is where real learning and innovation occur.

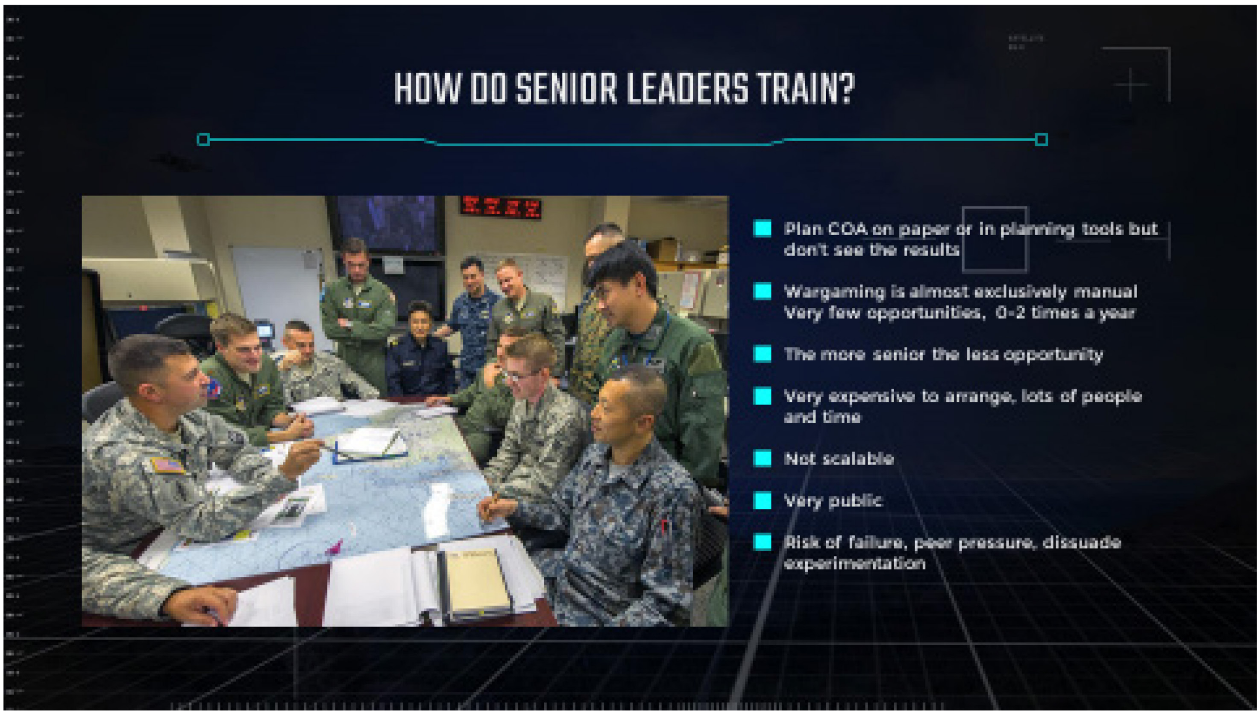

Figure 4-1: How Senior Leaders Currently Train.

4.1.1.2 High Level Procedural and Mission Training

4.1.1.2.1 The Importance of High Tactical Level Command Training

It is common sense that the more senior a Commander, the more people they have under their command, so the more people their decisions affect. Decisions made by Commanders affect the tactical situation the frontline soldiers find themselves in and this clearly impacts their chance of success. Good commanders are a force multiplier and bad commanders reduce the effectiveness of their troops. Clearly then it means that decisions made by senior commanders have more impact on the outcome of battles than junior commanders and frontline personnel. The conclusion then is that it is more important to train our senior Commanders than our frontline personnel (Figure 4-2).

All military leaders study history and know the stories of Hannibal and it's a good example (Figure 4-3). At Cannae, Hannibal was outnumbered and outclassed. Man for man his infantry was no match for the Roman legionaries and they were outnumbered. His only advantage was that the Roman cavalry was weak. Hannibal used this to his advantage, expecting his infantry centre to be pushed back while his cavalry enveloped the Romans, leading to one of the bloodiest single days of battle up until WWI.

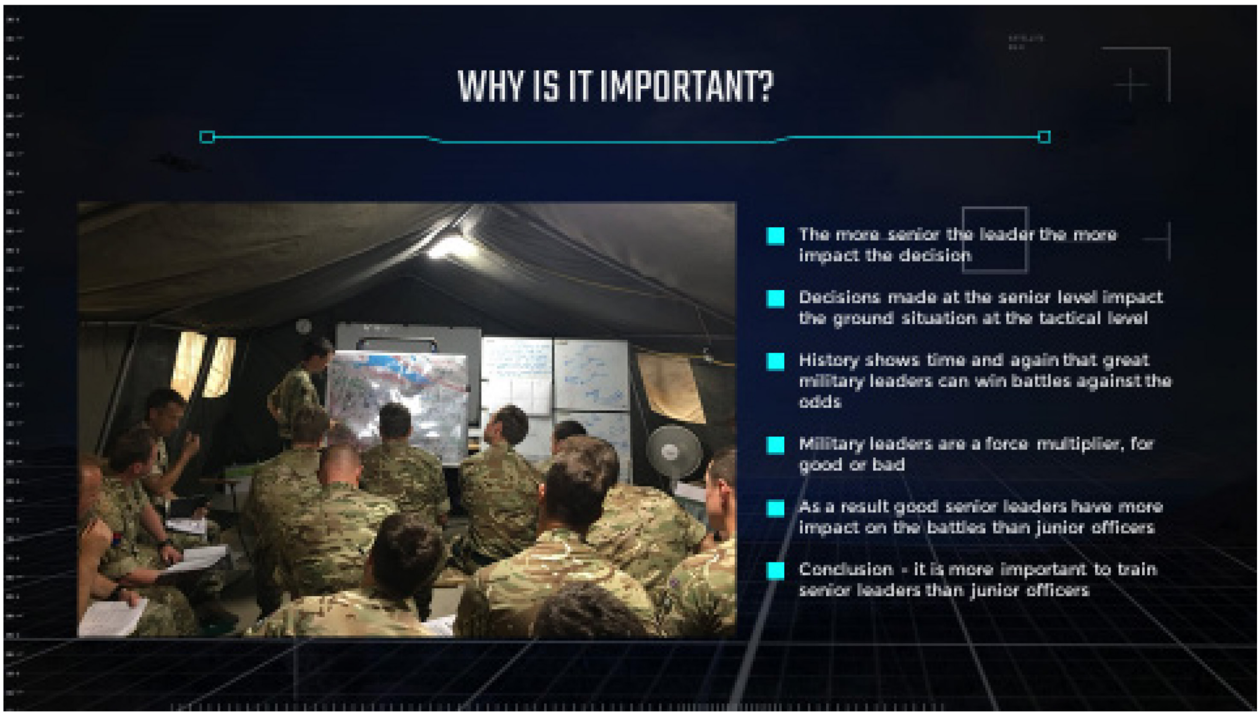

Figure 4-2: Why is Training for Senior Leaders Important.

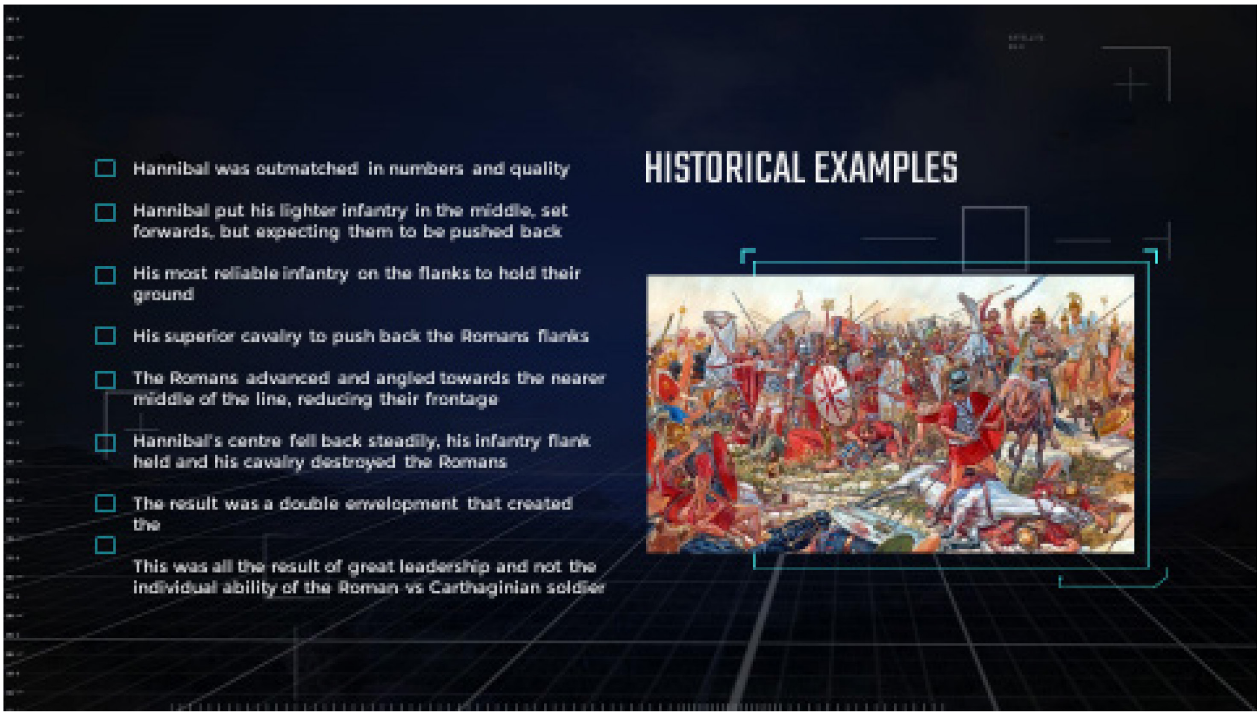

Figure 4-3: Historical Example – Battle of Cannae.

This is not an isolated example and history is full of such events where great leaders have won against the odds, including Napoleon at Austerlitz, Manstein in France (Figure 4-4). At the time of the invasion, the German tanks were no match at all for French tanks and couldn't hurt them frontally. In a head-on fight the Germans would have lost. Manstein's plan involved sucking the elite British and French troops into the Low Countries and surrounding them, cutting them from supply, making them easy targets. Similarly bad decisions can result in massive failure. The French Grand Armée that invaded Russia in 1812 was arguably the best in the world at the time and it got annihilated by the Russian winter. Hitler didn't learn from this mistake and repeated it in WWII.

Figure 4-4: History Repeats Itself.

There is limited access to Command Level Training, and it is not very standardised so there can be significant variety in how much and the type of training that officers receive. Tactical training is provided in a range of ways:

- **Systems like Command and Staff Trainer (CAST).** This is a digital system that lets officers and their troops train. It is very useful to experience how orders would be put in practice. The limitation is that every entity is human controlled so a commander would need hundreds of lower-level players to simulate even a medium sized operation. While it does allow the commander to train, it offers limited ability to try new tactics and strategy and experiment due to the number of frontline personnel in each "game."
- **Manual wargames (boardgames or table-top games).** These are manually moderated games, usually using custom rules set to resolve combat or SMEs to adjudicate, though can also be based on commercial board games. They are a good way to present interesting challenges to players and teach analytical tactical and strategic thinking. They present tricky problems with many possible solutions and the challenge is to find the optimal one. They can be organised with blue and red teams or just a blue team vs the umpire. Red vs blue presents a real thinking enemy that requires you to outsmart them.
- **Live exercises / rehearsal wargames.** These are live operations where troops will fight out pre-set battle plans. They are great for practicing how to get a large formation to move to a location at a set time. However, they are not really any use in learning tactics and strategy and are again aimed at providing training for the numerous frontline soldiers, so tend to be on rails with no real decision making for the commanders.

Note that different levels of command require different kinds of training. A Platoon Commander needs very different tactical training compared to a Battalion Commander, and a Battalion Commander is very different from a Divisional Commander.

4.1.1.2.2 Use Case: Land Operations Command and Staff Training

To date, the field of military Modelling and Simulation has been mainly involved in training applications for training of the lower military levels (Figure 4-5). Significant investments in M&S are made for training of frontline personnel such as pilots, gunners, drivers, and infantry. This is done through a range of systems using 3D and VR trainers. Many of these trainers aim at training skills and procedures rather than tactics.

Compared to the widespread use of lower tactical level training, there is a huge gap in the use of M&S applications such as wargames to train and assist the more senior tactical commanders to make better decisions. Reasons are that although training applications for these higher-level tactical commanders exist these require a lot of manpower and budget to perform and consequently these commanders cannot be trained frequently. New technologies, like gaming and AI, however, would enable these higher military levels to be trained better and more frequently. We discuss how using new technologies could enhance their training.

Figure 4-5: Focus is Currently on the Frontline at the Expense of Senior Leaders.

There are a number of problems with our current training. There is far too much focus on the frontline soldier. Clearly these people need to be trained but currently it is at the expense of the more senior commanders. We need to develop systems to allow our commanders and their commanders to train digitally so they can do it in their own time at their own speed and wargames are a great potential tool for this.

There is a misconception that by making graphics more detailed and moving to AR or VR there will be benefits for everyone (Figure 4-6). Whilst this is true for that soldier on the front line, this is less true for a company commander, or someone making operational level decisions. The higher up the command chain you are the less you need realistic views and the more you need an annotated COP. It is important that we do not over focus on VR and 3D and ensure we provide the right tools for the commander. In a recent demo presented by a developer, a missile defence system was being controlled in VR. In reality, the missile defence system would engage the target long before it came into range and the technology is unfortunately redundant, but it still gained a lot of attention. In some ways realistic views higher up the command chain can be a distraction rather than a decision aid, and in the UK officers are trained to ignore video feeds in HQs for just this reason. In another school of thought the idea exists that in some circumstances the use of AR and VR technologies may be valuable for a higher-level commander to get a good overview of the mission. Therefore, the lesson to keep in mind is that it is important to only feed the commander with information relevant to the decision they are making. There is a real risk of "overfeeding" the commander with additional information/visualisation.

Figure 4-6: Graphical Fidelity can be Mistaken for Simulation Validity and Usefulness.

Another common problem in defence is stovepiping (Figure 4-7). Each service has its own systems and models and funding paths. The modern battlefield is multi-domain, and any simulation needs to model cross service operations and be funded cross service. This is not just at cross service but also at the sub service level. For example, to support senior commanders, the model must be able to simulate large scale engagements and command and control. The M&S team may see this as a C2 problem, but the C2 people have no ability to build models and so neither side can get the senior support and traction to actually develop the system. It requires someone with vision who can look at the problem holistically and enough political power to push these ideas through and these people are few and far between (Figure 4-8).

Based on the following **land operation use case**, we describe how training at the higher command level is currently performed and present a vision of how training could be performed in the future. The gap between these two will give indications of the new technologies and research that will be required to fulfil this vision.

Although not frequently used, computer assisted training applications for command training do exist. These systems currently require a large training exercise staff. The current state of the art of these systems is discussed in this section after which in subsequent sections a possible future will be discussed.

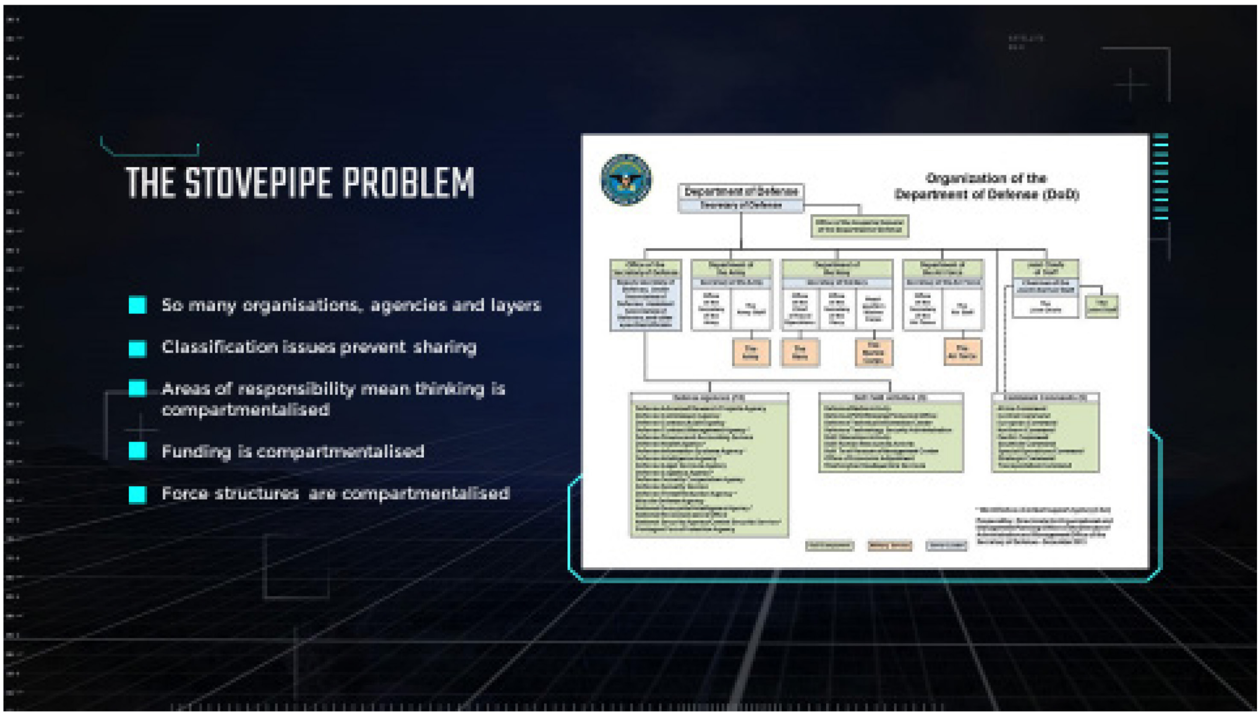

Figure 4-7: Stovepiping Restricts Investment and Prevents Good Development.

Figure 4-8: The Way Ahead.

Before presenting the use case, we outline the different levels involved in land operations training. These are visualised in Figure 4-9.

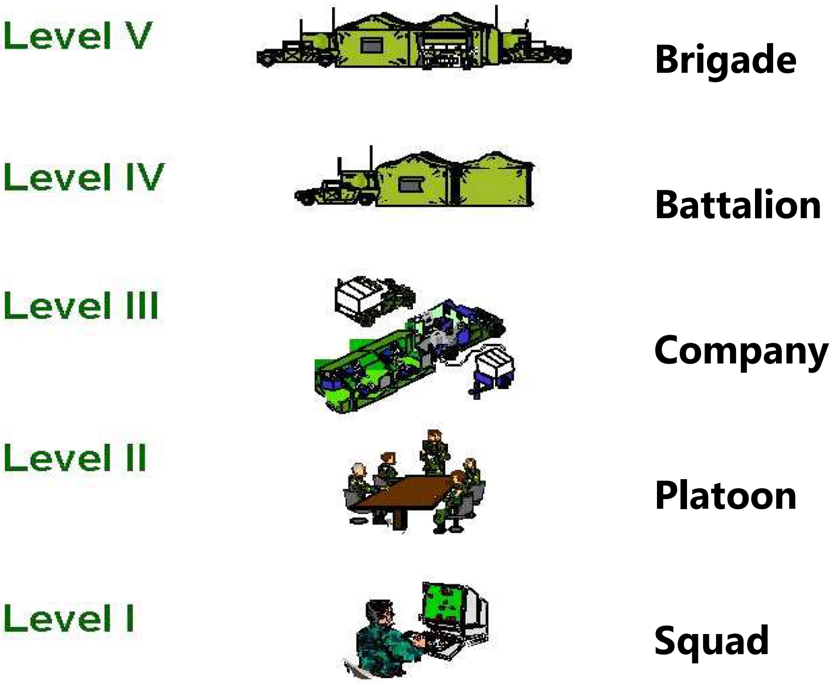

Figure 4-9: Land Operations Training Levels.

Current Situation in Command and Staff Training

Current digitally supported Command Staff training systems use a combination of computer simulation and a training staff.

As an example, think of a Battalion commander who is trained in commanding his subordinates and following the Military Decision-Making Process (MDMP). He will issue commands to his subordinate Companies, where each Company consists of say three Platoons and each Platoon consisting of say, three squads. All these subunits can carry different weapons and can be transported by vehicles. All these entities involved need to perform realistically following the Commander's orders.

This is where Lower Control operators come into play, transforming the higher-level commander's orders into lower-level orders that the simulation can execute. The "simulator" in that sense is a combination of a computer model supported with operators. This has been visualised in Figure 4-10.

Three types of operators are involved:

- LOCON (LOwer CONtrol operators), in Figure 4-10 (also called Pucksters) transform the trainee's commands into simulator executable commands.
- FLANCON operators represent Flanking units' commanders that control the subordinates of the flanking units in the simulator. In Figure 4-10 the trainee is the Battalion commander the FLANCON is a Battalion Commander.
- HICON represents the Commander's (trainee's) higher-level commander. In Figure 4-10, the trainee is the Battalion commander the HICON is a Brigade Commander.

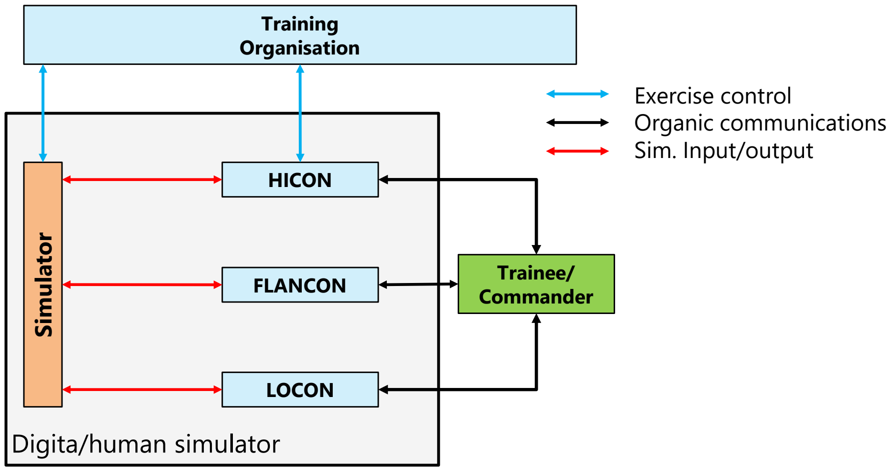

Figure 4-10: Command and Staff Training Configuration and Roles.

As can be seen, the trainee is completely emerged into a realistic environment, usually a command post tent using this organic available communication means. The two other components involved are:

- Training organisation or exercise control. This steers the training session by defining what needs to be trained and by operating the digital simulation. The actual order that the trainee will receive, through HICON, based on the available skills of the trainee compared to the required level of skills.
- The hybrid (digital/human) simulator consisting of the digital simulator and the manual HICON, FLANCON and LOCON components.

The type of training involved in the above Command training example is both procedural as well as tactical.

Vision for Future Command and Staff Training

Given the fact that current training sessions in a digital/human training system as described in the previous section require so many staff that it can only be done infrequently or can only be done on paper without digital support, the question arises of what kind of technology could make these kinds of training sessions more accessible.

The vision that we present here is that by using AI technology and (currently available) gaming simulators a lot of the currently required staff will no longer be needed. Figure 4-11 represents this vision.

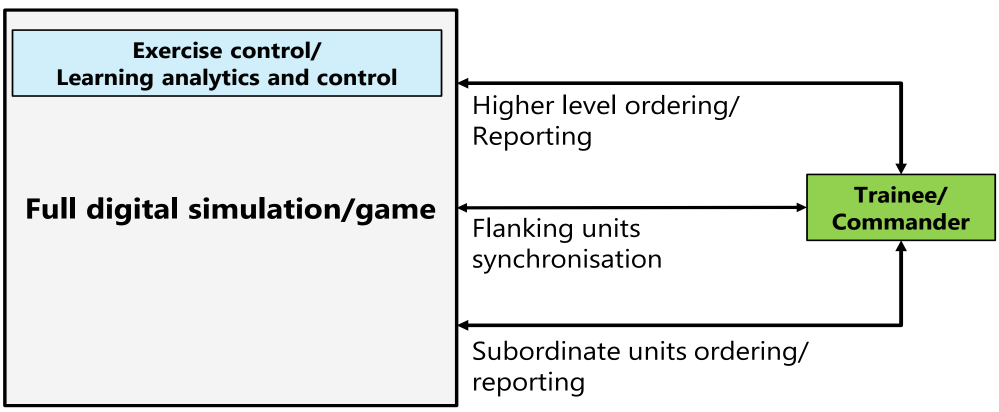

Figure 4-11: Future Vision for Command and Staff Training Configuration and Roles.

This would enable military staff to train more often, with an aim that commanders can train in spare hours and don't need a full staff to support that training.

Three examples of automation that would help to fill the gap between the current situation and the vision are:

- **Automation of military co/counter-play:** the role of the subordinate and flanking units as well as the higher command are currently fulfilled by humans. Artificial Intelligence could also fulfil this role. This could be done initially using complex systems and rules-based AI and later adapted to machine learning approaches. These machine learning approaches could be based on reinforcement learning where strategies are learnt that optimise behaviour or could be based on a data driven approach where data from an expert role player is recorded and used with so-called imitation learning techniques to mimic the expert's behaviour.
- **Education support:** an exercise control module could, in combination with a HICON module, and based on the trainee's progress, define scenarios and orders for the trainee. LOCON modules could determine the best way to transform the trainee's orders into subordinate orders and a FLANCON module could play flanking units. A Red unit behaviour module could be used to play the enemy.
- **Communications automation:** the way that the trainee currently receives and gives orders is by the organic communication means. It is imaginable that speech technology could be used to provide the trainee a way of communicating that has the same look and feel and thus is sufficiently viable for training.

Some challenges related to the future Command and Staff training are:

- **Fidelity level of simulation**: the statement in the section above about the level of fidelity of the simulation that should be selected carefully for the higher command level is true, especially for the interface and the provisioning of information to the commander. The commander should not get too detailed battlefield information and therefore should not use VR or 3D technology, for example, because it can be distracting. On the other hand, the level of the battle resolution in the simulator should be sufficiently high to ensure realistic behaviour. This will also depend on the training purpose which can be tactical training or procedural training. 3D and VR can also be useful for after-action reports to understand why things happened but are of limited use at runtime. The challenge will be to find the "right" fidelity level, depending on the training purpose. For instance, if a simulation system is to be used for rehearsal of a given mission, the modelled environment, including the behaviour of (own and co-acting) units, needs to be close enough to the real environment, however if it is only to learn tactics, this requirement can be relaxed.
- **Train as you fight:** the "Train as you fight" paradigm means that a warfighter should use his operational systems wherever possible and not be forced to use a surrogate simulation interface. For C2 training this translates to the requirement that the native C2 information system should be used, which should obtain its input form the simulator/game. In practice the C2 information system must interface with the simulator/game. The challenge then is to implement the use of C2 – Simulation Interoperation standards (see Ref. [54]) or create tools that can replicate this behaviour. There is potential for middleware tools to be created that allow users to work in familiar processes and the tools convert this input to language the simulation understands. In the mid to long term, it may even be possible to use AI assistants to convert spoken or written instructions to simulation-parsable formats.

4.1.1.3 Lower Tactical Level Mission Training

A significant amount of time and effort goes into training frontline personnel in mission tactics. This ranges from simulators to live training. There has been a significant push towards simulation training and virtual reality in recent years. Initially the focus was on pilots and teaching them how to take off and land, how to dogfight and much more in a simulator before they get to try it on a live platform. Increasingly the technology is being put to use on infantry, tank operators and sailors to teach similar tactical skills. As the frontline soldiers make up the vast majority of staff who need to be trained, there is a tendency to focus the vast majority of effort on training them.

In the next two subsections, two example use cases for the use of new technologies at the lower tactical level Mission training levels are discussed.

4.1.1.3.1 Use Case: Wargaming Against AI in Flight Simulators

Currently, most of the wargaming simulators have rule-based agents and their behaviours can be predicted after a few plays (Figure 4-12). Reinforcement learning based training of these agents gives a human-like decision and action capability to these agents and they may behave outside the conventional patterns and doctrines. Hence every play becomes a different scenario with different tactical challenges. This approach can be used for all the levels from frontline to HQ simulators. At the HQ level playing against an AI commander is much more challenging since that AI commander has trained itself with many different conditions, tactics, and manoeuvres for the same theatre. The challenging part in this approach is training all frontline AI agents for different roles and above that training the commander with his new AI force.

Figure 4-12: Wargaming Against AI in Flight Simulators.

AI based training (Figure 4-13) also may have the flexibility to adapt to the abilities of the trainee. Training should be in the frontiers of the knowledge domain, providing the correct dose of the challenges during the war against AI. If the task is challenging, the scenario will prevent the trainee to handle the situation and learn the correct skills needed. Again, if the task is straightforward, the trainee will not be learning any novel skills but only repeat what is readily acquired. The AI should also be learning from the ongoing experience to assess the abilities of the trainee and proposing new challenges consistent with this info during the wargame.

Figure 4-13: AI Based Simulator Trainings.

4.1.1.3.2 Use Case: Smart Training Scenario Generation in Flight Simulators

The most beneficial part of this fight against AI is learning new tactics and strategies from their behaviour and using it against to the AI in the next play (Figure 4-14). Also, having such a system decreases the need to write many rules for each different scenario so the scenario generation duration decreases. The AI agent can provide the flexibility to blend into the theatre and act realistically. The preparation time for scenario formation has the potential to be drastically decreased with this approach.

Figure 4-14: Smart Training Scenario Generation in Flight Simulators.

4.2 THE TACTICAL LEVEL DECISION SUPPORT DOMAIN

Tactical level decision making is a huge domain that includes land, air, maritime (or multi-domain) as well as the different tactical levels where new technologies could be used in a multitude of ways. Therefore, because of the necessarily limited scope of this study, this section can only describe a very limited number of possible applications. In the following two subsections three use cases are discussed for lower as well as the higher tactical level.

4.2.1 Lower Tactical Level Use Case: Decision Support System for Pilots

Reinforcement Learning (RL) can be used to support pilots in their decision making (Figure 4-15). It has two main advantages: 1) Adaptation to the changing environment; and 2) Potential to synthesise smart moves that is hard to replicate by human planning. After getting trained in digital domain for an extended period of time, there is a possibility to transfer this knowledge to the real domain without replacing human pilots. Human agent and AI agent can work together and cooperate to achieve a common goal. A natural way of doing this is using the intelligence in the form of a decision support system for real pilot.

The RL powered decision support system has the potential to empower the experienced pilots with instantaneous action recommendations during an engagement such as a dogfight. The psychological and physical stress induced on a fighter jet pilot or pilot trainee may cause inefficiency in pilots’ judgement or motor controls. The support system can be coupled with the pilot’s actions in order to provide the best performance in a fight scenario.

Figure 4-15: RL Powered Decision Support Systems for Pilots.

4.2.2 Higher Tactical Level Use Cases

This section describes two higher tactical level use cases, one maritime and one land operations use case.

Use Case: Decision Support for Maritime Surveillance (Figure 4-16**)**

The future battlespace will have many more sensors all delivering data across multiple domains and the result will be a sea of data. In addition, red forces will be using our own system to feed us huge amount of dummy and decoy data. On top of this the future war will be fought at a pace never seen before with hypersonic missiles and stealth technology meaning there will be seconds rather than minutes to make decisions. These all combine to create an environment that will overwhelm a human brain and require massive amounts of support from AI to eliminate the noise and present the relevant annotated data to the decision maker. These tools can be built in a simulation and be very similar or maybe even identical to tools used operationally.

Figure 4-16: Stressing Maritime Scenario that Requires Decision Support.

Use Case: Decision Support for the Military Decision-Making Process in Land Operations.

The current approach to military tactical decision making in land operations planning is a process that is used from Brigade/Battalion level down to subordinate units. The lower the level, the less time and detail is involved in the process. However, in all these levels, in general seven steps can be distinguished which are visualised in Figure 4-17.

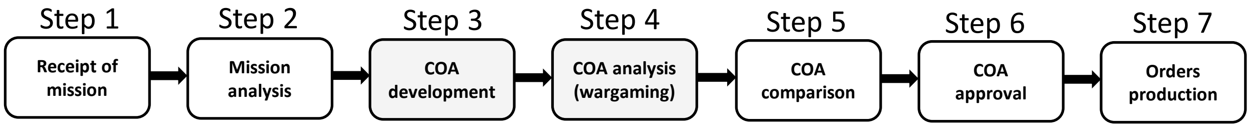

Figure 4-17: The Military Decision-Making Process.

For instance, at the Brigade level, various experts from different fields come together to develop a combined Course Of Action (COA) that takes into account all the different disciplines (for example infantry, fire support, engineering, medical). Although the use of AI is possible in many of the steps, two important steps that can benefit a lot from AI are COA development and COA analysis (wargaming) steps. In COA development, AI can support in considering many options in order to come up with a "best" solution. In COA analysis (wargaming), AI can support in red teaming by presenting realistic enemy tactics. These items are currently studied in a research project called COSMOS (Combat Operations Support with Modelling and Simulation) [55].

Chapter 5 – REQUIREMENTS

5.1 INTRODUCTION

As described in Chapter 1, among the main objectives of the MSG-189 Specialist Team, there is the study of how M&S can support the training of military personnel at all levels making use of innovative and disruptive technologies.

In particular, the greater effort is focused on studying the support to be provided to the upper levels of the military hierarchies (High Rank Decision Makers) both for what concerns their advanced training needs and for the operational aspects. This because it has been realised that this specific area of training has, up to now, not been adequately supported by M&S tools.

Fundamental components of this study already addressed in other chapters (2, 3 and 4) are:

- The research and critical analysis of new technologies made with a view to their use in the topics indicated.
- The analysis of the existing gaps between the training of military personnel carried out with current systems and what could be done in the near future using the identified new technologies and architectures.

The final outcome of these activities will lead to the definition of a simulation framework/ecosystem that, using state-of-the-art technologies and referring to the most advanced architectures used in M&S systems, will aim to constitute a reference for upcoming new M&S systems.

This chapter adds to the described process a list of requirements classified as follows:

- User Requirements.
- Domain Specific Requirements.
- Security General Requirements.

They define in the broadest and most inclusive possible way the requirements that the simulation and training environment will need to fulfil. Some of them come from experiences into defining M&S systems, others are the result of the needs emerged from the investigation phase.

Each requirement has been uniquely identified and classified according to its type (System, functional, etc.). Requirements related to common themes have been aggregated into groups and labelled as sub-requirements.

The inputs received were further separated out by identifying those relating to specific domains or qualifying specific aspects of the system; these requirements have been grouped into separate tables like, for example, a table listing containing the security requirements.

Three more columns have been inserted in the requirements tables ("Requirement Applicability", "Requirement Rational" and "Emerging technologies possible contribution").

For each requirement:

- The "Requirement Applicability" column indicates the scope of application of the requirement itself (Training, Decision-Making, General);
- The "Requirement Rational" column indicates the rationale that led to its formulation. It can also describe the simplest solution to implement the requirement (or the one currently implemented); and

- The "General Remarks / Notes" column indicates instead how, using some of the technologies described in Chapter 2 and Chapter 3, the requirement can be fulfilled in an innovative way. This is not going to be always easy to describe. For this reason, the answer will be provided only in some cases in this column; in Chapter 7 any requirement will be fulfilled with the identified products / services coming out as the outcome of the complete MSG-189 ecosystem.

The tabular form used has the advantage of providing a synoptic view and making it easier to read and understand the requirements but has the drawback, at times, of not being able to adequately illustrate the concepts and rationale behind it. Where necessary, the details for these requirements have been included in Section 5.6.

5.2 SCOPE

It is not the intention (or within the possibilities) of the Specialist Team to specify in detail all the functional and implementation aspects of the framework and therefore the requirements listed below certainly do not cover all the functional aspects.

The goal is rather to outline scenarios and innovative future solution directions for both the hypothesised technologies and the architectural structure of the framework.

The Specialist Team has the goal of imagining a complete system designed to operate with very advanced technologies and concepts.

The aim of the team in any case is to describe the most possible complete architecture that encompasses all the features and technologies identified. Indeed, the architecture will be a "Reference Architecture" which will provides a template for the definition of future "Solution Architecture."

5.3 USER REQUIREMENTS

The general and qualifying requirements for the entire system have been included in Table 5-1.

Most of the requirements have been defined within the group based on experiences with past M&S projects.

Table 5-1: Users' Requirements.

#		Requirement	Req. Type	Req Appl	Requirement Rationale	General Remarks / Notes
1		**The user is interested in a long-term relationship with the provider, preferring a multi-year contract and having the provision of an all-inclusive training service.**	S	G	A long-term relationship with the provider allows the final user to put in place an open relationship based of mutual and trusted way to work. In addition to that multi-year contract provide the parties with continuity and save time avoiding hand overtake over time between providers. Time that can be dedicated and allocated to reach the common target.	*The optimal solution is to establish a services platform that allows the end user to concentrate only on specific problems related to his/her work, making the services provider in charge for the configuration management, SW and HW upgrades, platform maintenance, etc.*
2	a	**The system should allow for scalable Training and Exercises (from single operator basic theoretical training up to large joint international multi-crew combined exercises).**	F	T	A unique and coherent way of enabling the user to deal with different levels of instruction. The system must have an interface that allows access to specific information regardless of the level of education (if the user is already authorised to do so).	*LVC architectures, MTDS, MSaaS, supporting theoretical and procedural training (e.g., CBT expanded with xR, virtual mock-up, …), single and collective mission training (e.g., immersive, and not immersive virtual environments).*
	b	**The system should allow the user to execute, evaluate, and score the complete training activities starting from the mission planning, mission execution and mission debriefing, at all levels.**	F	T, DM	It is of paramount importance to standardise the method of assessing students at all levels of education/training to allow the instructor to understand, in a unique way, if the student is ready for the next stage while also having a complete view of his/her status and potential.	*Already present in the Training Systems for the theoretical and procedural parts. For the Mission part and Decision-Making support an extensive use and support from AI can be investigated.*

#		Requirement	Req. Type	Req Appl	Requirement Rationale	General Remarks / Notes
	c	**The system should allow for multi-site interconnected training systems providing a Common Synthetic distributed Environment** *(es. SPARTAN or VIKING Exercises).*	S	T, DM	Nowadays it is increasingly common to have exercises involving sites that are remote apart (even located in different countries), avoiding the need to move people (skills) and hardware resources. It is also intended to maximise the exploitation of site-specific excellence.	*This is an intrinsic characteristic of distributed simulation systems based on international standards (IEEE DIS/HLA, Training and Training Enabling Architecture (TENA)).*
	d	**The system should allow for multi-domain interconnected training systems providing a Common Synthetic Environment.**	F	T, DM	Nowadays it is increasingly common to have exercises involving multi-domain scenarios. This will imply the capability of the synthetic environment to address and represent such as domain.	
	e	**The system should allow for realistic and challenging tactical and strategic training (adaptable scenarios with higher degree of complexity).**	F	T		*Leveraging artificial intelligence in support/replacement of personnel to replicate human behaviour and functionality of "Red Forces" weapon systems (making behaviour more adherent to TTPS, improving modus operandi by having reasoning behind red forces operations).*
	f	**The system should allow for extended Recording Capability allowing the Playback, and Resume, from a given point, of the simulation.**	F	T		*Intrinsic characteristic of training simulation based (especially having standard After-Action Review utilities (AAR)).*

#		Requirement	Req. Type	Req Appl	Requirement Rationale	General Remarks / Notes
3		**The system should allow for repeatable scenario for a highly effective learning and CD&E processes.**	F	T, DM	Capability of changing some parameters of the same scenario in order to analyse different outcomes and CoAs.	
4	a	**The system should allow for ensuring secure *technical* interoperability across different forces from different countries.**	F	G	Innovative interoperable cross-domain solutions: the ability to interoperate across countries has already been demonstrated but Cyber Security solutions are key to securing network infrastructures.	
	b	**The system should allow for ensuring secure *operational and procedural* interoperability across different forces also from different countries.**	O	G		
5		**The system should allow for supporting operationally the evaluation / certification of resources (staff, means, systems, etc.).**	O	G		*Use of AI in the on-line operational monitoring or after-action operation review.*

#		Requirement	Req. Type	Req Appl	Requirement Rationale	General Remarks / Notes
6	a	**The system should allow a training environment good to be used to support in defining new CONOPS and CONUSE (Developing, Testing and Proofing of techniques, tactics and procedures, tools to improve decision-making/mission planning), including a new way toward “wise procurement.”**	O	T, DM		*Use of virtual scenarios (including advanced features previously mentioned) in supporting high-level command lines and decision makers.*
	b	**The system should allow for supporting the capability analysis by identifying needs for new capabilities and evaluate the value of a specific (new) capability within an existing force structure and with reference to specific scenarios.**	S	DM		*Development of specific simulated scenarios to investigate the differences between the previous state (legacy systems) and the new one after the proposed change/improvement with the introduction of innovative services/capabilities/platforms.*
7	a	**The system should allow for building training environments that can save time on “Live” training, reducing the number of participating assets (valuable assets must be dedicated exclusively to operational missions)**	S	T		*Intrinsic characteristic of virtual scenarios delivered through distributed simulation systems based on DIS/HLA standards. Use of AI agents to replicate assets (red or blue).*

#		Requirement	Req. Type	Req Appl	Requirement Rationale	General Remarks / Notes
	b	**The system should allow for reducing limitations related to hazard and environmental restrictions. For example, no hazards for personnel involved in the exercise or the availability of a proper training environment (e.g., a large enough physical battle space).**	O	T		*Intrinsic feature of scenario simulation systems in which people are not physically engaged and the environment can be set according to the needs of the specific exercise virtually without restriction.*
8		**The system should allow for facilitating re-use of Customers' already available assets.**	S	G		*Use of proper gateways to interface the new architecture with legacy systems.*
9		**The system should facilitate security handling (i.e., Protect and secure systems and connections among all the connected sites and assets.)**	S	G		*Finding state-of-the-art solutions for cross-domain security.*
10		**The system, when used for training, should be aligned with the MTDS Reference Architecture.**	F	T	In order to avoid confusion, at least the training part of the generic system should extend the MTDS reference architecture and not contradict it.	
11		**The system should allow for providing COA analysis in order to identify possible gaps and alternative solutions.**	F	DM		*Dynamic programming, AI, and Big Data analysis (if a significant exercise log is available).*

#		Requirement	Req. Type	Req Appl	Requirement Rationale	General Remarks / Notes
12		**The system should facilitate the use of different fidelity levels and allow the user to simulate the same entity/sensor/phenomena with different level of fidelity in accordance with the required levels of details for the different users (e.g., trainee and the instructor or soldier and commander)**	F	T, DM		*The availability of different fidelity levels for the models is one of the characteristics for a modern simulation environment. This functionality is, of course, related to the available technology with a clear impact on the system cost.*
13	a	**The system should allow for simulate the different scenarios in a statistical way and analyse the output of each simulation. By means of an iterated approach it will be possible to identify the best configuration and assets to be used. This will allow the reduction of number of trials to be executed at higher level and therefore to allow trials cost reduction.**	F	DM		*To answer to this requirement two approaches can be foreseen:* • *Monte Carlo Simulations to obtain a significant statistical sample;* • *A real-time approach to perform a large set of experiments in simulation mode that can be repeated in real world only for a limited selected number of them (Data Farming??).*
	b	**The system should allow the user to execute the same scenario in simulated mode and in live allowing comparison and evaluation of the outputs (also validating the simulation accuracy).**	S	G		*The validation of a model is performed comparing the output coming from the real system and from its model.*

#	Requirement	Req. Type	Req Appl	Requirement Rationale	General Remarks / Notes
14	**The system should allow the user to generate realistic complex behaviour in constructive forces.**	S	G	Complex Constructive Force doctrine has to reflect both blue and red forces doctrine. In other words, constructive forces have to replicate real-world modus operandi. Especially for Mission Rehearsal eXercise (MRX – CPX CAX series) that has to be necessary, to allow friendly forces to train themselves in preparation for the upcoming deployment. Concerning SITFOR/RED FORCES (the enemy) real doctrine when applicable has to be considered in order to achieve the principle "train as you fight." In addition to that, when talking about asymmetric treat (local militia/terrorist groups, insurgents, etc), their TTPs (Tactic Techniques and Procedures) in other words the way they fight blue forces, has to be scripted/uploaded and used both during the MEL-MIL scripting phases and then replicated over a constructive simulator during the execution phase of any exercise.	*See Section 5.6.2.*
				Intel scripting and intel simulation, as regularly happen in live when different parties face each other on the field, have to be part also of constructive exe in order to give fidelity and realism to the real-world situation.	

Requirement Type Legend:

S = System

- System Requirements specify capabilities and characteristics applicable to the whole ecosystem.

F = Functional

- Functional Requirements define the system behaviour and its capabilities and characteristics applicable to specific functions of the system. Essentially, they describe what the system does or must not do. They can be thought of in terms of how the system responds to inputs.

O = Operational

- Operational requirements are those statements that identify the essential capabilities and the process or series of actions to be taken in effecting the results that are desired in order to address mission goals. Operational requirements are the basis for system requirements.

Requirements Applicability Legend:

G = General

T = Training

DM = Decision-Making

5.4 DOMAIN SPECIFIC REQUIREMENTS

The requirements listed in Table 5-2 relate to specific application areas of the system. They can be seen as a characterisation of the simulation and training environment for specialised uses where particular performance and functionality are required.

Table 5-2: Domain Specific Requirements.

#		Requirement	Req. Type		Requirement Rationale	General Remarks / Notes
101	a	**The system should allow for defining training and simulation scenarios with manned-unmanned systems and UxV swarm.**	F	T	Testing in simulation scenarios for a real-time route optimisation service in relation to a dynamic change in the environment (e.g., restricted areas for sites with unexpected crowding).	
	b	**The system should allow for supporting training and simulation scenarios with swarms that operate in surveillance areas.**	F	T		
	c	**The system should allow for supporting data acquisition from sensor data (pictures, video, infrared, radar) in scenarios with manned-unmanned and UxV systems in order to identify objects of interest and contribute to the common operational picture for decision-making training.**	F	T, DM		

#		Requirement	Req. Type		Requirement Rationale	General Remarks / Notes
102		**The system should allow for defining training and simulation scenarios that support target allocation. Optimally allocate effectors to identified targets by effect, availability, costs, etc.**	F	T	Analysis of the results of a series of simulated scenarios to define the rules for obtaining the best possible allocation choices depending on the known parameters. (see work of NMSG 155 – Data Farming) [56].	
103		**The system should allow for supporting Collateral Damage Estimation specific for Urban Environment and support INFO OPS to warn CIVPOP.**	F	T, DM		
104		**The system should allow for including in the simulated scenarios the Cyber and Electromagnetic Activities (CEMA) effects.**	F	T, DM		*Testing the cyber resilience of systems simulating a cyber-attack on virtual and/or real assets using an extended cyber range.*
105		**The system should allow for considering different level of System Validation campaign Field Validation (e.g., Red Flag) HW Validation (Using validation Rig) SW Validation (Using Emulated SW) and their different level of cost.**	S	T, DM	See Section 5.6.1	

#		Requirement	Req. Type		Requirement Rationale	General Remarks / Notes
106		**The system should allow for analysing social media activities related to the area of interest in order to enhance the situational awareness with respect to the population.**	O	DM	Use the social media channel as one of the shared data in an MSaaS architecture that provides a service to analyse public “sentiment” and use the results as input in the simulated scenario. For example, to improve a decision-making process and/or a new definition of CONOPS.	

5.5 SECURITY REQUIREMENTS

The requirements listed in Table 5-3 relate to the security aspects that the simulation system will have to provide; in particular, the safety standards that must inspire all phases of design, construction, and maintenance of the HW, SW and network components of the M&S environment.

Table 5-3: Information Security Requirements.

#	Requirement	Req. Type	Req Appl	Requirement Rationale	General Remarks / Notes
201	**In the system, "Secure By Design" principles should be adopted in the implementation of the system and related applications.**	S	G	Considering a distributed and interconnected system, cyber and information security aspects are a key concept to be taken into account. Cyber security aspects should be considered from the beginning of the activities, in order to ensure proper security practices and to avoid possible future adjustments (time consuming and expensive).	*Adoption of common standards and methodologies in all the phases of development, from the design to the rollout, evaluating all the aspects that may affect the system as a threat from the early stages of implementation. In particular, a DevSecOps model (integration of security in early stage of development cycle) should be followed as a continuous improvement process.*

#		Requirement	Req. Type	Req Appl	Requirement Rationale	General Remarks / Notes
202	a	**The system should define and implement processes and procedures to ensure proper management of service-related, user and administrative accounts and related credentials, especially for machine identities.**	S	G	The management of the accounts for access and management of the systems (with particular reference to those related to machine identity) should be carefully managed and follow certain policies and procedures established considering the exposure of the data and information to external threats, taking into account the increase of digital identities used to automate and integrate processes.	*Adoption and definition of technologies, processes, and procedures able to grant proper account and access management, particularly focused on machine identities management, including the following aspects:* • *Develop a full-life cycle for machine identity management;* • *Establish a procedure to drive automation with certificate environments;* • *Secure virtual systems environments;* • *Discover and securely manage machine identities.*

#		Requirement	Req. Type	Req Appl	Requirement Rationale	General Remarks / Notes
	b	**The system should adopt security best practices such as segregation of duties and need-to-know / need-to-use in the definition of user access, implementing dynamic access provisioning but also reducing the attack surface.**	S	G	It is of relevant importance to ensure that all users and administrator are allowed to perform only the actions they need to perform because of their tasks. On the other hand, rapidly changing DevOps environment require more adaptability, such in a dynamic access provisioning model, based on adaptive access control.	*Adoption of technologies and/or processes for analysis and monitoring of user accesses (including external service providers), managing provisioning and de-provisioning, and enabling normal user control, able to grant proper adaptive access control, such as Zero Trust Network Access (ZTNA), or Software-Defined Perimeter (SDP), in order to create an identity and context-based, logical access boundary around the applications in scope. Access to the applications is restricted through the use of a trust broker to a set of determined entities. The broker, after verifying the identity, context, and policy adherence of the specified participants, allow the access with configured role and permissions.*
203		**The system should establish and ensure the use of standard secure operating system configurations.**	S	G	All components forming part of the infrastructure should be configured and hardened following a well-defined set of settings, related to all possible aspects of the system: • General security settings. • Domain group policies. • Server hardening. • Workstation hardening. • Databases.	*Adoption of hardening practices able to quickly scale and adapt to large and distributed environments. Evaluate the use of Artificial Intelligence (AI) and Machine Learning (ML) on large sets of data related to system configuration, in order to rapidly detect anomalies and focus the manual analysis only on relevant and non-standard configurations.*

#	Requirement	Req. Type	Req Appl	Requirement Rationale	General Remarks / Notes
204	**System and network environments of the system must be protected by infrastructure security solutions able to detect cyber threats with advanced analytics techniques able to enhance process automation.**	S	G	Prevent the unauthorised release of information (more generally any unauthorised communication) outside the perimeter of the system. Advanced analytics techniques should be used to enhance and complete traditional perimeter protection mechanisms, such as file integrity analysis tools (host-based) and network intrusion detection systems.	*Adoption of advanced analytics techniques based on Artificial Intelligence (AI), aimed at the reduction of required time to perform data analysis and the improvement of decision-making processes, such as:* • *Deep neural networks (deep learning);* • *Decision intelligence;* • *Knowledge graph;* • *Machine learning.*
205	**The system should allow for recording logs in a standard format, so that audit logs can be used for troubleshooting purposes or for security analysis reasons.**	S	G	Logs can be used either to identify malfunctions and to perform troubleshooting, as well as to identify anomalous system and user behaviours. Logs should be archived and stored centrally, physical, and logical access to them must be limited to authorised personnel only. Ensure that all systems that store logs have adequate storage space for the logs generated on a regular basis, so that log files will not fill up between log rotation intervals. The logs must be archived and digitally signed on a periodic basis.	*Configure all systems to log the required data and according to a defined procedure for log management.* *Log analysis should be used to enable traditional security analytics (e.g., correlation rules) but also to enable advanced analytics techniques, such as User and Entity Behaviour Analytics (UEBA), predictive analytics, threat hunting, etc. even in collaboration with other tools or external data feeds.*

#	Requirement	Req. Type	Req Appl	Requirement Rationale	General Remarks / Notes
206	**The system should allow for secure remote access for management purpose. It should leverage encrypted communications aligned with innovations in the field.**		G	Remote access to the system components (e.g., management network) should comply with the following methods: • Must be allowed only through encrypted communications; • It must be possible to authenticate to the services through strong authentication systems; • It must be secured even considering the enhancements in quantum technology field.	*Definition and adoption of proper protocols for encrypted and secure communications, able to be used for the next years, considering all possible use and impacts that the use of quantum technology and Quantum Computing (QC) can have on the field of cryptography.*
207	**In the system, proper processes, tools, and methodologies should be defined to grant resilience and operations continuity in case of an accident or service disruption.**	S	G	Consider all possible impacts of a service interruption, disruption, or degradation, defining response procedures and activities to be performed to go back to normal operations (e.g., backup and restore, etc.).	*Definition and implementation of procedures and processes to ensure proper backup management and proper management of the operational continuity of the service and supporting infrastructure. Even if such practices are standard when applied to on-premise systems, the availability of data and applications needs to be carefully considered for cloud and/or SaaS environments, especially for cloud-generated data and its recoverability (e.g., cloud data backup).*

#	Requirement	Req. Type	Req Appl	Requirement Rationale	General Remarks / Notes
208	**In the system, secure Software Development methodologies should be used and adopted during all phases of design and realisation.**	S	G	Software development activities must be performed in accordance with a documented systems development methodology. It is possible to adopt one of the many already defined and available (e.g., OWASP SAMM) or create a new one.	*Definition or adoption of a Secure Software Development Life Cycle (SSDLC) methodology and use it during all stages of development. For example, the methodology should address topics such as:* • *During software development activities, control routines on the input fields must be guaranteed.* • *The developed applications must prevent the display of error messages containing information considered critical to end users (sanitisation of the outputs).*
209	**The system should allow for conducting a security assessment before the release of the system and on a predetermined frequency, taking into account vulnerability prioritisation and related risks.**	S	G	Vulnerabilities in the systems, networks and applications adopted must be avoided as soon as possible, through the execution of scheduled vulnerability assessments or other automated tests, relying on a product or test able to include risk-based considerations for vulnerability prioritisation.	*Adoption of a Vulnerability Prioritisation Technology (VPT), able to integrate assessment executed by Vulnerability Assessment (VA) tools, Configuration Management Databases (CMDB), Application Security Testing (AST), and cyber threat and vulnerability intelligence, to prioritise actions for vulnerability treatment, enabling an efficient Risk-Based Vulnerability Management Process (RBVM).*

#	Requirement	Req. Type	Req Appl	Requirement Rationale	General Remarks / Notes
210	**The system should ensure proper data security protection functionalities able to grant resilience, reliability, transparency, and trust, provided by decentralised functions.**	S	G	Data security should be granted through the use of data security applications able to ensure integrity of data, data transparency and with decentralised authority, reducing all trust issues.	*Data security enabled by blockchain applications can leverage decentralisation capabilities to offer methods to establish data protection, with minimal reliance on centralised components. Such tools can enhance data encryption, transparency, and all aspects of the CIA triad.*
211	**The system should implement data protection techniques able to secure data at rest, in transit but also while in use by the applications.**	S	G	Implementation of a data management strategy that can ensure secure and private sharing and analytics of data, mediating between data availability needs and data security specific and technical requirements.	*Adoption of methods based on distributed computing and cryptography that can enable applications to handle data while keeping data itself or encryption keys in a protected state: technologies such as Secure Multiparty Computing (SMPC) can be evaluated for the purpose.*

5.6 DETAILS OF REQUIREMENTS

The tabular form, used in the preceding sections of this chapter, has the advantage of providing a synoptic view and making it easier to read and understand the requirements but has the drawback, at times, of not being able to adequately illustrate the concepts and rationale behind it. This paragraph describes requirements that need more details that cannot be explained in the table form.

5.6.1 Requirement 105

The system should allow for considering different level of System Validation campaign Field Validation (e.g., Red Flag) HW Validation (Using validation Rig) SW Validation (Using Emulated SW) and their different level of cost.

Requirement Type: System

5.6.1.1 Requirement Rationale

The objective of the requirement is to extend the capabilities of the system beyond those specific to the training, i.e., into the domain of decision-making support.

What is required of the system is the ability to run different simulation trials aimed at verifying:

- The effectiveness of the specific asset for the specific mission;
- The correctness and effectiveness of the mission data produced for a specific mission; and
- The effectiveness of specific Techniques, Tactics and Procedures.

These trials can be performed in the following ways (others can be created, these are by way of example):

- **1st level – Scenarios composed exclusively of SW components**
  - In this case it is assumed to perform a high number of simulation sessions using the same scenarios with automatic iterations and with controlled variation of the variables involved.

    Once the *N* iterations have been carried out, a sample of variables will be identified (which corresponds to the best tactic, the best set of Mission data, etc.) that performed best in the iterations carried out and this sample will be subjected to a second level evaluation.
- **2nd level – Scenarios in which there are dedicated SW and RIG HW components**
  - In this case it is assumed to use some completely SW assets and others that also include HW components.

    In this case the number of trials to be performed is certainly lower, but the veracity of the simulation will be greater because real HW components are also inserted in the loop.
- **3 level – Live Scenarios**
  - In this case simulation sessions are performed, always the same scenario, with real assets in a dedicated test range with recording capability.

In order to manage the types of trials described, the simulation system must be equipped with an analysis system of all the simulations carried out in order to be able to correlate all the trials, verify the validity of the simulations carried out and create dedicated and detailed reports.

Obviously, in order to analyse and compare the enormous amount of data (even heterogeneous), the evaluation system must be equipped with an adequate Big Data Analysis system.

5.6.2 Requirement 14

The system should allow users to generate realistic complex behaviour in constructive forces.

Requirement Type: System

5.6.2.1 Requirement Rationale

Complex Constructive Force doctrine has to reflect both blue and red forces doctrine. In other words, constructive forces have to replicate real-world modus operandi. Especially for Mission Rehearsal eXercise (MRX – CPX CAX series) that has to be necessary to allow friendly forces to train themselves in preparation for the upcoming deployment.

Concerning SITFOR/RED FORCES (the enemy) real doctrine when applicable has to be considered IOT achieve the principle "train as you fight."

In addition to that, when talking about asymmetric treat (local militia/terrorist groups, Insurgents, etc), their TTPs (Tactic Techniques and Procedures) in other words the way they fight blue forces, has to be scripted/uploaded and used both during the MEL-MIL scripting phases and then replicated over a constructive simulator during the execution phase of any exercise.

Intel scripting and intel simulation, as regularly happen in live when different parties face each other on the field, have to be part also of constructive exe IOT give fidelity and realism to the real-world situation.

5.6.2.2 Thinking About….

From what is indicated in the rationale of the requirement, the customer expects that the simulation system under study is able to use the doctrines that constitute the guidelines of the behaviour of the forces engaged in military operations.

As regards the "friendly" components of these forces (blue forces), these doctrines are represented by doctrinal publications augmented with for example, by the rules of engagement that each military/department must follow in order to cope with the possible situations in which it might find itself in the course of a mission.

These rules are codified in detail and are taught in training activities at various levels. The applications of doctrine, augmented with rules of engagement, requires the commanders to use clever tactics which can be acquired by training (as is the subject of Section 4.1).

As for the doctrines of the opposing forces present in the training scenarios (red forces) these are deduced from typical behaviours that each type of adversary (terrorist groups, opposing armies, hostile organisations, etc.) has shown in the past or from information obtained through intelligence, cyber activities, etc.

For an effective training of the various components of the armed forces it is essential to reproduce these doctrines as faithfully as possible in simulation and training environments; in this way the staff can train themselves to face situations that are very close to real ones.

The problems related to this need are mainly related to the technological aspects of the simulation environment and to the cognitive ones.

5.6.2.3 Technological Aspects

The creation of complex, heterogeneous, and high-fidelity simulation scenarios involves a considerable commitment from the point of view of the HW and SW to be used.

As the entities involved grow, the dynamism of the situation to be reproduced and the real-time responses that the system is required to provide, the computing and graphics needs of the HW components used grow exponentially.

The SW to be used must be able to interface with each other, to process the enormous amounts of information in real time and to manage all aspects related to the coordinated evolution of the scenario.

To best meet these specifications, the simulation system must be designed using the most advanced component virtualisation techniques that allow dynamic and optimised management in terms of memory, configurability, and resource management.

The networks that interconnect the various sites participating in the scenarios must also have very advanced characteristics in terms of reliability, speed of data transfer and security of the information transferred.

5.6.2.4 Cognitive Aspects

Even more demanding are the cognitive constraints: in order to satisfy them, synthetic agents must be created which, using Artificial Intelligence, machine and deep learning techniques, acquire the typical behaviours of the subjects that respond to the specific doctrines that are to be reproduced.

In other words, the system will have to provide functionalities that make it possible to translate the various doctrines into instructions, procedures, and data to be provided to synthetic agents through learning phases (machine learning).

At the end of the learning processes the various agents will be ready to be used in the scenarios; their behaviour will be determined by the specific doctrine they have learned.

The learning phase will be an incremental and iterative process and will aim to make the agents' behaviour ever closer to that expected.

Also, in this case the main challenge lies in developing the algorithms and formalisms that allow the user to effectively translate the procedures, formalisms, and data available into information that the learning engines can transform into the conceptual maps that determine the "modus operandi" of the specific synthetic agents.

Chapter 6 – REFERENCE ARCHITECTURE

6.1 INTRODUCTION

The objective of the reference architecture (or simulation framework) is to define an effective and comprehensive environment that is able to deliver training and Decision-Making (DM) services across the volume of interest of MSG-189 (with reference to Figure 1-3). The environment will employ an opportunistic combination of constructive, virtual, and live environments. The underlying philosophy is that the basic concepts and procedures involved in the tasks for both applications (training and DM) are basically the same. The use of a single environment to achieve related objectives offers advantages in terms of consistency, simplicity, resource savings and human-machine interaction. The latter, in particular, also has many advantages in terms of usability and speeding up the learning curve of interacting with the resulting environment.

Actually, most of the existing environment, can be also used to support the Concept Development and Experimentation (CD&E). This activity can be seen as a special case of training where the "teacher" and the "trainee" are collapsed into the same person or group of people.

In summary, most of the methodologies and techniques used to guide trainees during lessons, can also be used to guide an expert to make the right decision or to develop a coherent set of new operational concepts.

The system is therefore able to serve other types of functions in relation to the experimentation of extreme cases, CONOPS and CONUSE not yet verified, offering a training environment at strategic level. This approach is also useful to envision a new and agile way of interacting with such systems following what is done in most, if not all, modern software: proposing several high level human-machine interface rules that allow the user to be immediately familiar with the main components and features of the system.

Central to the approach is the use of a common core of the environment that is placed alongside different specialised services addressing common functions across Training, DM, and CD&E.

Summing up, the reference architecture will cover the complete training path for a hypothetical individual who starts from learning the basic information about the equipment he is going to use, up to the ability to manage it together with other resources in extremely complex strategic decision.

The environment also inherits all the standard features offered by simulated systems: the opportunity to operate as many times as you want and the ability to stop in order to review the theory behind a certain problem and its related solution. Likewise, the distributed architecture offers the possibility of involving, at a lower cost, more frequently, as many people as possible offering a common collaborative environment that does not necessarily have to be synchronous and where not all staff members have to work in the same place, being able to have a faster training, on "extreme" situations in complex but repeatable scenarios, with tests of new capabilities even on equipment not necessarily already operational.

Thus, the architecture offers a comprehensive environment that integrates:

1) Theoretical and procedural preparation;
2) Synthetic environment including simulations across all the five environments (Air, Land, Sea, Space and Cyber); and
3) Traditional kinetic operations when needed.

6.2 SYSTEM OPERATION VIEWS

The reference architecture described in the introduction envisions a comprehensive and flexible infrastructure to support training and decision-making applications based on a core environment oriented to the paradigm of Live, Virtual and Constructive Simulation (LVC) and sets of specialised services and products to fulfil common needs in those applications.

No assumption will be made in the following about which product or other tools (commercial or otherwise) can be used, leaving the best choices for different needs to future implementations. This is also due to the fact that the availability of such tools is very wide, with continuous improvement and update.

In this section, to provide a general rationale for architectural choices, two aspects are described to illustrate the scope and flexibility of the architecture, namely its use across different levels of military operation (Section 6.2.1) and its use across different phases of military operation (Section 6.2.2).

More details with an operational focus will be given in Chapter 7.

6.2.1 System at Various Levels of Operation

In the proposed approach, the architecture should be flexible and modular to support training and decision making of military personnel that operate at different levels. These levels have been defined in the "Action Dimension" (see Table 1-2 in Section 1.2.4.1) and are shown in Figure 6-1.

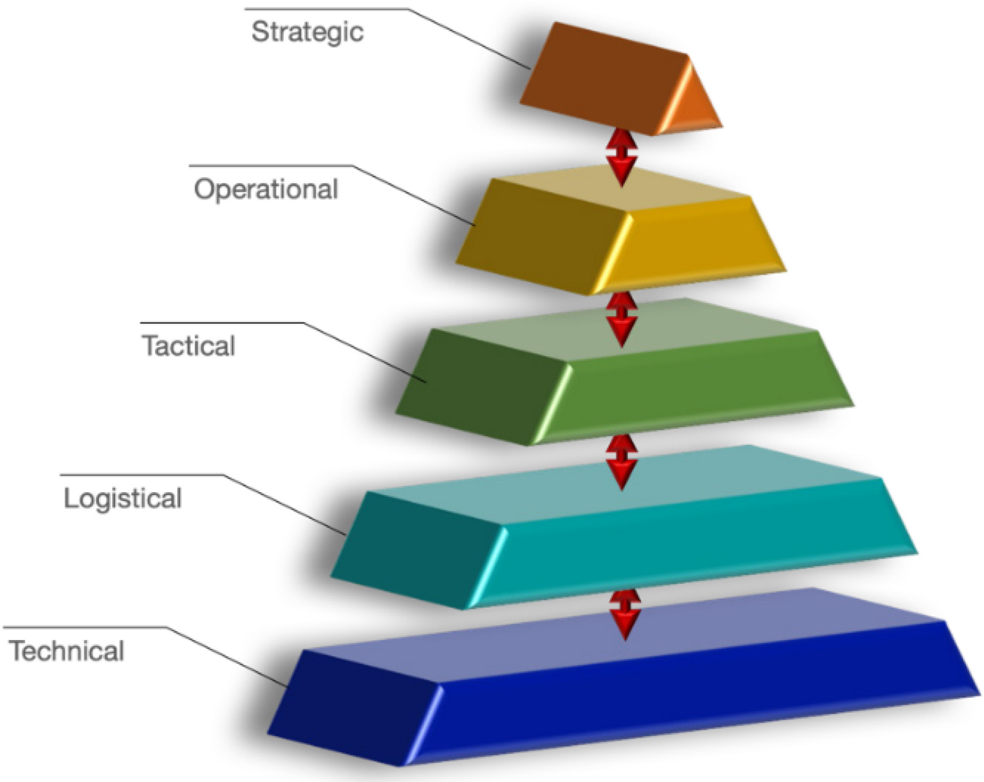

Figure 6-1: Levels of Operation.

The different levels characterise different needs and qualities with respect to the type of decision making that takes place.[1] The decision-makers at different levels thus have a different perspective on their operational environment. These perspectives are related to for instance:

1) The geographical coverage that is relevant to the decision-maker.
2) The quantity of entities and their interactions (humans, platforms, and equipment) that the decision maker has to be aware off, as well as their level of detail and abstractions.
3) The mission-critical timings where higher levels typically operate in contexts of longer timespans which are associated with higher degrees of uncertainties, margins, and accuracy of mission dynamics.

The reference architecture proposed in this chapter should be able to cope with such different perspectives, regarding the M&S capabilities across LVC environments, training and decision-support services and the human-machine interfaces with the environment and those services.

6.2.2 System at Various Phases of Operation

6.2.2.1 Decision Making

From the decision-making point of view, the flexibility of the architecture implies that it has to support user participation with the system throughout various phases of operation. This is best illustrated by the *mission-related* training capabilities defined in the Expertise Dimension (single, team or collective mission training).

Figure 6-2 shows various phases of mission operation. The large arrows show a typical sequential flow from planning to debrief. This can be viewed both from a training perspective (upper flow) and from an operational perspective (bottom flow). The dashed arrows show alternative transitions that can be supported to facilitate cycles for the whole process or parts of the process.

Note that in a training context, the term mission here can also relate to parts of a mission or specific situations or strategies/plans to train.

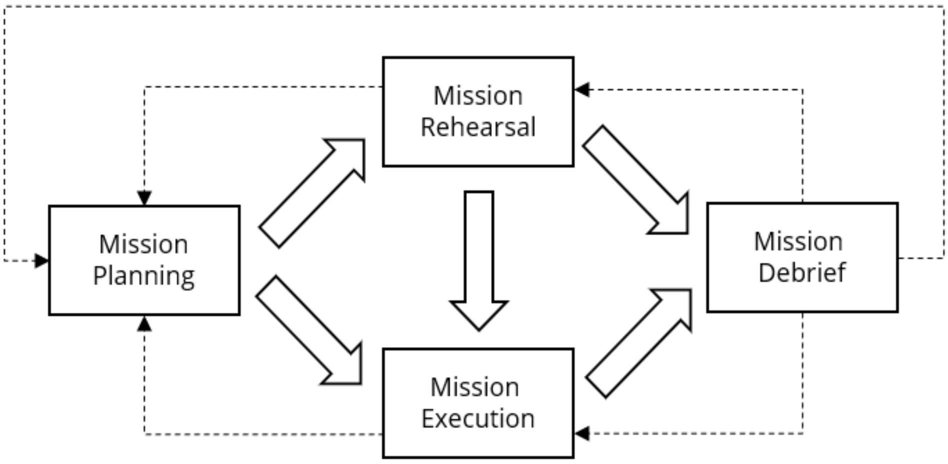

Figure 6-2: Contexts of Operation for Planning.

[1] For instance, compare the tasks of a Joint Forces Air Component Commander (JFACC) to produce an Air Tasking Order (ATO) in planning cycles of 72 hours, in contrast to a Flight Lead in the field that has to be able to make split-second decisions.

An architecture should be able to support users through all mission phases and allow for transitions between phases.

Examples of transitions are shown by the dashed arrows between phases in Figure 6-2. Description of these transitions is given in Table 6-1.

As previously mentioned, a more detailed description of this situation will be provided in Chapter 7.

Table 6-1: Transitions Descriptions.

Mission Rehearsal to Planning	During rehearsal, a chosen CoA is found to be ineffective and the users decides to return to the planning phase with lessons learned.
Mission Debrief to Rehearsal	During post-mission analysis, a specific situation during the mission was found that justifies re-evaluation of a CoA. The user can set up a rehearsal session that allows re-enactment of the specific situation in a virtual simulation, where alternative CoAs can be practiced using constructive simulation.
Mission Debrief to Planning	The results of post-mission analysis can be used to revisit the planning phase in retrospective and simulate alternative CoAs, taking into account the last mission dynamics and data collected during the executed mission.
Mission Execution to Planning	A decision-support service that provides real-time advice on CoAs during a mission operation allows for adaptive planning by the user during a mission. This enables a faster planning-execution cycle.

6.2.2.2 Training

The volume of interest for MSG-189 includes a broad scope for training. As stated in the defined "Expertise" dimension, it includes theoretical training, procedural training, mission training (individual, team and collective) and strategic training.

It could easily be shown how the same operations are done in the case of a training system.

Referring to the Figure 6-3, the same scheme can be used substituting "Assignment" with "Exercise."

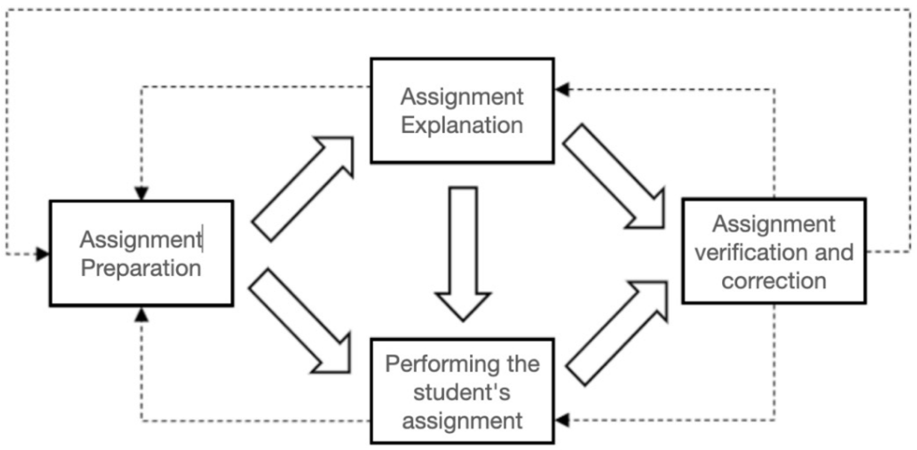

Figure 6-3: Contexts of Operation for Training.

These examples further support the logic, necessity, and usefulness of a modern choice for a scalable, modular, multi-level and multi-phase architecture.

6.3 REFERENCE ARCHITECTURE: HIGH LEVEL PICTURE

Figure 6-4 illustrates the very high level of the reference architecture that will be described in more detail in the following paragraphs.

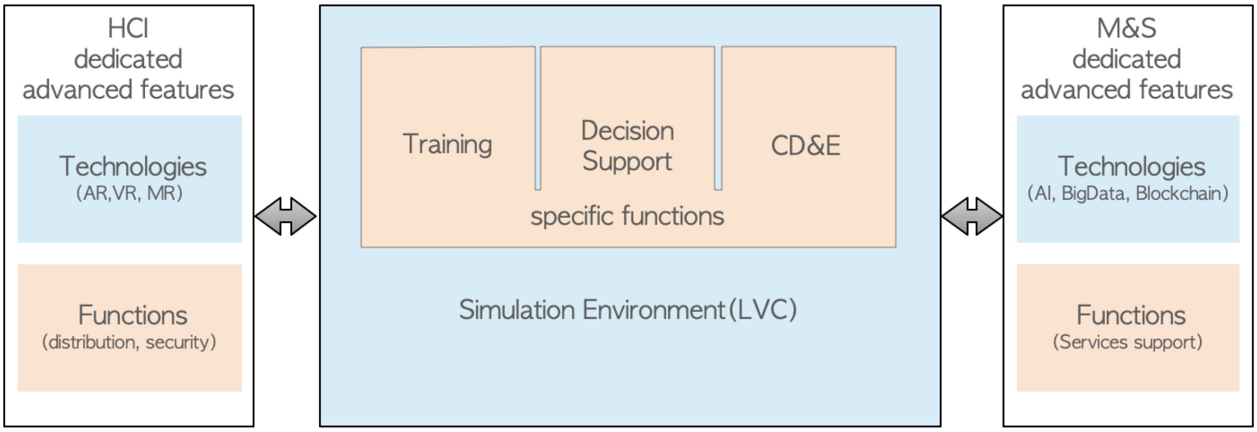

Figure 6-4: Main Blocks of Reference Architecture.

The blue rectangle in the centre represents the Simulation Environment defined according to the LVC principles and, consequently, making it possible to mix all types of simulation.

This environment contains the core modules as well as the specialised modules to match the different needs for Training, DM, and CD&E.

This is envisioned to be made with a classic approach of distributed simulation (e.g., HLA/DIS based[2]) even including some specific bridge or gateway to include the required legacy systems.

The rectangle on the right represents the availability of the most advanced modules, both in terms of technologies and functions offering new possibilities to complement the main environment at all levels.

On the left-hand side, the interfaces to the user are represented, showing some examples of possible new technologies and functions, highlighting the extended reality and security specifically addressed to network security which is a particularly sensitive point in distributed simulation.

6.3.1 Core Capabilities: Environment Simulation

Figure 6-5 represents the proposed architecture at a high level of abstraction for the core module starting to go deeper into the description of Figure 6-4.

The figure is segmented into three horizontal areas roughly belonging to the Live, Virtual and Constructive simulation. For this specific aspect, the figure aims to show that there is an "osmosis" between the three levels as a result of a not so clear and defined differentiation between the three.

[2] These standard examples were chosen because of the popularity of these approaches, but, from a logical point of view and at this level of abstraction, it is easy to see that it can be valid for any other future communication standard allowing distributed simulation.

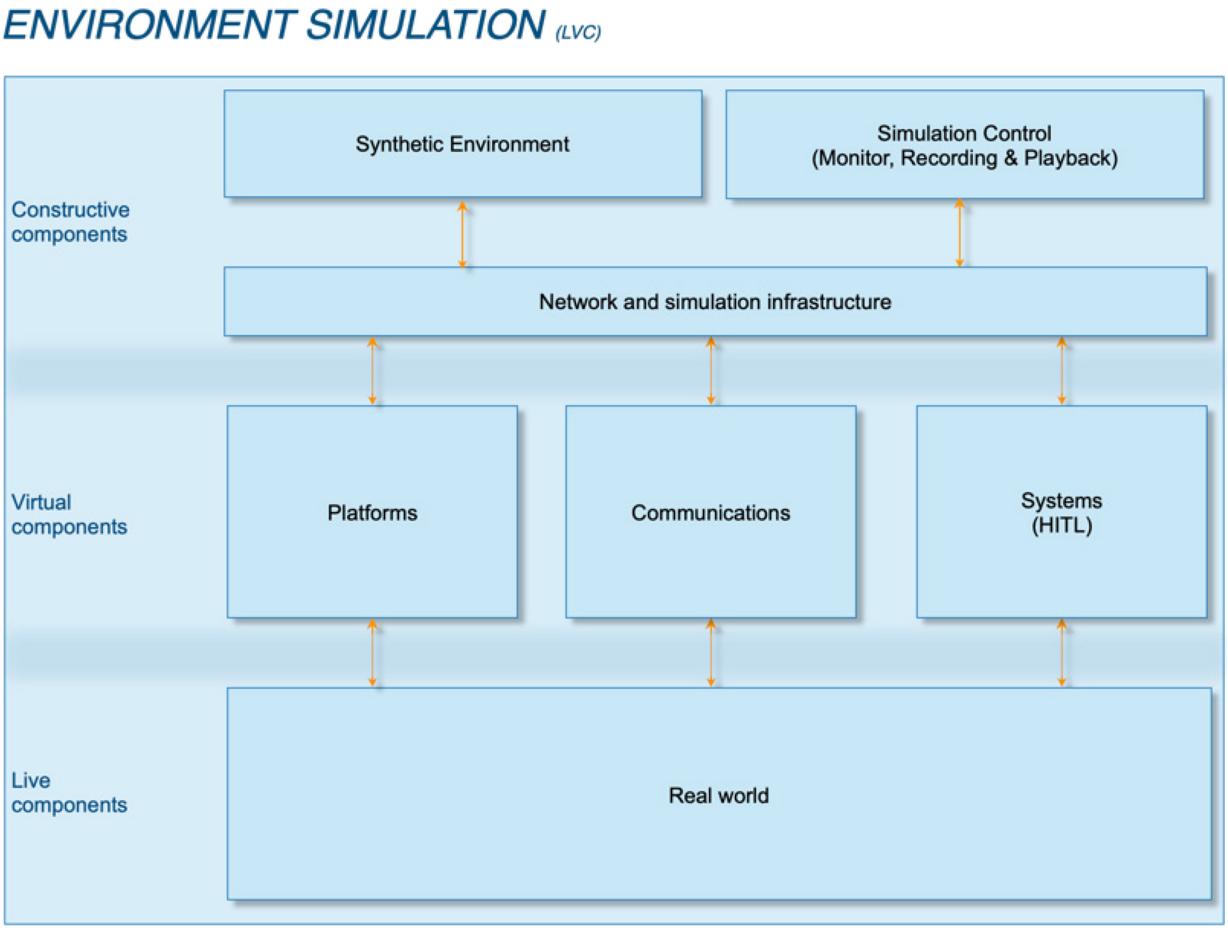

Figure 6-5: Environment Simulation Block in Reference Architecture.

From a general point of view all the blocks revolve around the "Network and simulation infrastructure" (Figure 6-6).

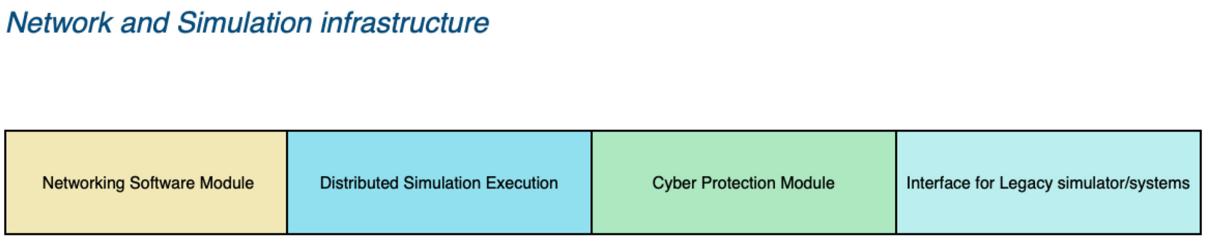

Figure 6-6: Network and Simulation Infrastructure.

This can still be a typical system architecture for distributes simulation that includes items connected through a local LAN and other components connected through a WAN.

This approach has been recognised as the most valid in several NATO exercise experiences.

Legacy simulators and/or simulators not supporting the HLA/DIS interactions (supposed to be the most popular communication standards required for a specific exercise) can be interfaced through the Synthetic

Environment where interfaces should be specifically designed to provide a correct and consistent interface. The development of these interfaces (which very often has to be heavily customised) will make it possible to recover previous investments.

The orange arrows in the main schema generally indicate the existence of these or any other interface and/or gateway required to connect all other blocks to the network (e.g., Web interface, sound/voice, etc.).

For this plethora of different interfaces and messages, it is essential to be equipped with a robust "Simulation Contro" with a powerful set of tools to monitor, record and reproduce any network activity (not only simulated but always related to simulation execution), especially if the network is widely distributed (Figure 6-7). The proposed architecture foresees at least four different modes: the first one is dedicated to simulation messages "tout court" (e.g., HLA messages); the second one is dedicated to systems that operate at a virtual level (e.g., when a real system is stimulated by the simulation); the third one is dedicated to systems that are in the real world and that can send data in the simulation; the last one should include all the tools specifically dedicated to instructors to make their life easier (e.g., providing information about students' behaviour and results). All these subsystems are good places to insert some AI features to support human activities.

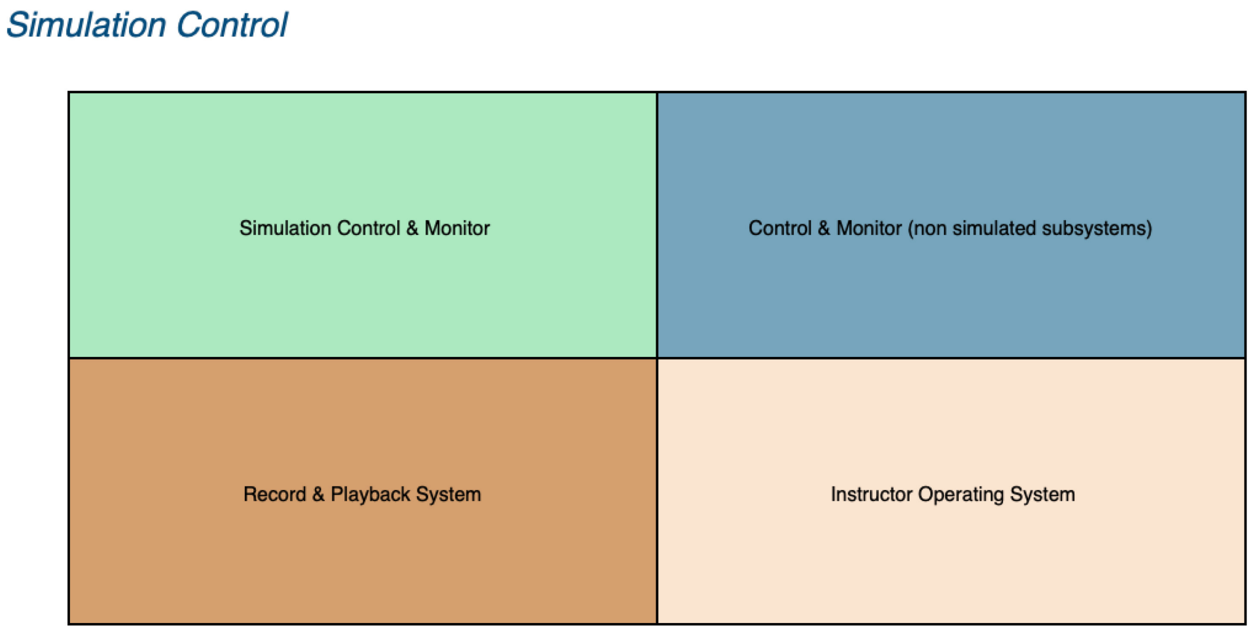

Figure 6-7: Simulation Control Block.

The "Synthetic Environment" (SE) block has the main function of stimulating the rest of the blocks by offering models of the real environment according to the specific needs of required simulation (Figure 6-8).

The SE offers models for the orography, meteorological conditions, and can also directly include models that refer to the natural environment such as buildings, vegetation, electromagnetic fields, roads, etc. In general, objects that may not directly participate but that are, in several ways, something of interest in the simulation.

This is also the environment where Computer Generated Forces can be placed and act, completing the context in which, the training, the system behaviour analysis as well as the CONOPS/CONUSE exercise, can be carried on.

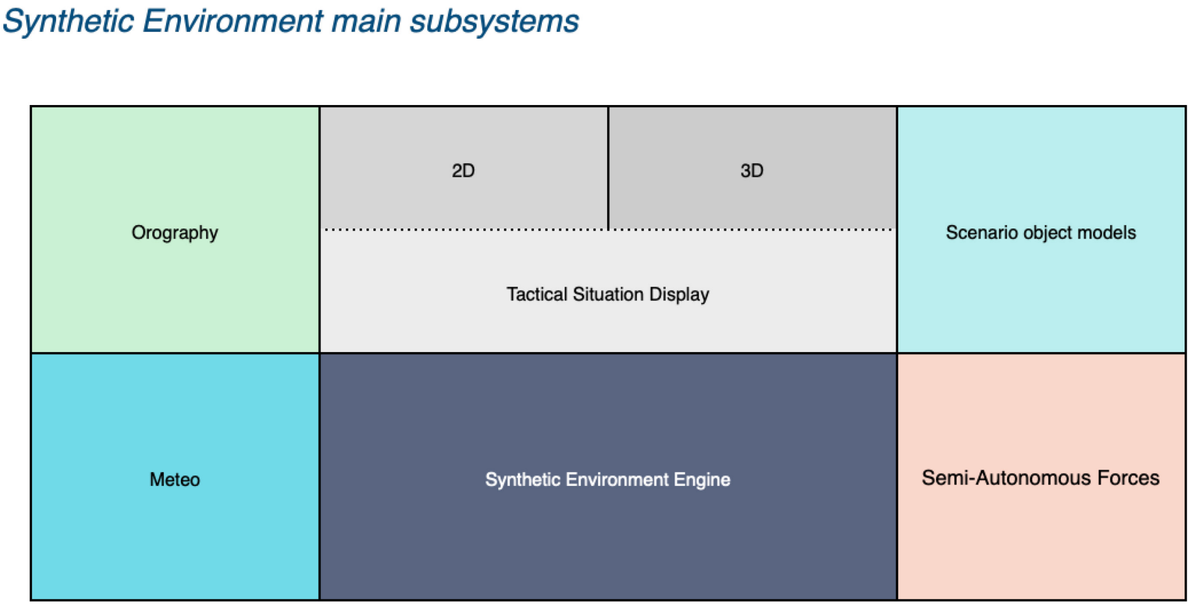

Figure 6-8: Synthetic Environment Block.

All of these objects can be largely improved by the use of technologies such as Artificial Intelligence and Big Data, both in terms of credible behaviour and huge amount of data production and analysis.

The "Platform" block contains standard intended platforms such as aircraft as well as naval, terrestrial, and space vehicles (Figure 6-9). This includes the object behaviour (starting from just a simple performance replica up to the digital-twin perfect reproduction). It can also contain and make available complex systems embracing infrastructures, sensors, and equipment such as ports, airports, etc. that have a specific behaviour that can be modelled. This block is therefore dedicated to objects that participate in the main simulation as specific actors that need dedicated and more accurate modelling. Each of them can be total software model or also including mock-ups, emulators, or real parts.

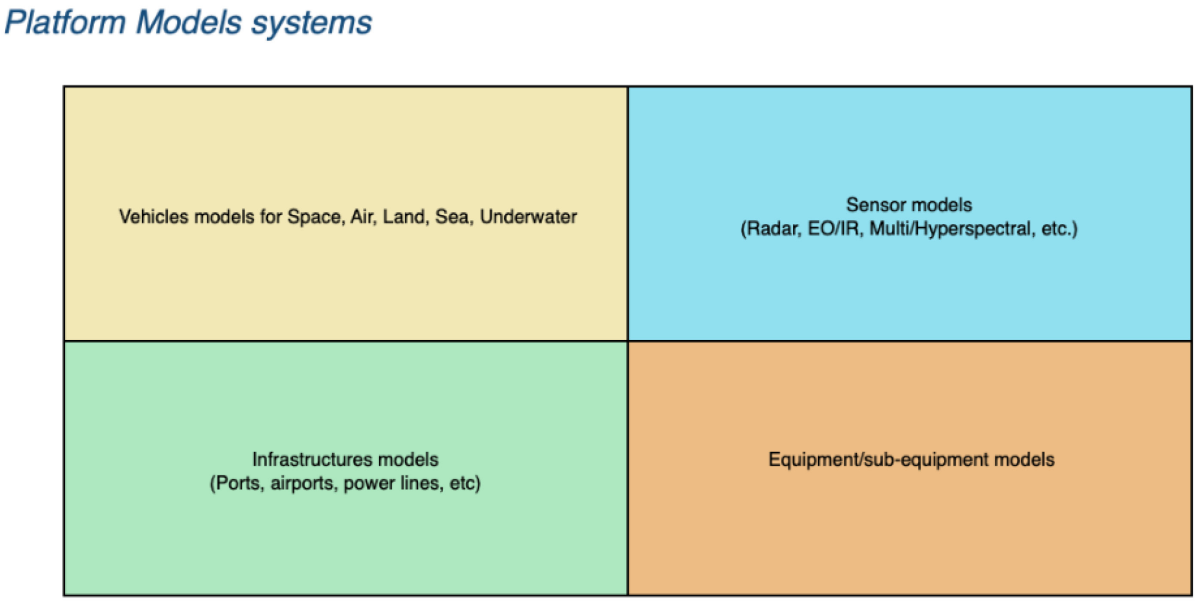

Figure 6-9: Platform Block.

The "*Communication*" block can also be made by mixing synthetic and real segments where wired and wireless communication are simulated. It also has to be equipped with the capability of including some real equipment in the middle.

The "*Systems*" block indicates that other simple or complex systems, including real parts, can be incorporated. In this case the Synthetic Environment is used to stimulate the real equipment. As previously mentioned by means of specific gateways or bridges (represented by the orange arrows), legacy systems are also intended to be included in this set.

Figure 6-5 is completed by the connection between the synthetic world and the real one. The double arrows indicate that is also possible to inject in the synthetic world messages and stimulus coming from the real world. The most important example is the possibility to send the behaviour of a real object from the Real World to the Synthetic World: for example, a speed vector of the platform or a signal of a sensor.

All these access possibilities are theoretically only limited by the number of services delivered by the MSaaS implemented, the completeness of the network of connected databases (cloud infrastructure), the power of the related hardware (cloud computing based).

6.3.2 M&S Infrastructure: System Interface, MSaaS Level, Basic Resources

The mentioned Modelling and Simulation as a Service (MSaaS) will provide services bonding the traditional cloud infrastructures with capabilities in terms of:

1) **Extend traditional virtual environments** for experimentation, test, and training activities with a dynamic (cloud-based) environment able to instantiate:
   - Virtual machines;
   - Containers; and
   - Virtual networks;

   in isolated or joined concurred sessions or to connect them and with:
   - Physical machines; and
   - Physical networks;
   - To create thematic rooms where monitoring and recording services can be performed together with other assets.
2) **Extend physical and virtual networks** for activities involving simulation of non-cabled communications such as simulation of wireless, radio or satellite networks.
3) **Manage all the simulation assets** (e.g., legacy and virtual simulators, containerized M&S services, etc.) including their related simulation session or experiments, through all the three classical phases of:
   - Discovery
   - Composition
   - Execution

The system is also expected to manage other aspects not directly or specifically dedicated to the M&S such as **rooms and labs** (virtual and real, local and remote) **management**.

Figure 6-10 depicts a typical infrastructure with the means to define a site designed to work autonomously or to be part of a distributed network ready to uphold a MSaaS system.

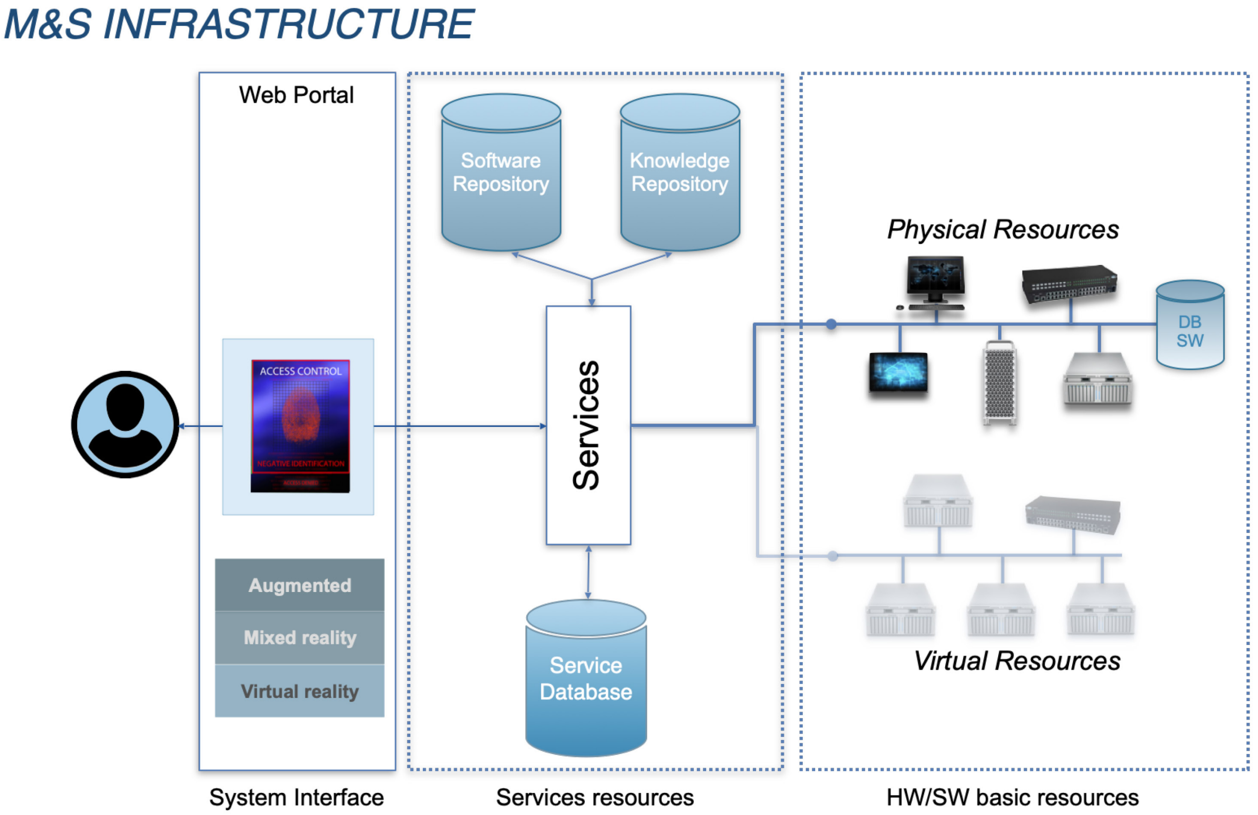

Figure 6-10: M&S Infrastructure Logic Blocks Ready for MSaaS.

This infrastructure can be used as a stand-alone system or be linked to other similar sites with a common standard interface.

Going from left to right:

1) The first block (Web Portal) represents the external interface covering both the interaction with the user (HCI) and with other systems connected on the network in order to prevent unauthorised access, ensure system consistency and safeguard against possible system malfunctions. In this case HCI, which can basically be a way of understanding who the user is and why connection to the system is required, can start with a typical username and password mode, enhanced with an opportunistic mix of mixed reality to allow a more modern interface to a very complex system offering a plethora of services. For example, once the user is accredited through passwords and/or other biometric recognition functions, the choice of all available options can be offered using, for example, virtual reality, to explore the database of services. The same interface can be used to respond to the user and offer the result of some particularly advanced service (e.g., a reasoned guide to the contents of the databases made available). The same block contains barriers to avoid both cyber-attacks and unintentional misbehaviour that can put the system in trouble.

   Shortly, the implementation of MSaaS provides a single point of access to the services and resources available in the infrastructure through a web portal.

   The portal can only be accessed through an identity management system that ensures both confidentiality and identification of the user and therefore of his profile.

   The structure is services-oriented and is intended to simplify:

   - The accessibility including cyber defence services;

- Configuration and setup;
- Versioning;
- Test and execution; and
- Termination and cancellation of the various sessions and related multiple and concurrent management.

2) By overcoming the first barrier, which also defines the associated specific profile, the user is authorised to access system services that exploit a number of different DBs:

   a) A SW repository where different simulation resources are contained: the simulation objects (artefacts, models, product information, terrains, synthetic environment resources, etc.) basic virtual machines (configured with OSs,) or already ready virtual machines (up to including synthetic environments ready for a simulation). All in accordance with the guaranteed service level.

   b) A Knowledge repository where formalised expertise can be used to train or support the user, together with knowledge that can be stored while using the system through Big Data or AI techniques.

   c) A DB cluster where the user can have available several management functions (e.g., save specific simulation sessions making easy to start again a suspended session or repeat the same simulation several times).

3) The third block represents access to the hardware resources (physical or virtual) in terms of both computers and networks that can be made available to the potential entire interconnected network. In this block is also present a local DB for backup reasons (e.g., lack of network connection) and/or specifically dedicated to resources that are not expected to be shared.

In a way the system represented in Figure 6-10 could be considered as the basic components of a cloud-based distributed network. It is able to work in stand-alone mode, as a single structure offering services to a number of distributed users or being just a repeatable element of a more complex network of collaborating centres.

6.3.3 M&S Infrastructure: MSaaS Layers

A true service-oriented architecture is envisaged, where different services and simulation resources will be available to enable the automatic composition (orchestration) of M&S services (i.e., without human intervention).

In Figure 6-11, the MSaaS system is seen by highlighting the stack of hardware and software able to offer the services to the distributed environment depicted in the previous paragraph which is perfectly suited to support these software layers.

The first layer is the physical equipment that forms the very basic structure. It is represented in Figure 6-10 as the basic HW/SW resources. On this layer the communication and computer elements are defined to allocate the next layer dedicated to the management of virtual elements (both computer and network).

The above layer is dedicated to the cloud management and other resources to be shared the last is about the core of MSaaS.

The last layer, the Orchestration Platform, provides the previously mentioned main functions of Discovery of services, Composition of sessions, Execution of sessions typical of a MSaaS.

For specific details about opportunities for Emergent Technologies in this reference architecture and application example, please refer to Chapter 7.

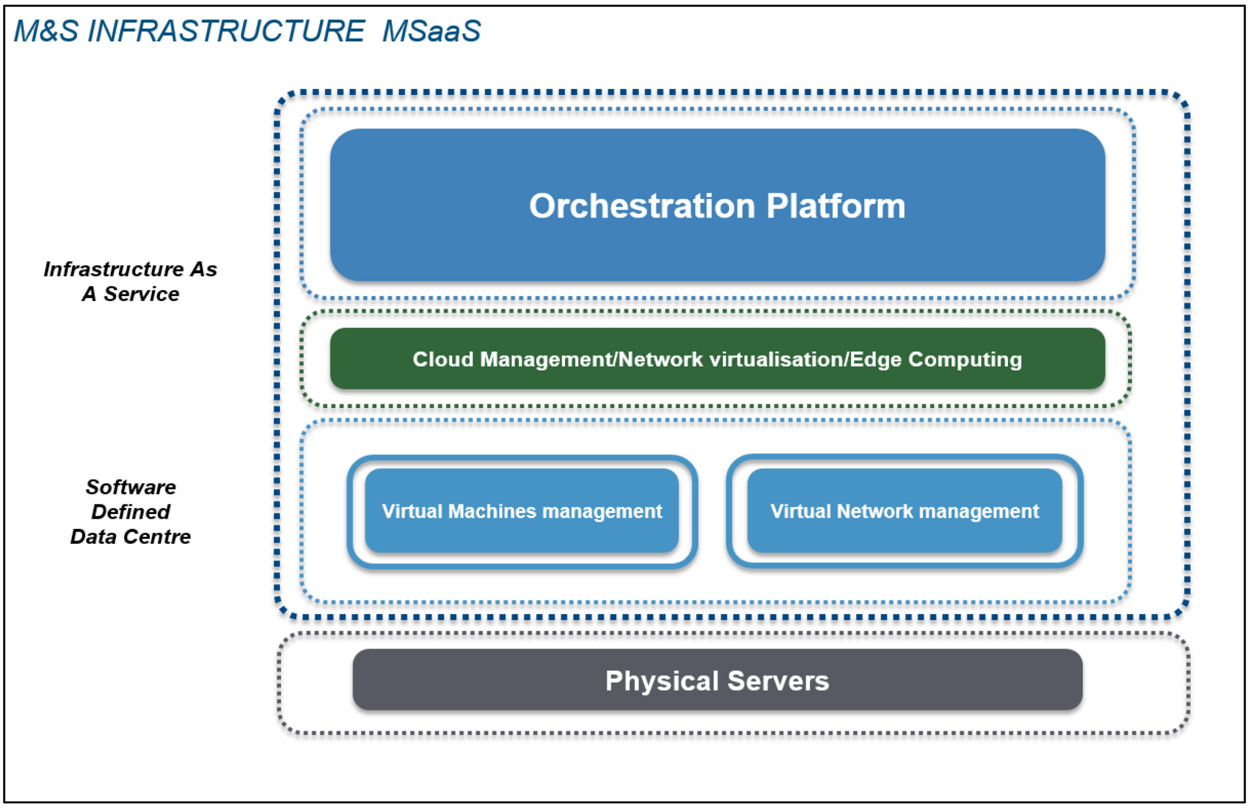

Figure 6-11: M&S Infrastructure Software Layers for MSaaS.

Chapter 7 – MAIN FUNCTIONALITIES

7.1 INTRODUCTION

In previous chapters, with the goal of defining an innovative M&S Ecosystem as outcome of the MSG-189 ST, the following items have been analysed:

- The main enabling innovative technologies (Chapter 2 and Chapter 3).
- The training and decision-making support gaps (Chapter 4).
- The existing and new requirements it must fulfil (Chapter 5).
- A possible Reference Architecture (Chapter 6).

This chapter will describe the main functionalities and interfaces that characterise the resulting product of this analysis. The chapter will verify whether the logical process followed in the report has reached the desired goals. Figure 7-1 depicts the relationship among the different chapters.

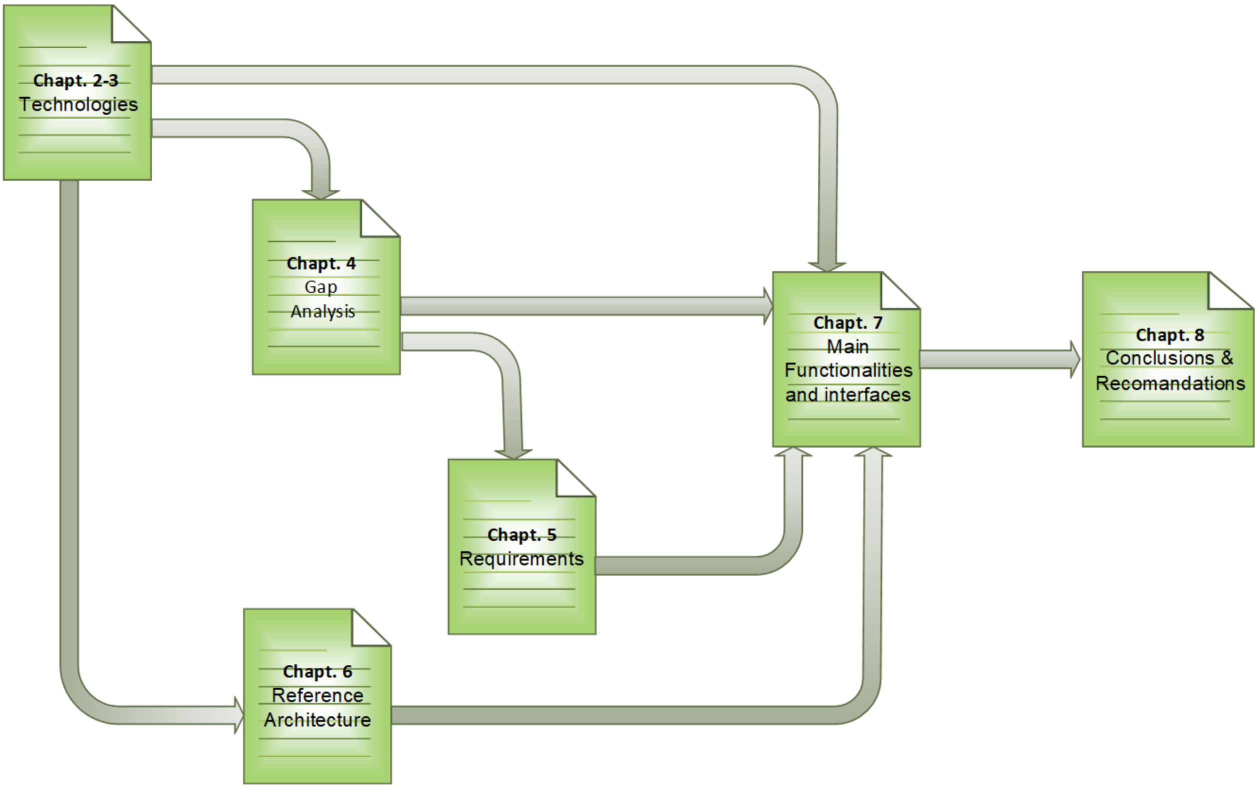

Figure 7-1: Report Chapters Relationship.

The idea behind the MSG-189 environment is to create an effective and comprehensive environment for training and decision-making support, which, through advanced representation of scenarios and the availability of extremely reliable models making use of the most innovative technologies, offers the possibility of creating realistic situations for the entire training and decision support life cycle. In other words, to propose an answer to the complete training path that starts from the learning of basic information about the equipment/system to use up to the ability to manage extremely complex operations making appropriate timely decisions.

Furthermore, it offers the opportunity to try as many times as possible, stop and review the theory behind a certain exercise and not be afraid to do something wrong. This solution provides, at a lower cost, and more frequently, the possibility of training high-ranking commanders more often without the need to involve a lot of supporting real staff. On the other hand, it also provides the possibility of involving as many people as possible while providing maximum safety for staff who do not need to operate in the same place. The system is therefore able to serve other types of functions in relation to the experimentation of extreme cases, CONOPS and CONUSE not yet verified (training “at strategic level”).

This means being able to have a faster training, on “extreme” situations in complicated but repeatable scenarios, with tests of new capabilities even on equipment or procedures not necessarily operational. The system can then also support “intelligent procurement,” where the customer is put in a position to make the choice of purchase, against tests “on the (virtual) ground,” what he intends to buy.

It is worth underlining that the products developed on the system architecture, although they can run locally, are designed to be used on a distributed architecture. In other words, the MSG-189 Ecosystem (built on physical and/or virtual assets) is cloud services-oriented and offers most of these components as a service according to the MSaaS paradigm. In a training context this concept implements the availability of Training as a Service (TaaS).

The MSG-189 Reference Architecture implements the five essential features of cloud computing as they were established by the National Institute of Standards and Technology (NIST):

- **On demand self-service** – automatic provisioning of computing capabilities;
- **Broad network access** –access through standard mechanisms via thin or thick client platforms;
- **Resource pooling** – multi-tenant model;
- **Rapid elasticity** – elastically and automatically provisioned and released capabilities; and
- **Measured service** – measurement transparency for both the providers and consumers of services.

To achieve this result, the architecture has been designed to be highly modular and reconfigurable, with particular attention to the reusability of modules through a wide use of interfaces that make specific implementations independent. In this way, it is also possible to integrate legacy systems.

Figure 7-2 describes the resulting MSG-189 Ecosystem in terms of a relationship among the different building blocks described so far and how they are linked together to create an integrated “holistic view.”

On the right of the figure are the Inputs that define the Ecosystem:

- Requirements received either as general Requirements (User, System, Operational).
- Additional Requirements produced by our Gap Analysis in Chapter 4.

On the left are the Enabling Factors, represented by the Innovative Technologies (described in Chapter 2 and Chapter 3) and the Reference Architecture System (described in Chapter 6), that will enable, with a mix of existing and new solutions, the delivery of the Innovative Products and Services that the MSG-189 Ecosystem is capable of and that represents its outcome.

This outcome is organised with respect to the type of Product/Service (Training or Decision-Making support) to be addressed. For any of these categories, a specific solution is described that, making use of the proper Architectural building block and Technology, is going to fulfil a set of specific requirements and solve specific gaps.

This is represented by the Cross Reference Inputs/Factors box that contains all the elements to be linked with the specific Product/Service. In the following paragraphs these linkages will be described in further details.

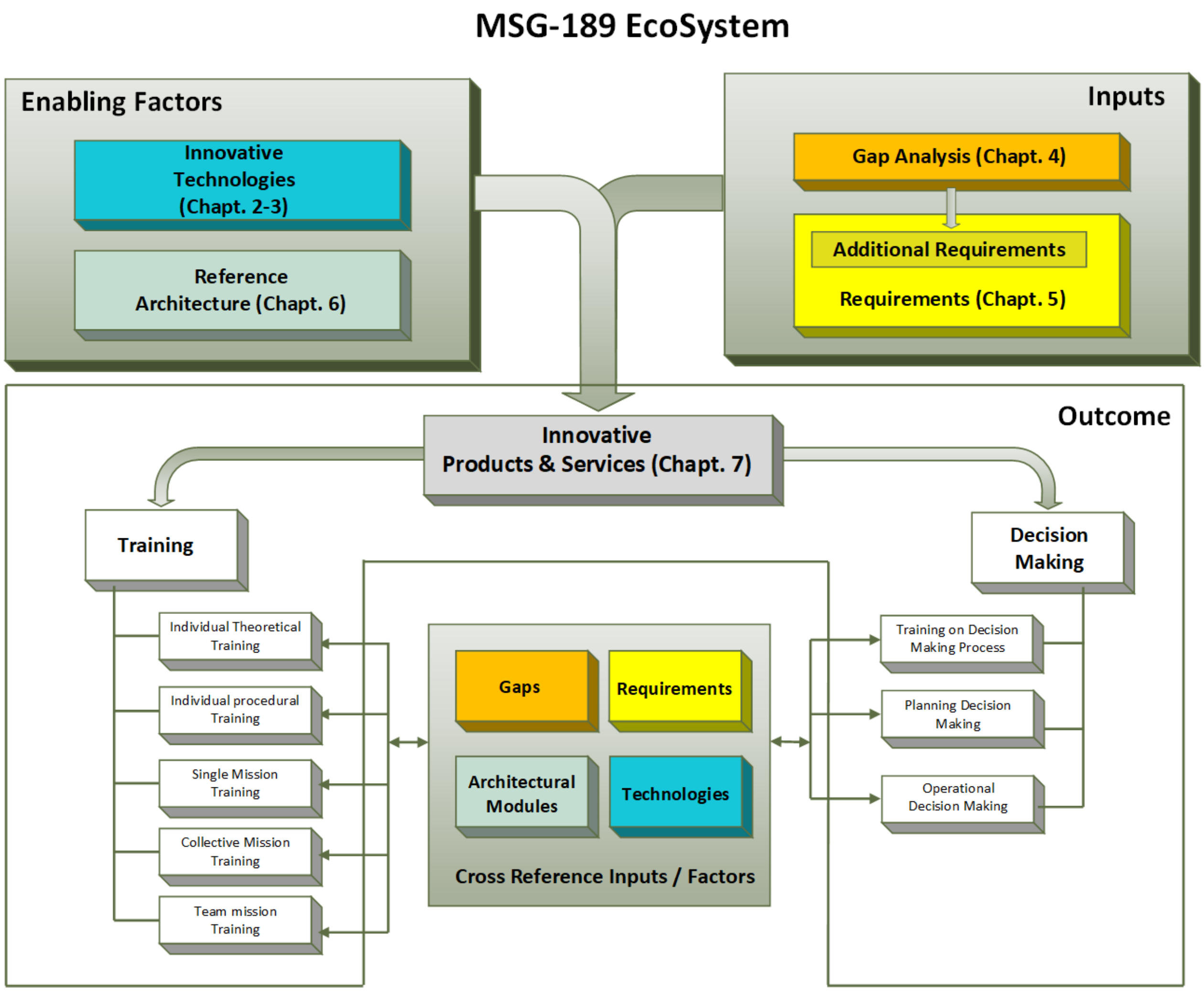

Figure 7-2: MSG-189 Ecosystem.

7.2 MSG-189 ECOSYSTEM ARCHITECTURAL BUILDING BLOCKS

Figure 7-3 shows the MSG-189 Ecosystem Architectural building blocks that will be referred to in the following paragraphs. The building blocks are a specific logic implementation of the Reference Architecture described in Chapter 6 and contain all the functionalities needed to execute the services described.

7.3 PRODUCTS AND SERVICES FOR TRAINING

The volume of interest for MSG-189 includes a broad scope for training. In Chapters 1 and 4, the dimensions of the simulation environment have been identified and described; in particular, the types of training present in the "Expertise" dimension (shown in Table 7-1) allow the definition of the services of the system.

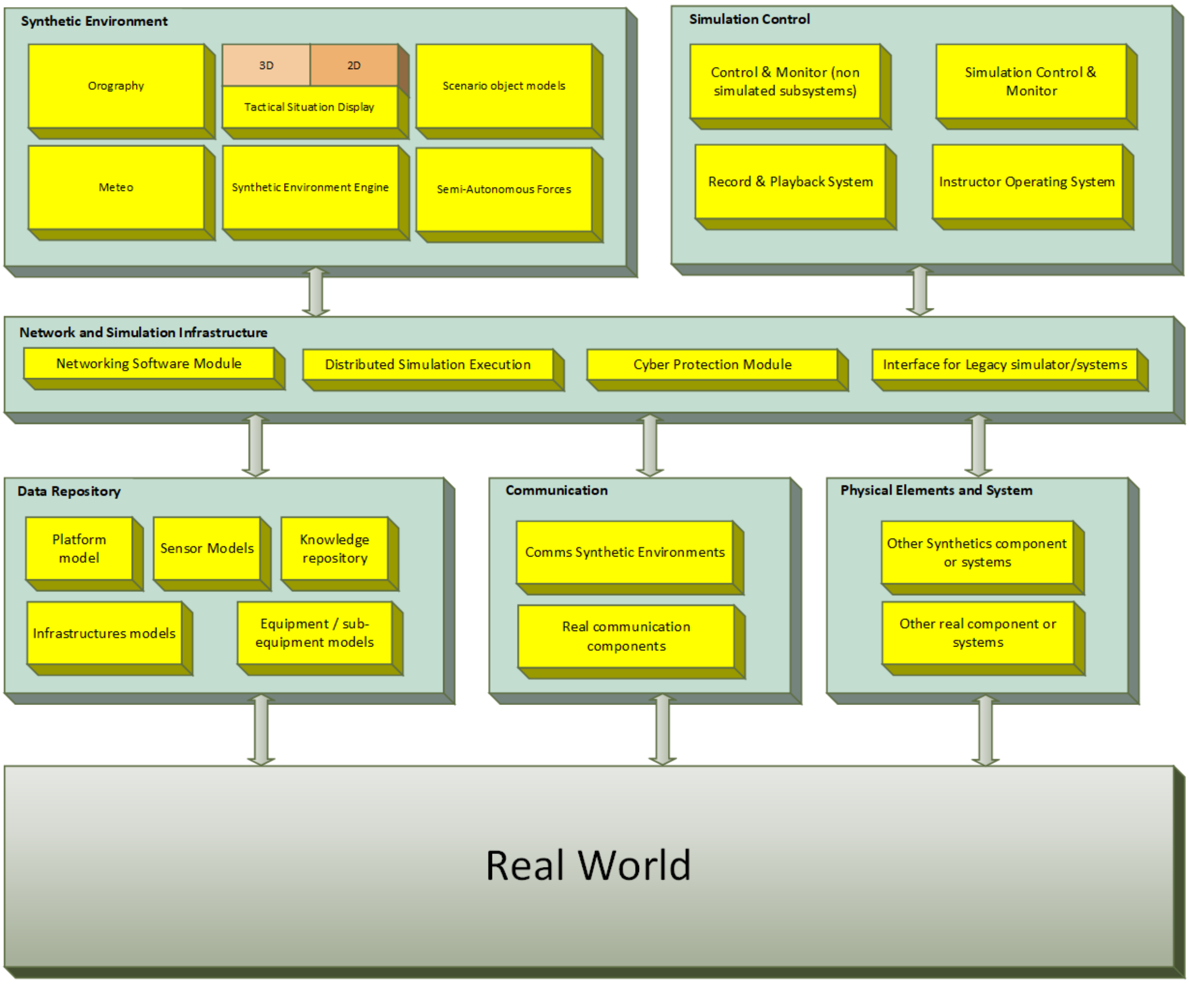

Figure 7-3: Architectural Building Blocks.

Table 7-1: Expertise Dimension Bar.

Expertise dimension

Theoretical Training	Procedural Training	Mission Training Single	Mission Training Team	Mission Training Collective	Strategic Training
Knowledge	Skill	Competences			

Training solutions in the M&S industry are continuously evolving, introducing new training philosophies (e.g., performance-based training), methods (e.g., blended learning) and training infrastructures (e.g., learning eco-systems). These solutions benefit from new technological developments and emerging technologies, e.g.,

- Big data analytics: advanced learning analytics.
- Immersive technologies: simulation-based training, AR/VR.
- AI: recommender systems, automated tutoring, virtual role-players.

This section explores how the envisioned architecture can be applied to a training context and how different emergent technologies can play a role. This is explained by describing a set of example services that support the design, execution, and evaluation of training exercises for military personnel.

First, a general-purpose view of a training context is given, illustrating basic functions required for any type of training (see Figure 7-4):

- Defining the training content and objectives (e.g., curricula, syllabi, lessons, scenarios).
- Providing means of training for trainees (e.g., textbook, serious game, immersive simulation).
- Assessing trainees by evaluating their performance.
- Implementing instructional strategies to guide the learning process based on trainees' performance.

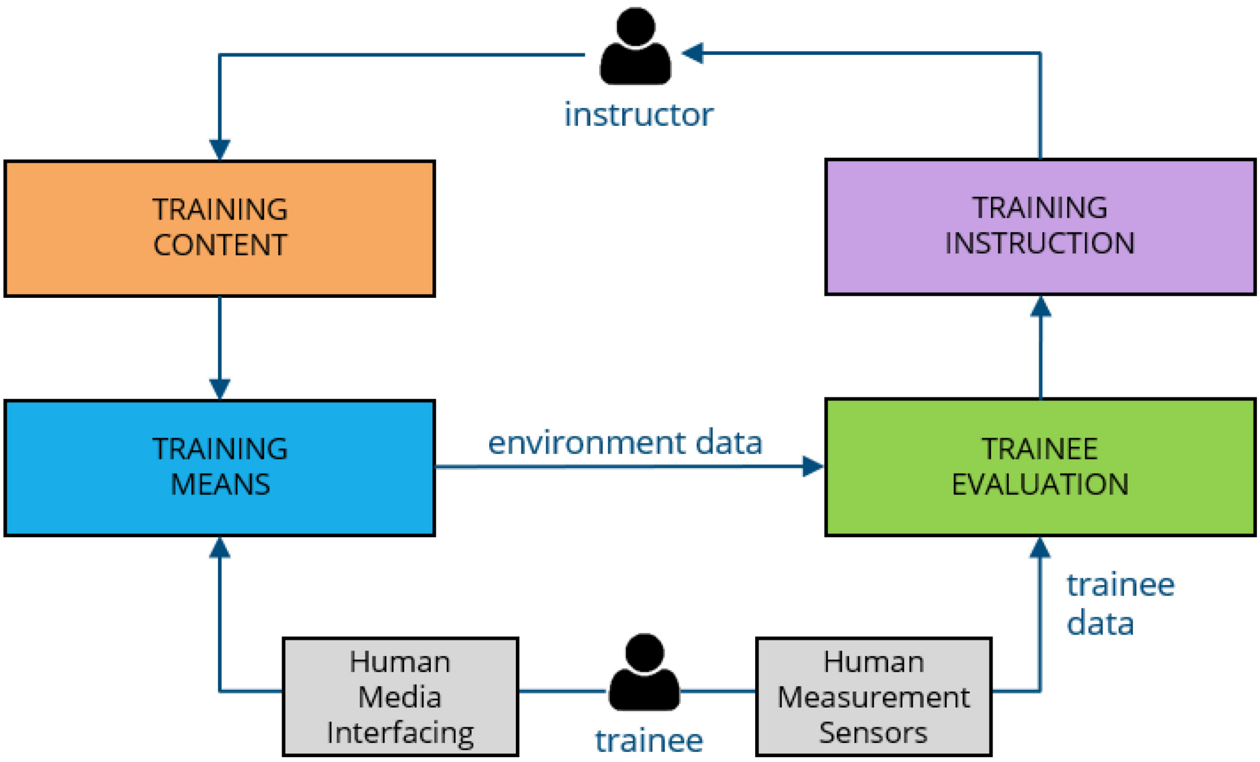

Figure 7-4: General Training Context.

To give an example, consider a trainee in a Mission Training context using simulation-based training: The instructor defines the training content in the form of a training scenario that is representative for the mission. The training means represent the simulated mission environment, achieved by an LVC environment that the trainee can interact with by means of HMIs. During training, performance data can be collected or observed from the simulation, which the instructor can use to judge and evaluate the performance of the trainee. Additionally, the instructor can evaluate the trainee based on its displayed physical or cognitive behaviour, for instance to judge its mental state or workload. In this evaluation, the instructor may be supported by tools to make its evaluation, such as dashboards that track certain performance indicators during the mission, or show behavioural metrics obtained from sensors that can measure the trainee's state (e.g., eye-tracking, heart-rate or EEG sensors) [57], [58]. Finally, the instructor can decide on an instructional action to optimise learning and adapt the training content. For instance, it may change the complexity of the mission when it is inferred from the evaluation that the current training is too simple for the trainee.

The instructional loop illustrated by this example could be treated either across training sessions (e.g., changing the training schedule for a trainee or recommending a new training scenario), or during a training session (e.g., adjusting complexity factors in real time *during* a session).

Computer-based training systems can facilitate instructors for each of the functions described above. By means of increasing levels of automation, analytics and AI, training systems can become more and more intelligent in their support for instructors, of even automate and replace the role of instructors.

Figure 7-5 shows a set of examples of automated processes that support the different functions. In the MSG-189 system, these can be thought of as services that jointly contribute to the concept of training as a service. In these services, data analytics and AI are enabling technologies.

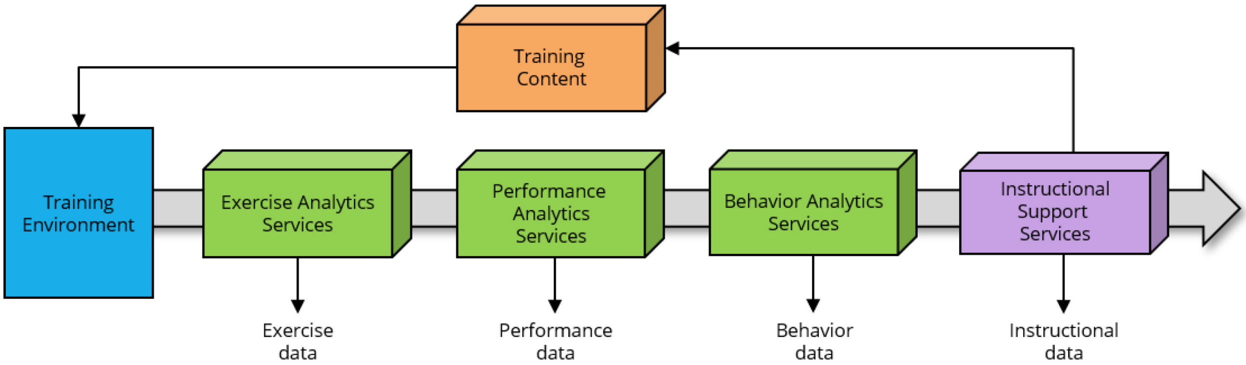

Figure 7-5: Services to Support Instruction.

Exercise Analytics Services

These services are able to collect and analyse objective (real-time) data from the simulation training environment. Analytics can be used to give insights into the developments of a training session. Examples of different levels of analytics are:

- **Descriptive:** What is currently happening?
- **Diagnostics:** Why is something happening?
- **Predictive:** What can happen now or later?
- **Prescriptive:** What is best to do in this situation?

The information that such analytics provide could be offered to the instructor, e.g., in a Common Operational Picture (COP) tool for use during training or After-Action Review (AAR). These services are not specific for training and can equally be used in a decision-support context.

Performance Analytics Services

These services are able to track, analyse and/or assess trainee (or team) performance:

- **Analysis:** Pre-programmed performance indicators can be used to distil relevant information from a training session in order to be able to assess a trainee (or team) performance (possibly in real time). In addition to exercise analytics, it can put objective data in the context of a specific training objective.
- **Assessment:** In order to be able to assess the performance and recognise if a trainee (or team) deviates from the desired performance, two methods are common:

- **Constrained-based evaluation:** uses a set of quantitative metrics to define constraint rules that together define the bounds of desired behaviour (and thus can detect situations of erroneous behaviour or bad performance).
- **Model-based evaluation:** uses a full model of desired performance, i.e., a golden path. Comparisons between desired and observed performance is used to assess performance.

The information provided by these services can be managed, for example, by Learning Management Systems (LMS).

Behaviour Analytics Services

These services are able to track and analyse the behavioural, physiological and cognitive states of a trainee, based on measurements of real-world sensors. A few examples are given:

- Inferring a measurement of situational awareness or workload based on sensors such as eye-tracking, heart-rate variability, or EEG.
- Detecting mental state indicators based on communication and speech analysis.
- Detecting physical postures, actions or intentions based on action and intent recognition algorithms.
- Detecting cognitive biases.

The information provided by these services can facilitate instructors into making instructional decisions.

Instructional Support Services

These services are able support the instructor in following instructional strategies and developing follow-up training content. Automated support requires information obtained from previously described services. Examples:

- **Predictive learning services:** services that facilitate training design and planning. For instance, recommender systems for part-task training or scenario suggestions, or algorithms that can propose training schedules based on recurrent training needs (e.g., through skill-decay predictions).
- **Scenario generation services:** services that are able to translate training needs or specifications to generate concrete training scenarios that can be offered to the trainee.
- **Adaptive instruction services:** services that are able to adapt training sessions in real time in order to optimise learning, e.g., to keep the trainee in the Zone of Proximal Development.

In conclusion, it can be stated that the described services, when used in conjunction, can progressively introduce more support and intelligence to the instructor in orchestrating trainings.

7.3.1 Individual Theoretical Training

The individual theoretical training is, in some ways, different from the other types of training due to some specific characteristics described in the following.

Its main purpose is to provide, via dedicated tools, specific courses aimed to increase the knowledge of users and therefore it can be seen as an "Educational" product. In addition, it usually makes limited use of simulation systems.

The services related to this type of training are based on the technologies of the Learning Management System (LMS).

LMS are software applications for managing training courses in all highly regulated organisations (both military and industrial) that need to ensure safety and compliance in the operational activities of their personnel requiring periodic training based on consistency with specific standards and up-to-date qualifications. The system manages the delivery of courses by providing course documentation and allowing monitoring of usage and results. It also provides support for the reporting of learning and training programmes. The LMS concept derives directly from e-Learning and uses its basic principles and content.

The evolution of LMS technologies provides for the use of training services with advanced methods, on mobile devices and with the support of SaaS and cloud architectures. An Advanced Learning Management Systems is a "mobile" LMS. A mobile, cloud-based LMS, is essential to meet the need to create effective training programmes without limits of time (24/7), space (location) and type of device (laptop, smartphone, etc.) and thus ensure no interruptions of courses due to, for example, staff reallocation. Therefore, the approach needs to support both a robust online and classroom trainings also assuring an affordable pay-per-use service.

7.3.1.1 Features

The main characteristics that distinguish the theoretical individual training are:

- On demand services performed through a system web portal.
- Services usable on heterogeneous devices (fixed, mobile, independent from OS).
- Use of the cloud platform to allow for distant learning.
- Low usage of simulation environment (apart from Serious Games).
- User profiles services management.
- The presentation of each course can be made using both textual components and multimedia content (photos, videos, interactive films, etc.).
- Each training session can include one or more verification phases (tests) with relative evaluation.
- Each session can be recalled, analysed, and rerun either totally or partially.

7.3.1.2 System Modules Used

- Physical Element / System – Other Synthetic component or system (serious games).
- Network and Simulation Infrastructure.
- Simulation Control – Control and Monitor (non-simulated subsystems).
- Data repository – Knowledge repository.

7.3.1.3 Technologies Used

- Artificial Intelligence in its various forms; in particular:
  - Machine Learning and Deep Learning.
  - Natural Language Processing (NLP).
  - Serious Games / Gamification.

7.3.1.4 Innovative Ways of Using Services

The innovative features that can be integrated into the individual theoretical training are as follows.

In formulating the courses:

- The formulation of the courses will be carried out using AI systems and, in particular, with NLP algorithms for the formulation of the course contents and their structuring.
- Possibility of accessing data repositories (including external ones) with advanced specialised contents for a continuous updating of the contents of each course.
- Use of machine learning and deep learning algorithms for continuous improvement of AI course management algorithms (presentation methods, content writing, evaluation of results, evaluation of user profiles, etc.)

In carrying out the courses:

- Each course will be dynamically customised to take into account the characteristics and attitudes of the user (this information is managed in the user profiles and is dynamically updated through AI algorithms).
- Each course can be enjoyed in the language chosen by the user using NLP algorithms.
- The content of the course, both in its presentation and in the interactions (tests or dynamic interactions) will be modulated according to the user's updated profile to optimise the learning phase.

7.3.2 Individual Procedural Training

Individual procedural training is the training of individual fighters to prepare them to do their missions. Individual training should be task-based, as realistic as possible, and performance-oriented; that is, it should concentrate on the actual performance of a specified task.

Individual procedural training can be operational or maintenance.

Individual operational training aims to prepare each fighter to perform a specific task or to use an apparatus, system, or platform for operational purposes.

Individual operational training also includes the acquisition of skills on procedural, legal or administrative aspects of systems and applications used by the armed forces. Training in the use of SW environments used in various contexts also fall into this category.

Maintenance training, on the other hand, allows the training of personnel assigned to the overhaul, maintenance and repair of vehicles and systems supplied to the armed forces.

7.3.2.1 Features

The main characteristics that distinguish the individual procedural training are:

- Use of simulation systems based on VR / AR / Mixed reality.
- Use of real systems or platforms.
- Use of SW systems (C2, logistics, administration, etc.).
- On demand services through the system web portal.
- Use of the cloud platform to allow for, where possible, the remote use of the services.

7.3.2.2 System Modules Used

- Data repository – all modules.
- Synthetic Environment Engine.

- Simulation Control.
- Physical Element / System.
- Network and Simulation Infrastructure.
- Real World.

7.3.2.3 Technologies Used

- Artificial Intelligence.
- LVC Synthetic Environments.
- Digital Twins.
- Serious Games / Gamification.

7.3.2.4 Innovative Ways of Using Services

The innovative features that can be integrated into the individual procedural training concern:

- Individual procedural training can take place both through the use of “real” equipment, systems, platforms, procedures, and synthetic environments (LVC). This applies to both operational and maintenance training.
- The use of augmented and/or immersive reality technologies and AI algorithms makes it possible to improve and speed up the training phases both in the use of the item and in the illustration of its features.
- Thanks to Human-Machine Teaming, the operator can receive constant, effective, and reliable support both in the training phase and in the operational use phases of the system.
- The MSaaS structure of the system and its cloud-based architecture allow the use of the services made available at any time and in any place.
- Using tools based on the Digital Twins paradigm, the trainee can practise on devices and platforms that are not accessible (or are not operational) with a very high degree of reliability and realism. Furthermore, during its operational activity, personnel trained using Digital Twins technologies will be able to operate on real equipment in connection with the corresponding virtual twins.
- Using the services of the system, it will be able to diagnose the status of the systems and operate on them remotely.
- In doing this, the trainee will be supported by synthetic entities equipped with AI algorithms that will be able to provide data, suggestions, and cooperation in a very similar way to what was done in the training phases.
- Thanks to the recording and playback functions, the training sessions carried out can be reviewed, analysed and repeated until the expected results are obtained. These activities can be managed by the instructors assisted by synthetic AI agents.

7.3.3 Single Mission Training

Single Mission Training aims to train military personnel to perform operational missions using simulation systems.

Also, in this case the types of simulators that can be used are systems ranging from purely constructive ones up to LVC systems; often there are training situations that involve the integration of simulated components with real equipment or systems.

It is the most common type of simulation and is suitable for training both front-line personnel and higher order levels.

In practice, what has been learned through the procedural training phase (how to use the various assets) is put into practice on scenarios that aim to achieve one or more objectives.

7.3.3.1 Features

The main characteristics of the Single Mission Training are:

- Generally, training of this type is carried out within a single domain.
- Use of Constructive scenarios.
- Use of SW environments (e.g., C2 systems) that interact with simulated or real – simulated environments.
- Using wargaming.
- Use of synthetic agents.
- Use of AR / VR / XR techniques.
- Use of Human-Machine interface.
- Predominance of simulators focused on the training of first-line or low-ranking military personnel.
- Use of blue force vs red force scenarios.
- Possible use of remote services (use of MSaaS paradigm and cloud architecture).
- Planned and configured mission and scenarios (Main Event list-MEL) (Main Incident List-MIL).
- LVC environments.
- Use of autonomous systems (real and simulated).
- Integration with real systems.

7.3.3.2 System Modules Used

- Synthetic Environment – all modules.
- Simulation Control – all modules.
- Network and Simulation Infrastructure – all modules.
- Data Repository – all modules.
- Communications – all modules.
- Physical Elements and System – all modules.
- Real World.

7.3.3.3 Technologies Used

- Artificial Intelligence in its various forms; in particular:
  - Machine Learning and Deep Learning.
  - Natural Language Processing (NLP).
  - Constructive Entities AI based.
- Big Data Analytics.
- Immersive Technologies:
  - Virtual /Mixed/Augmented Reality.
  - CAVE.
  - DOME.
- MSaaS/TaaS.
- Cyber Security Technologies.
- Serious Games / Gamification.
- Mission / Exercise Management.
- Record and Playback Systems.
- Autonomous Systems.

7.3.3.4 Innovative Ways of Using Services

The MSG-189 Ecosystem can help make this type of training more innovative by providing services that:

- Allows for integrating different types of simulators; a flight simulator or a tank simulator, for example, can be integrated into synthetic scenarios in which synthetic entities, based on AI algorithms, operate.

  These entities can perform collaborative functions towards (Human-Machine Teaming) or they can be adversaries to be countered (red force).
- Allow the user to analyse and eventually repeat the various phases of the mission thanks to the playback services.
- Furthermore, the proposed scenarios can be dynamically adjusted according to the profiles of the trainee.

7.3.4 Team Mission Training

The mission-training team aims to train military personnel to carry out operational missions that involve the collaboration of a certain (limited) number of individuals to achieve one or more objectives in a tactical scenario.

The team members involved can play different roles and be in different places; the common factor is that of contributing, each with their own role, to achieving the objectives of the mission.

The types of simulators that can be used range from purely constructive ones up to LVC systems; often there are training situations that involve the integration of simulated components with real equipment or subsystems.

In the simplest cases, this type of training is carried out through live exercises which involve carrying out a mission in the field; in more complex cases, on the other hand, LVC-type simulation systems are used which, integrated into a single scenario, coordinate with each other to allow each of the team members to collaborate with the others.

7.3.4.1 Features

The main characteristics of the Mission-Training Team are:

- Multi-platform.
- Distributed (using MSaaS/MTDS paradigm).
- Planned and configured mission and scenarios (Main Event list-MEL) (Main Incident List-MIL).
- LVC environments.
- Use of autonomous systems (real and simulated).
- Ability to operate in Blue Force vs Red Force mode.

7.3.4.2 System Modules Used

- Synthetic Environment – all modules.
- Simulation Control – all modules.
- Network and Simulation Infrastructure – all modules.
- Data Repository – all modules.
- Communications – all modules.
- Physical Elements and System – all modules.
- Real World.

7.3.4.3 Technologies Used

- Artificial Intelligence in its various forms; in particular:
  - Machine Learning and Deep Learning.
  - Natural Language Processing (NLP).
  - Constructive Entities AI based.
- Big Data Analytics.
- Immersive Technologies:
  - Virtual /Mixed/Augmented Reality.
  - CAVE.
  - DOME.
- Distributed and Collaborative Simulation.
- MSaaS/TaaS.

- Cyber Security Technologies.
- Serious Games / Gamification.
- Mission / exercise Management.
- Record and Playback Systems.
- Autonomous Systems.

7.3.4.4 Innovative Ways of Using Services

The MSG-189 Ecosystem can help make this type of training more innovative by providing services that:

- They allow training missions to be carried out in a distributed and coordinated way, thanks to its structure based on MSaaS and Cloud architecture.
- Allow the user to replace, thanks to the use of AI techniques and algorithms, some team members with synthetic agents; this makes it easier to carry out training sessions even if not all the members of the team involved are present.
- They allow the user to analyse and possibly repeat the various phases of the mission thanks to the Record and Playback services.
- They allow the user to dynamically adapt the proposed scenarios according to the profiles and experiences of the participants.

7.3.5 Collective Mission Training

Collective mission training aims to train military personnel to carry out operational missions that involve the collaboration of a certain number of individuals, units, and platforms to achieve one or more objectives in a complex scenario that can take place in different domains, with objectives multiple (but connected to each other) and in different environmental situations. The common factor is that of contributing, each with their own role, to achieving the overall objectives of the mission.

Joint operations are typical examples of this type of training.

The types of simulators that can be used range from purely constructive ones up to LVC systems; often there are training situations that involve the integration of simulated components with real equipment or subsystems.

In the simplest cases, this type of training is carried out through live exercises which involve the deployment of a number (even a very large number of people and platforms) on the theatre of operation.

In more complex cases, LVC-type simulation systems are used, these environments integrate all participants into a single operational and coordinate scenario and allow personnel to be trained to perform specific tasks coordinated with other entities.

Some of the entities present in the scenario may represent simulated military units or complex platforms operating in autonomous (or semi-autonomous) mode guided by AI algorithms.

7.3.5.1 Features

- Multi-domain (Joint / Combined).
- Multi-platform.

- Distributed (using MSaaS/MTDS paradigm).
- Planned and configured mission and scenarios (Main Event list-MEL) (Main Incident List-MIL).
- LVC environments.
- Use of autonomous systems (real and simulated).
- Ability to operate in blue force vs red force mode.

7.3.5.2 System Modules Used

- Synthetic Environment – all modules.
- Simulation Control – all modules.
- Network and Simulation Infrastructure – all modules.
- Data Repository – all modules.
- Communications – all modules.
- Physical Elements and System – all modules.
- Real World.

7.3.5.3 Technologies Used

- Artificial Intelligence in its various forms; in particular:
  - Machine Learning and Deep Learning.
  - Constructive Entities AI based.
- Big Data Analytics.
- Digital twins.
- Immersive Technologies:
  - Virtual /Mixed/Augmented Reality.
  - CAVE.
  - DOME.
- Distributed and Collaborative Simulation.
- MSaaS / TaaS.
- Cyber Security Technologies.
- Wargaming / Tabletop exercises.
- Mission / Exercise Management.
- Record and Playback Systems.
- Autonomous systems.

7.3.5.4 Innovative Ways of Using Services

The MSG-189 Ecosystem can help make this type of training more innovative by providing services that:

- Allow training missions to be carried out in a distributed and coordinated way, thanks to its structure based on MSaaS and Cloud architecture;
- Allow the user to replace, thanks to the use of AI techniques and algorithms, some member, or components of the joint scenario with synthetic agents equipped with decision-making capabilities based on AI algorithms; this makes it easier to carry out training sessions even if not all the actors involved are present;
- Allow the user to analyse and possibly repeat the various phases of the mission thanks to the Record and Playback services;
- Furthermore, the proposed scenarios can be dynamically adjusted according to the profiles of the participants;
- This type of training lends itself to being used for the execution of planned missions through Decision-Making services (Mission Planning);
- The use of the distributed capabilities of the system (cloud) and the interoperability of the services managed by the system (MSaaS) allows the realisation of coordinated exercises like "red force vs blue force;" and

  This type of exercise can be carried out, for example, with personnel of different armed forces who exercise against each other in a real virtual war to validate the respective doctrines and advanced services (based, for example, on AI algorithms).

7.3.6 Cross Reference Between Requirements and Products and Services for Training

Table 7-2: Cross Reference Requirements vs P&S for Training.

#	Requirement	Individual Theoretical Training	Individual Procedural Training	Single Mission Training	Team Mission Training	Collective Mission Training
2a	The system should allow for scalable Training and Exercises (from single operator basic theoretical training up to large joint international multi-crew combined exercises).					
2b	The system should allow the user to execute, evaluate, and score the complete training activities starting from the mission planning, mission execution and mission debriefing, at all levels.					
2c	The system should allow for multi-site interconnected training systems providing a Common Synthetic distributed Environment. *(es. SPARTAN or VIKING Exercises).*					
2d	The system should allow for multi-domain interconnected training systems providing a Common Synthetic Environment.					
2e	The system should allow for realistic and challenging tactical and strategic training (adaptable scenarios with higher degree of complexity).					

#	Requirement	Individual Theoretical Training	Individual Procedural Training	Single Mission Training	Team Mission Training	Collective Mission Training
2f	The system should allow for extended Recording Capability allowing the Playback, and Resume, from a given point, of the simulation.					
3	The system should allow for repeatable scenario for a highly effective learning and CD&E processes.					
6	The system should allow a training environment suitable to support the definition of new CONOPS and CONUSE (Developing, Testing and Proofing of techniques, tactics and procedures) tools to improve decision making / mission planning, including a new way toward "wise procurement."					
7a	The system should allow for building training environments that can save time on "Live" training, reducing the number of participating assets (valuable assets must be dedicated exclusively to operational missions).					
7b	The system should allow for reducing limitations related to hazard and environmental restrictions. For example, no hazards for personnel involved in the exercise or the availability of a proper training environment (e.g., a large enough physical battle space).					

#	Requirement	Individual Theoretical Training	Individual Procedural Training	Single Mission Training	Team Mission Training	Collective Mission Training
10	The system, when used for training, should be aligned with the MTDS Reference Architecture.					
12	The system should facilitate the use of different fidelity levels and allow the user to simulate the same entity/sensor/phenomena with different level of fidelity in accordance with the required levels of details for the different users (e.g., trainee and the instructor or soldier and commander).					
101a	The system should allow for defining training and simulation scenarios with manned-unmanned systems and UAV swarm.					
101b	The system should allow for supporting training and simulation scenarios with swarms that operate in surveillance areas.					
101c	The system should allow for supporting data acquisition from sensor data (pictures, video, infrared, radar) in scenarios with manned-unmanned and UAV systems in order to identify objects of interest and contribute to the common operational picture for decision-making training.					

#	Requirement	Individual Theoretical Training	Individual Procedural Training	Single Mission Training	Team Mission Training	Collective Mission Training
102	The system should allow for defining training and simulation scenarios that support target allocation. Optimally allocate effectors to identified targets by effect, availability, costs, etc.					
103	The system should allow for supporting Collateral Damage Estimation specific for Urban Environment and support INFO OPS to warn CIVPOP.					
104	The system should allow for including in the simulated scenarios the Cyber and Electromagnetic Activities (CEMA) effects.					
105	The system should allow for considering different level of System Validation campaign Field Validation (e.g., Red Flag) HW Validation (Using Validation Rig) SW Validation (Using Emulated SW) and their different level of cost.					

7.4 PRODUCTS AND SERVICES FOR DECISION MAKING

Chapter 1 described the main features of Decision Making and outlined some doctrines used by the MoDs to guide the activities of the commanders in the difficult and complex activity that seems to be on the border between a science and an art.

For the tactical and operational level MDMP is used by the US Army for mission planning and while others have other processes in place, the process steps are generally comparable. To provide an example of a possible architecture to support the decision-making process, the MDMP on a tactical level is used as a frame, but other processes could be chosen as well.

Ultimately, all the procedures indicated envisage a series of codified steps, which, starting from an order of a strategic nature, allow the commanders and their staff to identify one or more COAs necessary to achieve the objectives (Figure 7-6).

These well-defined steps can be translated to services that can be conducted by automation and/or human personnel as is mostly done today. Typically, wargaming is used to develop and analyse various enemy and friendly COAs. Using the services of the system, they can choose the most appropriate one, break it down into its tactical components and generate operational orders for the implementation of the mission.

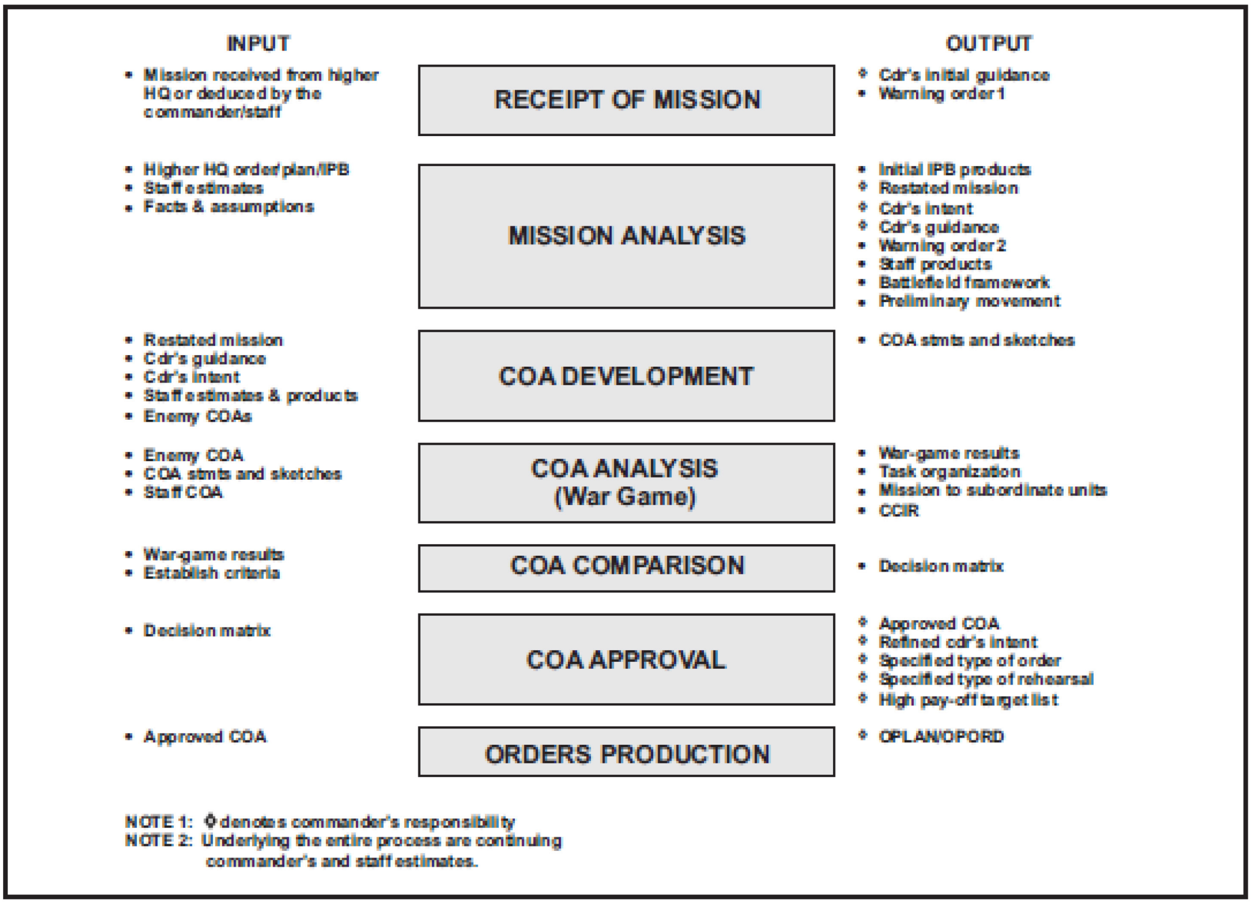

Figure 7-6: MDMP Process.

7.4.1 Phases of Decision-Making Process

In Chapter 6 the main phases concerning the decision-making process in the military field have been identified; the phases identified are:

- Mission Planning.
- Mission Rehearsal.
- Mission Execution.
- Mission Debrief.

The scheme in Figure 6-2 in Chapter 6 illustrates the sequence of planning activities and the relationships between the various phases.

In the MSG-189 Ecosystem, for each of these phases, services can be identified that allow for the automation and support of commanders their staff and the personnel involved in the process (Figure 7-7).

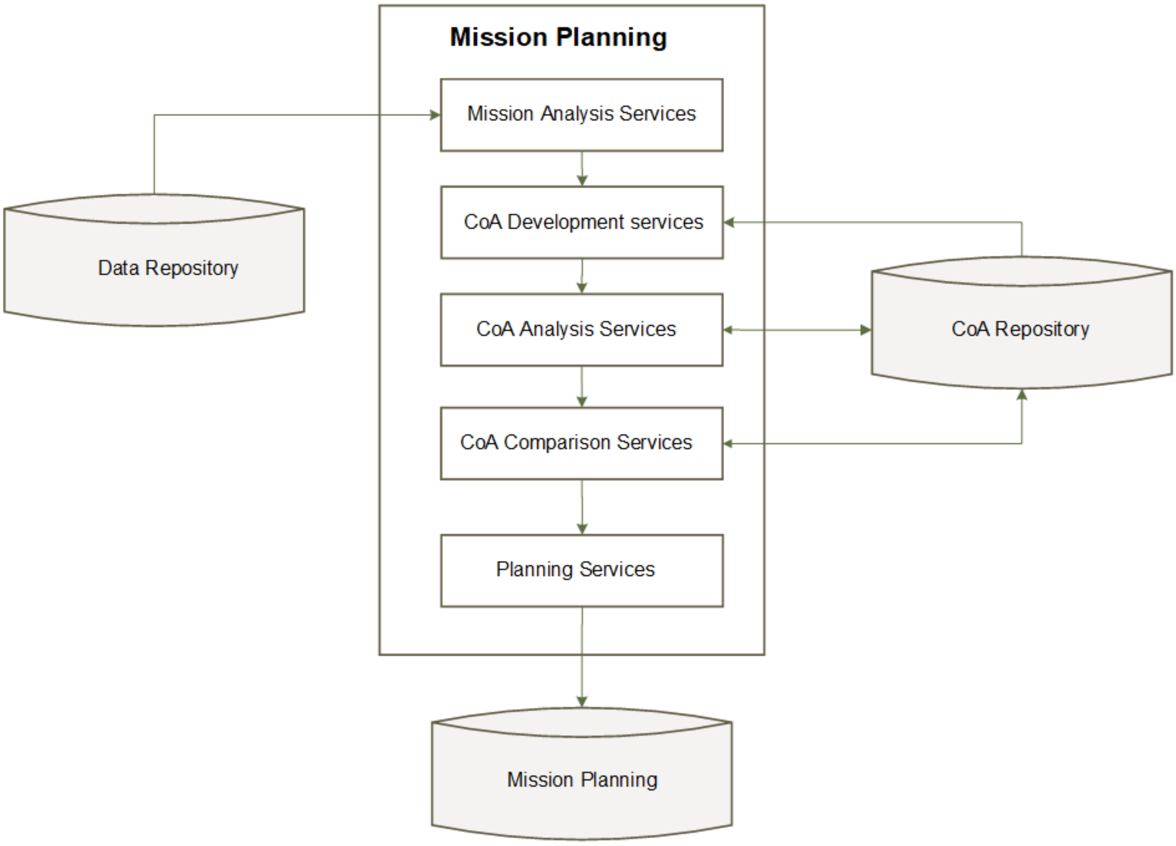

Figure 7-7: Mission Planning.

7.4.2 Decision-Making Data Repository

A fundamental component for the management of the decision-making phases is the database.

The correct design and management of these structures allows for effective management of the planning and implementation processes of missions, the possibility of using past used plans in new contexts that have characteristics similar to those stored constitutes the basis for possible training sessions of the personnel.

The following main components can be identified in the design of the database:

Data Repository – It contains the general data that allow the user to activate the decision-making process such as the strategic orders that start the planning of the missions, the entities involved in the planning and the ancillary information (cartographic, meteorological, intelligence, social networks, etc.).

COA Repository – When wargaming utilises more technology, the developed COA can potentially be stored in a repository preserving the relations between enemy COAs and possible friendly COA(s) during the COA development to allow re-use and refinement later on, potentially in new (training) missions.

While the labelling of these COA is probably mission-specific, for example the (most) likely, (most) dangerous and the friendly COA(s) are developed to be matching, storing the COAs may serve as inspiration for new mission and perhaps improve the COA development or make it more complete within the time available.

Mission Planning – This component contains the final data related to the planning process such as executive orders, timelines, selected COAs, etc.

7.4.3 Mission Planning

The following are the main services identified to support the mission planning phase.

7.4.3.1 Mission Analysis Services (Step 2)

Mission analysis is the method to clearly identify the problem and the tools available to solve the problem.

The services provided in the mission analysis phase allow the commander and his staff to analyse the order received and to fully understand mission, intent, resources available, constraints and limitations, and specified and implied tasks.

The mission analysis services must include, among other things:

- Perform Initial Intelligence Preparation of the Battlefield (IPB).
- Determine specified, implied, and essential tasks.
- Review available assets and identify resource shortfalls.
- Determine constraints.
- Identify critical facts and develop assumptions.
- Begin risk management.
- Update plan for the use of available time.
- Develop Course Of Action (COA) evaluation criteria.

7.4.3.2 COA Development Services (Step 3)

A COA is a broad potential solution to an identified problem. The COA development step generates options for follow-on analysis and comparison.

The services of this step use the problem statement, mission statement, commander’s intent, planning guidance, and the various knowledge products developed during mission analysis to develop COAs.

The development of COAs must include, among other things:

- Assess relative combat power.
- Generate options.
- Array forces.
- Develop COA statements and sketches.
- Conduct COA briefing.
- Select or modify COAs for continued analysis.

When a data repository is in place, the COA development services are able to select the relevant COA(s) and to develop new mission specific COA(s) that are again stored in the repository.

The selected relevant COA(s) are labelled using characteristics (e.g., likelihood).

7.4.3.3 COA Analysis Services (Step 4)

Course of action analysis enables commanders and staffs to identify difficulties or coordination problems as well as probable consequences of planned actions for each COA being considered.

The COA Analysis uses the selected relevant COA(s) as input and analyses the COA(s) using MSaaS/LVC and/or traditional wargaming to assess the performance of the friendly COA(s) and identify possible emerging threats and opportunities that may lead to new COAs that are again stored in the repository.

The COA analysis services must include, among other things:

- List all friendly forces.
- List assumptions.
- List known critical events and decision points.
- Select the wargaming / simulation method.
- Select a technique to record and display results.
- War-game the operation and assess results.

7.4.3.4 COA Comparison Services (Step 5)

The COA comparison services compare the analysed mission specific COAs against the enemy COAs by their characteristics to determine the mission plan. The COA repository preserves the relation between the different COAs specifically for this mission along with the determined characteristics and analysis results for future re-use and/or debriefing.

7.4.3.5 Other Mission Planning Services

Other services related to the mission planning phase will have the task of managing the final stages of the process such as the definition of the selected COA and the issuance of operational orders.

All information related to the planned mission will be stored in the repository.

7.4.4 Mission Rehearsal

Rehearsals are the commander's tool to ensure that staff and subordinates understand the commander's intent and the concept of operations. They allow commanders and staff to identify shortcomings in the plan not previously recognised. Rehearsals also contribute to external and internal coordination, as the staff identify additional coordinating requirements.

During a rehearsal, all participants rehearse their roles in the operation. They make sure they understand how their actions support the overall operation and note any additional coordination required.

During the Rehearsal phase, themed scenarios are generated which, starting from the mission planning and the COA chosen to implement it, allow all participants to acquire the knowledge necessary to carry out the tasks assigned to them (Figure 7-8).

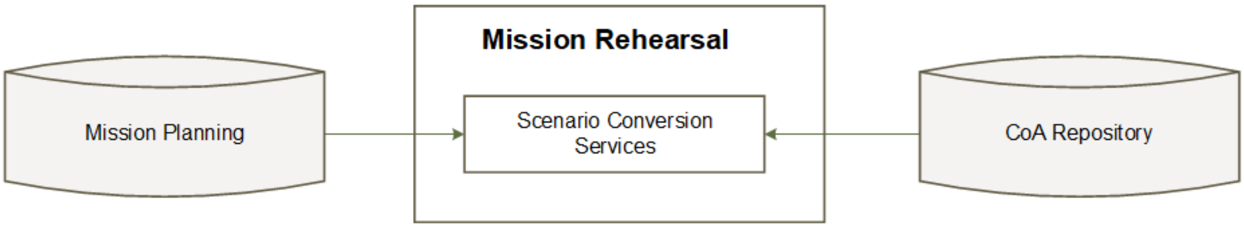

Figure 7-8: Mission Rehearsal.

7.4.4.1 Scenario Conversion Services

The services envisaged in this phase convert the information present in the mission plan and in the selected COA into a series of simulation scenarios that detail the various phases/actions according to the implementation of the plan.

These scenarios are coordinated with each other and use the LVC environments present in the system.

Each participant in the plan (from the commander to the managers of the tactical units up to the front-line personnel) can interact with the simulation environment that involves them and train or verify the actions, timing and other aspects of the plan that concern them.

7.4.5 Mission Execution

During mission execution the envisioned end state established during planning is the target that may be achieved by executing the mission plan. However, during execution generally not everything happens according to plan, and deviations occur. For small deviations, the best approach may be to rapidly execute a new decision-making process to get back on plan. However, new opportunities of threats may arise that call for adjustments in the plan in order to assure achieving the envisioned end state. For these situations reaching back to already developed COAs and alternative plans may be possible and effective but restarting the decision-making process may be needed in unforeseen situations albeit on a different scale.

Should this be supported by decision support systems, the following services may be needed during the mission execution phase:

- COA comparison.
- Mission Execution Decision Support.
- Mission Adjustment Decision.

7.4.5.1 COA Comparison Services

The COA comparison service continuously monitors if the current COA and mission align and triggers events when the execution starts to deviate.

7.4.5.2 Mission Execution Decision Support Services

The mission execution decision support service responds to the triggers that indicate such deviations when there are no significant changes. These decision support services resemble the COA services during the planning phase (Figure 7-9).

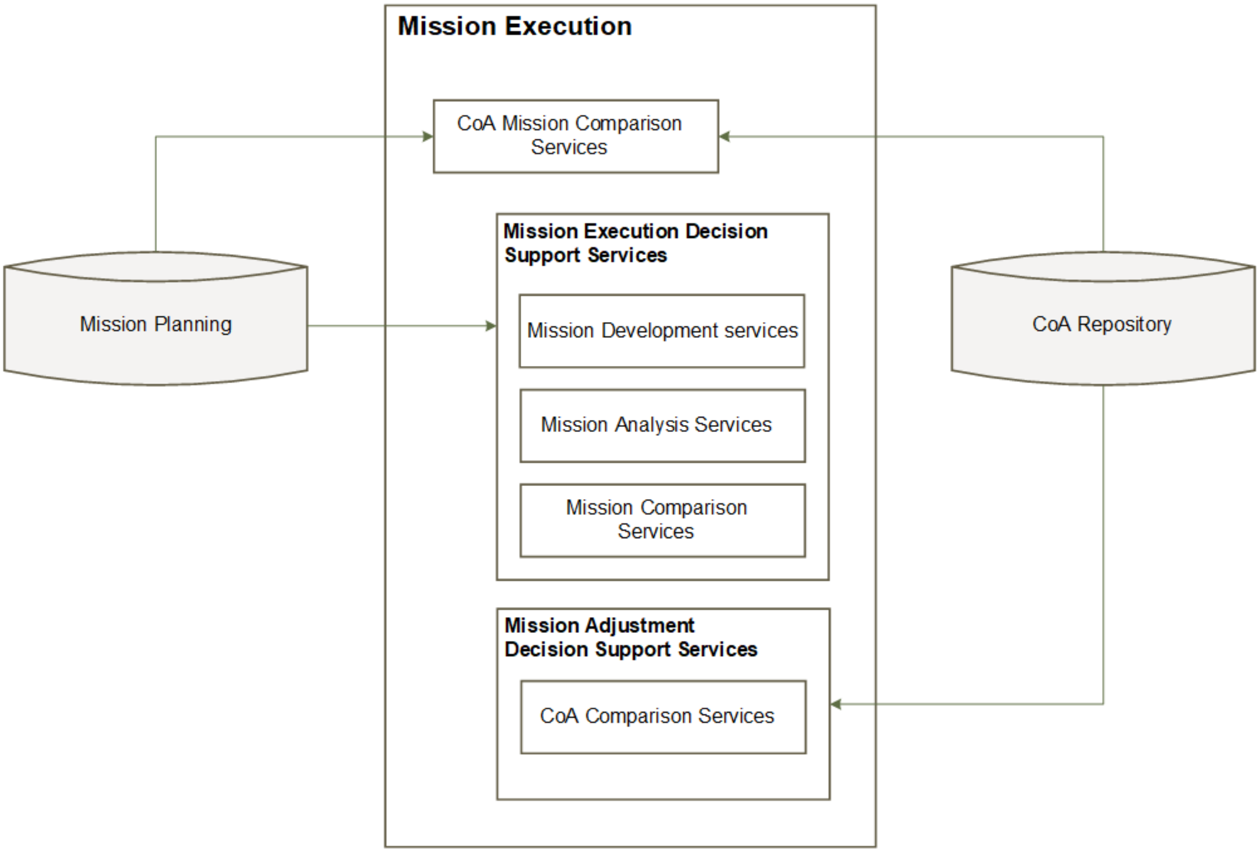

Figure 7-9: Mission Execution.

7.4.5.3 Mission Adjustment Decision Support Services

When there are significant changes and new opportunities and/or threats arise, the Mission Adjustment Decision Support uses a comparable COA Comparison service as seen in the planning phase to assure achieving the envisioned end state.

7.4.6 Mission Debriefing

The debriefing activities concern the meetings and the verification sessions with the members of the team that carried out the planning and execution of a mission through the decision-making tools described above.

Typical debriefing activities include analysing how well mission objectives were met (or not met), describing any difficulties encountered, identifying errors, describing encounters and generally the reporting back of information of interest for analysis.

Debriefing provides a powerful and essential structure for maintaining the capacity to learn. When we create lessons learned through the Debriefing process, we are generating a form of knowledge

Mission planning is most valuable when you follow up with an effective Debrief meeting. The objective of the Debrief meeting is to root out the mistakes and errors and stop them from recurring.

The debriefing activities use the mission data recorded using the tools made available by the Simulation Control modules and in particular the Record and Playback functions.

The services of the mission debriefing, also thanks to the AI components they are equipped with, allow presentation of the qualifying aspects of the mission as well as comparison and analysis of data acquired during the mission with those provided by the COA defined in the planning phase.

7.4.7 Typologies for Decision-Making Support

From the point of view of the products and services delivered by the MSG-189 Ecosystem, a distinction can be made between training on the Decision-Making process and Planning Decision Making.

In addition to the two typologies mentioned, in the future, the functionalities of the Reference Architecture could be used to assist the commanders and their staff during the carrying out of the planned operations in the operational theatre This typology could be defined as “Operational Decision Making.”

The Reference Architecture defined in the MSG-189 working group, therefore, can offer services that, using state-of-the-art technologies, integrate the various components of decision making and allow a more realistic, frequent, and complete training for both commanders and the members of their staff.

The decision-making-oriented services present in the Ecosystem must include both general modules and specific modules of the different types of managed Decision Making.

The general modules, such as those that incorporate the various doctrines used by different countries, provide simple, complete, and flexible work environments that can guide the staff members in the various phases of the execution of the doctrine used for the typology of DM.

It is important to note that the “core” features of the Decision-Making support environment are the same for all three types listed.

The differences between the various types are mainly related to the objectives that each of them aims to achieve, the more or less structured interaction with external entities and the use that is made of synthetic agents equipped with AI to replace some “human” components.

7.4.8 Training on Decision-Making Process

The aim is to train commanders and their staff to hone their skills in developing strategic and tactical operational plans using the services made available by the MSG-189 Ecosystem.

One of the qualifying factors in this type of training is the possibility of elaborating the various phases of the decision-making process even in the absence of some (or all) of the surrounding components, (i.e., the staff members or the heads of the units involved in the execution of the COA). Synthetic agents based on special AI algorithms can replace these components: in this way, the training will no longer be limited by the availability of staff.

Furthermore, thanks to the possibility of carrying out a detailed, realistic, and coordinated simulation sessions of the processed COAs, it will be possible to check the progress of the mission, the achievement of the objectives and the possible presence of errors or situations not adequately managed in the processed COAs. The COA in question may be modified to remedy the problems encountered and the simulation may be repeated to verify the effect of the changes made.

In this case, the instructor indicates the order that starts the mission planning process, the procedures to be followed in the planning process (MDMP, COPD, etc.), the available units, and the opposing ones.

The personnel in training assisted by the synthetic entities (see Section 7.4.3) carry out all phases of the mission planning process.

The rehearsal phase (Section 7.4.4) can be performed both after the conclusion of the planning of a mission and as an independent exercise that takes its cue from a mission present in the data repository.

For this type of DM, the execution phase of the mission (Section 7.4.5) is based on the use of LVC simulation scenarios that have been automatically created starting from the elaborated mission plan and the related COA.

During the execution of the mission, the control services (Section 7.4.5.2 and Section 7.4.5.3) allow its modification, which is received in real time by the simulation environments.

All the capabilities described can be carried out remotely using the MSaaS approach.

7.4.8.1 Features

The main characteristics of the training on the Decision-making process are:

- Generate complete simulation scenarios based on the mission (and COA) elaborated from the flow of DM.
- Replace staff components necessary for the processing of the DM flow with synthetic components that use AI algorithms.
- Perform simulation sessions based on the COA processed and verify the evolution of the scenario.
- Insert in the system the organisational schemes of the main DM doctrines.
- Develop new doctrines of DM, test them, and insert the new template in the system.
- Use data and COA stored in the repositories of the system to review the tactics adopted, the results obtained, and the points of vulnerability detected.
- Recall stored COAs and mission, modify them and train on them (*what if* analysis).
- Carry out simulation sessions based on the elaborated COA that foresee the presence of opposing forces in the scenario (blue forces vs red forces) both as “real” and synthetic components.
- Use appropriate human-machine interfaces to be able to process the various phases of the DM template such as decision panels, augmented reality tools, tactical tables, immersive environments, NLP tools, etc.

7.4.8.2 System Modules Used

- Synthetic Environment – all modules.
- Simulation Control – all modules.

- Network and Simulation Infrastructure – all modules.
- Data Repository – all modules.
- Communications – all modules.
- Physical Elements and System – all modules.
- Real World.

7.4.8.3 Technologies Used

- Artificial Intelligence in its various forms; in particular:
  - Machine Learning and Deep Learning.
  - Constructive Entities AI based.
- Big Data Analytics.
- Immersive Technologies:
  - Virtual /Mixed/Augmented Reality.
  - CAVE.
  - DOME.
- Distributed and Collaborative Simulation.
- MSaaS / TaaS.
- Cyber Security Technologies.
- Serious Games / Gamification.
- Mission / Exercise Management.
- Record and Playback Systems.

7.4.8.4 Innovative Ways of Using Services

The MSG-189 Ecosystem can help make this type of decision making more innovative by providing services.

- They allow commanders and their staff to carry out training sessions with data and orders contained in the decision-making data repository. For example, they will be able to train with situations from the past and plan historical battles reported in military doctrines as topical situations.
- In the training sessions it will be possible to apply different doctrines of decision making (for example MDMP, COPD, etc.) or develop new ones and verify the strengths and counter-indications of each of them.
- In the training sessions it will be possible to apply different doctrines of decision making (for example MDMP, COPD, etc.) or develop new ones and verify the strengths and counter-indications of each of them.
- In the training sessions, synthetic agents based on AI and ML may be used to replace some staff members; this will allow the user to exercise the staff even if some staff members are not available (they are replaced by synthetic agents).
- The use of cloud architecture and MSaaS will allow remote training sessions to be carried out.

7.4.9 Planning Decision Making

The purpose of planning decision making is to support real mission planning.

In general, DM activities can be related to different types of missions ranging from planning tactical (companies, groups, etc.) operations up to a “campaign” level planning involving large units (Divisions, Brigades, etc.) even from different Armed Forces (multi-domain).

In general, higher level schedules involve a larger number of units and have larger theatres of operation. This type of missions is planned with a longer time interval (even a few days or weeks) and can in turn provide input to more limited level planning which, in turn, will have more limited theatres of operation and timing.

The services that the Ecosystem can make available are completely similar to those illustrated for the training DM (*train as you fight*); however, the use of the functions is aimed at optimising the defined COA, its validation and the production of operational orders to be sent to the units in the field.

In this case it is hoped the presence of all the staff who collaborate with the commander in developing the various components of the COA.

7.4.9.1 Features

- Mission planning is based on a “real” order, the units available are defined in the contest and information on the opposing entities is obtained through intelligence tools, social media, and sensor networks.
- In the various step of implementation of the mission plan and related COA, the commander responsible for mission planning and his staff are supported by the architecture functionalities and advanced tools of AI, xAI, Data Analysis.
- These functions provide in real time updated information on the various aspects to be taken into consideration and ensure the consistency of the decisions taken.
- The executive mission orders are sent, in real time, to the commanders of the units involved through secure communication networks.
- All the personnel involved in the mission can carry out the Rehearsal phases of the mission using simulation environments that assist them to understand the assigned objectives and to contextualise the battle space.
- The observations that emerged during the Rehearsal phase can be sent, in real time, to the headquarters, received and processed in order to update the mission plan.
- All the capabilities described can be carried out remotely using the cloud structure of the system.

7.4.9.2 System Modules Used

- Synthetic Environment – all modules.
- Simulation Control – all modules.
- Network and Simulation Infrastructure – all modules.
- Data Repository – all modules.
- Communications – all modules.

- Physical Elements and System – all modules.
- Real World.

7.4.9.3 Technologies Used

- Artificial Intelligence in its various forms; in particular:
  - Machine Learning and Deep Learning.
  - Constructive Entities AI based.
- Social media.
- Advanced Sensor Network.
- Tactical Communication Network / 5G.
- Big Data Analytics.
- Immersive Technologies:
  - Virtual /Mixed/Augmented Reality.
  - CAVE.
  - DOME.
- Distributed and Collaborative Simulation.
- MSaaS.
- Cyber Security Technologies.
- Serious Games / Gamification.
- Mission / Exercise Management.
- Record and Playback Systems.

7.4.9.4 Innovative Ways of Using Services

The system of the MSG-189 study can help make this type of decision making more innovative by providing services that:

- Foresee the use of tools, based on Big Data Analysis algorithms, which allow for acquiring all the data coming from the various sources of information (sensors, intelligence, social media, availability of units and vehicles, weather factors, etc.), analyse them, correlate (through AI and Data Science algorithms) and present them to decision makers in the clearest and most concise possible way (possibly applying xAI algorithms).
- Thanks to data and automated processes, they allow decision makers to focus their attention on the qualifying aspects of the problem by delegating the more formal parts to the SW systems; this will allow the processing of COAs that are complete, consistent and have the best characteristics for achieving the objectives.
- Using the analysis services of the various COAs developed thanks to wargaming technologies, the decision makers will be able to choose the most appropriate one and activate the detailed processing phases provided for by the doctrine that is being used. This will allow the issuance of operational orders that will be distributed to the tactical units that will have to carry out the mission.

7.4.10 Operational Decision Making

Operational decision making is a possible use of the features made available by the MSG-189 Ecosystem.

Using the same SW environment, it will be possible to follow, in real time, the progress of the operations planned in the CoA on the theatre of operations and verify the differences between what is expected and what is happening in reality.

This analysis will be made possible mainly through the acquisition of large amounts of data from the field (sensors, intelligence, social media, availability of units and vehicles, weather factors, etc.) real-time processed and compared with the synthetic data generated during the planning phase through reinforcement learning and AI algorithms.

7.4.10.1 Features

- Using the functionalities of the architecture (see Section 7.4.5) it will be possible to follow, in real time, the progress of the operations planned in the Mission Planning and described in the COA.
- During the operations, data flows will be generated from the sensor networks present in the operations theatre, from social media and information exchanged, through secure and broadband tactical networks, between the various commands and the units present on the field.
- The data flows will be processed through Data Analysis algorithms, interpreted, summarised, and presented to the operations commander and his staff.
- Furthermore, the acquired data will be used by the synthetic scenario generation functions (Section 7.4.4.1) to manage simulation environments that reproduce the real situation on the field.
- Through the comparison functions between the real situation and the planned one in the COA (Section 7.4.5.1) it will be possible to have information on the deviations between what was planned and the situation on the field.
- The mission control and rescheduling functions (Section 7.4.5.2 and Section 7.4.5.3) will make it possible to report significant deviations and to propose rescheduling of the mission to take into account the new situation and ensure the achievement of the set objectives.

7.4.10.2 System Modules Used

- Synthetic Environment – all modules.
- Simulation Control – all modules.
- Network and Simulation Infrastructure – all modules.
- Data Repository – all modules.
- Communications – all modules.
- Physical Elements and System – all modules.
- Real World.

7.4.10.3 Technologies Used

- Artificial Intelligence in its various forms; in particular:
  - Machine Learning and Deep Learning.
  - Constructive Entities AI based.
- Social media.
- Advanced Sensor Network.
- Tactical Communication Network / 5G.
- Big Data Analytics.
- Immersive Technologies:
  - Virtual /Mixed/Augmented Reality.
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- Mission / Exercise Management.
- Record and Playback Systems.

7.4.10.4 Innovative Ways of Using Services

The services made available by the system (based on AI and BD algorithms) can support all participants in the operation to have a coordinated and updated view of their role and the context in which they operate.

The services of the system that operate in support of the staff have the purpose of acquiring data from the field, analysing, correlating, and summarising them in the most understandable way for each of the participants.

Each participant in the operation receives the data useful for achieving their goals; this information derives from holistic data processing and therefore may include (especially for front-line personnel) data beyond its direct perceptual capacity.

The system services also deal with constantly comparing the evolution of the operating scenario with what is expected in the mission planning phase; the detected changes are reported by proposing possible corrective actions.

In the case of rescheduling of the mission, or some parts of it, the new operational orders may be generated in a coordinated manner by the system services and sent to those participants in the operation involved in the change in the COA.

All decisions proposed by the system must be approved by human personnel of the appropriate grade; in addition, the sending of new operational orders must take place only after the explicit approval of the commander or a member of his staff.

Using specific system functions it will be possible to process altered COPs that present a situation that is not real but artificial in order to be able to deceive the opposing forces.

Thanks to the system services, false or misleading data deriving from this COP will be injected (for example through social tools or compromised communication networks) with the aim of deceiving the opposing forces on the real evolution of the operating theatre.

Other system services, on the other hand, will be in charge of analysing the data flows and validating the information contained in order to highlight false or misleading data.

7.4.11 Cross Reference Between Requirements and Products and Services for Decision Making

Table 7-3: Cross Reference Requirements vs P&S for DM.

#	Requirement	Training on Decision Making	Planning Decision Making	Operational Decision Making
2b	The system should allow the user to execute, evaluate and score the complete training activities starting from the mission planning, mission execution and mission debriefing, at all levels.			
2c	The system should allow for multi-site interconnected training systems providing a Common Synthetic distributed Environment. *(e.g., SPARTAN or VIKING Exercises).*			
2d	The system should allow for multi-domain interconnected training systems providing a Common Synthetic Environment.			
3	The system should allow for repeatable scenario for a highly effective learning and CD&E processes.			
6a	The system should allow a training environment suitable to support the definition of new CONOPS and CONUSE (Developing, Testing and Proofing of techniques, tactics and procedures) tools to improve decision making/mission planning, including a new way toward "wise procurement."			
6b	The system should allow for supporting the capability analysis by identifying needs for new capabilities and evaluating the value of a specific (new) capability within an existing force structure.			

#	Requirement	Training on Decision Making	Planning Decision Making	Operational Decision Making
11	The system should allow for providing COA analysis in order to identify possible gaps and alternative solutions.			
12	The system should facilitate the use of different fidelity levels and allow the user to simulate the same entity/sensor/phenomena with different level of fidelity in accordance with the required levels of details for the different users (e.g., trainee and the instructor or soldier and commander).			
13a	The system should allow the user to simulate the different scenarios in a statistical way and analyse the output of each simulation. By means of an iterated approach it will be possible to identify the best configuration and assets to be used. This will allow a reduction in the number of trials to be executed at higher level and therefore to allow trials cost reduction.			
101c	The system should allow for supporting data acquisition from sensor data (pictures, video, infrared, radar) in scenarios with manned-unmanned and UAV systems in order to identify objects of interest and contribute to the common operational picture for decision-making training.			
103	The system should allow for supporting Collateral Damage Estimation specific for Urban Environment and support INFO OPS to warn CIVPOP.			
104	The system should allow for including in the simulated scenarios the Cyber and Electromagnetic Activities (CEMA) effects.			

#	Requirement	Training on Decision Making	Planning Decision Making	Operational Decision Making
105	The system should allow for considering different level of System Validation campaign Field Validation (e.g., Red Flag) HW Validation (Using validation Rig) SW Validation (Using Emulated SW) and their different level of cost.			
106	The system should allow for analysing social media activities related to the area of interest in order to enhance the situational awareness with respect to the population.			

Chapter 8 – SUMMARY AND RECOMMENDATIONS

This chapter draws conclusions from the work done by the ST MSG-189. The activities carried out to achieve the ST's objectives followed the approach stated in the original TAP [1] and subsequently described in the One Pager document [2].

In particular, the objectives indicated in the One Pager document were:

- An overview of the state-of-the-art of each of the enabling technologies (AI, BD, XR, etc.) aimed at defining the qualifying aspects that each of them can play in defining the proposed future simulation framework for training and decision-making support.
- The indication of the gaps, in the training and decision-making military fields, to which the proposed technologies can provide a valuable and viable solution.
- The definition of the system requirements of the simulation framework.
- The definition of the framework architecture.
- A survey on the possible SW tools to be used for the implementation of the framework and on the HW environment.
- The definition of the main functionalities.
- The definition of interfaces with other systems (for example C2 and decision panels).

8.1 SUMMARY OF APPROACH

Due to various limitations, imposed both by the short time available, but also to the COVID-19 pandemic which prevented any regular face-to-face meetings, not all the objectives indicated in the One Pager document have been adequately developed.

The activities were all carried out in virtual mode remotely, using the available web platforms, and off-line both during plenary meetings and specific ad hoc sessions held by the 2 subgroups (Tech and Ops) defined to investigate and deepen the aspects of the research areas and identify and define the main operational aspects.

The first phase of the work was dedicated to identifying and describing the issues indicated in the TAP and in the One Pager document (Training and support for Decision Making).

Also in the first phase, the areas of interest of the research were defined to outline and scope the work; this led to the definition of the M&S Volume of interest of the MSG-189 working group, summarised graphically in Figure 1-3 of the report.

The next phase was dedicated to the research and description of the main innovative technologies to be integrated into the architecture of the simulation framework (renamed MSG-189 Ecosystem) whose definition is one of the objectives of the study.

The research and description of the enabling technologies of the framework, entrusted to the technological subgroup, was one of the most demanding activities carried out in the first phase; during the meetings held on the subject, many technologies useful for achieving the purpose were identified.

The description (even if at a high level) of each enabling technology would have involved the drafting of a very extensive document. It was therefore necessary to make choices that, on the one hand, limited the number of technologies mentioned to those most directly applicable to the Ecosystem functionality and, on the other, reduced the descriptions of the technologies to the essential and qualifying aspects.

Another activity carried out by the ST had, as its objective, the description of some of the current procedures currently used in the military field both for training and for supporting decision making; in this case the goal was to identify the gaps between what is being done with the technologies and methodologies currently available and what could be done with the help of new technologies.

The analysis performed showed that this problem can be treated from at least two different points of view. The first pursues the objective of integrating new technologies into current decision-making and training processes with the aim of improving them and/or making them more efficient and in line with the new operational needs. This approach does not upset the procedures but integrates/improves them.

A second approach, on the other hand, proposes a completely overturn of the current modus operandi and, starting from the possibilities offered by new technologies, envisages an approach that radically modifies the way of dealing with problems and the procedures necessary to do so.

The second approach, while being more “disruptive” and in some ways more innovative, nevertheless presents implementation difficulties linked mainly to overcoming the inertia of military forces to react to sudden changes in consolidated procedures as well as significant effort to change existing systems and/or develop new systems.

The work of the Ops subgroup, on the other hand, led to the definition of the high level requirements of the Ecosystem and the definition of the Reference Architecture building blocks or services on which the MSG-189 Ecosystem is based.

The identified requirements have been classified according to the purpose, scope, and specific domain they describe (user, system, operational, functional, and specific to particular domains).

The points of view expressed were at times very far from each other and represented the sensitivities of each of the participants; for example, concerning the definition of the architecture different points of view were expressed by the group about the proposition of defining a Reference Architecture that, by default, should not be too implementation-specific and a solution or project architecture seen as almost ready to be used.

A consensus was reached, as already stated, in the definition of a Reference Architecture and its building blocks.

Also, with regard to the emphasis to be given to the various issues of training and decision making, different sensitivities were noted regarding the importance to be attributed to some training and operational aspects compared to others. The formulation adopted is of a general nature; the goal achieved was to outline the main features that holistically address training and decision-making support by making use of the new identified technologies without going into implementation details that would have been beyond the objectives of a ST. In a subsequent phase, they could be deepened and specialised to respond to the specific needs of the system to be created and assessed or further developed in a CD&E approach.

The last phase of the group’s work was dedicated to the synthesis of what was previously investigated. In particular, the main categories of Training and Decision-Making support were correlated with the technologies identified and integrated into the building blocks of the architecture. In this phase, possible innovative uses of the system functions applied to the issues of training and decision making were also identified.

As can be deducted from the summary description given above, the approach of the group was to explore multiple aspects of the involved issues trying, in the final phase, to find a synthesis on the main and qualifying aspects to respond to the objectives set in the One Pager document.

For the reasons of time and resources already mentioned, and to give the group's work a homogeneity of treatment, many insights and correlations have only just been briefly mentioned and might generate ideas for further working groups whose task will be to deepen the research with a greater degree of detail.

In conclusion, it can be said that most of the objectives established have been achieved. The only initial objective that has not been explicitly explored is the definition of use cases to describe the capabilities of the system in specific operational contexts.

The choice not to explicitly define these use cases also derives from the logistical difficulties under which the working group has operated, but in particular from the difficulty of interfacing with the stakeholders involved in order to define together with them areas of application and dynamics of correct, consistent and complete use.

8.2 RECOMMENDATIONS

The purpose of an ST is to quickly explore an issue of interest to the stakeholders who have endorsed it and decide whether further investigation is necessary with follow on activities on certain topics and/or correlations/synergies identified during the development of the ST itself.

The main objective is to outline possible scenarios by tracing their outlines and hinting at possible areas of application.

These principles inspired the work of the MSG-189 ST; the result of the activity carried out was presented in the chapters of this document. Part of the material produced was not included in the document both for reasons of space and to give the discussion a homogeneous level of detail. Another result, perhaps the most important, obtained during the meetings held by the working group was that of sharing different experiences, points of view and knowledge.

This plurality of points of view, together with the possibility of deepening understanding and adding detail to what has been described in the report of the group's work, can be an inspiration for new working groups that intend to continue the study of the different issues addressed by the ST MSG-189.

The recommendation to NMSG is to further develop the topics that have been addressed or just only highlighted as of possible interest in the specialist team. Here is a suggested list of topics.

DOTMLPF Impacts of new M&S related technologies in the Training and Decision-Making process

The report does not address the challenges that are always related to the introduction of new types of technology in Defence Organisations. These organisations normally have existing systems and are keen to acquire new and better technology to replace their old technologies. The problem is that they want it to slot new technology into their current way of doing things. This could be difficult as new technologies often do things differently and getting the most out of a new technology can happen only if the processes and methodologies of work structure change as well. This to not forget that a new technology may require new procedures so that it can be used to maximum benefit. A detailed analysis of the full DOTMLPF (Doctrine, Organisation, Training, Materiel, Leadership and education, Personnel and Facilities) implications related to the introduction of such disruptive technologies into Defence Organisations would have to be taken into account.

Detailed definition of the Reference Architecture of the MSG-189 Ecosystem.

The architecture and functionalities of the MSG-189 Ecosystem outlined by the working group are of a high level and completely general; the creation of real systems that perform the functions defined by the ST MSG-189 requires an in-depth analysis and a detailed definition and assessment of the functionalities, interfaces, AI algorithms and both traditional and Big Data-based data structures.

All these tasks should be carried out by a task group, which, starting from what has been done, defines all the technical and functional aspects necessary for the realization of a "real" prototype of the system.

The structure of the project, in this case, should not be that of a specialist team, but of an interdisciplinary working group whose goal is to create a demonstrator with functionalities capable of experimentally implementing the assumptions made.

The duration of the project, the structure of the work team, the resources available and the objectives to be pursued should certainly be more demanding than those of an ST.

Detailed further analysis of Decision-Making support issues

One of the fields of greatest interest analysed during the team's work concerned the issues related to the procedures implemented by some military organisations to govern the processes necessary for mission planning and preparing the personnel involved in its execution. This seems to fit better with decision-making support and also fits with the current focus of the FMN (see activity of MSG-193 ST).

The analysis carried out revealed that in many cases the procedures used are poorly automated and that the teams that carry out these activities (mainly composed by high rank officers) use non-computerised tools.

We have also seen how over the years, each nation and organisation has developed its own procedure that guides the teams in the various stages of the process.

These considerations have not been studied in-depth by the MSG-189 working group, but their in-depth analysis may be the subject of further study groups that focus their attention on the procedures adopted by the various organisations with the aim of aligning them and obtaining the specifications necessary for the development of novel applications and tools to be integrated into the simulation system.

These tools, thanks to the use of technologies based on AI, ML and BD, could provide considerable help to decision-making teams at all stages of the process.

The various doctrines could also be used to train staff in techniques other than those used in their own organisations, thus increasing knowledge of the problems underlying each procedure and providing very useful interoperability tools in the case of teams made up of multinational personnel.

Furthermore, a study group could further deepen the analysis of the various doctrines and procedures in order to propose a single doctrine that best summarises all those currently used also in the perspective of an intensive and "disruptive" use of new technologies

This analysis could lead to the definition of a doctrine with characteristics and points of view that differ from the current ones, which may represent a point of discontinuity with respect to what is currently being done.

FMN [59] related issues and possible applications

As a final recommendation, MSG-189 ST suggests the formation of follow-up working groups which, taking inspiration from what has been done in the MSG-189 ST and MSG-193 ST [59], can define a certain number of use cases in the FMN domain in order to validate the choices made and demonstrate the validity of the Reference Architecture of the system and of the technologies indicated.

Chapter 9 – REFERENCES AND BIBLIOGRAPHY

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14. Abstract

The MSG-189 Technical Report describes the Reference Architecture of an innovative framework aiming at integrating emergent technologies into an advanced simulation environment used for Training and support for Decision Making in the military field. Technologies such as Artificial Intelligence, Machine Learning, Big Data, immersive AR/VR/XR, Cloud computing and Virtualization techniques are integrated with each other and provided as services in a typical simulation architecture based on the MSaaS paradigm. This integration produces a distributed and open Ecosystem in which the services, managed by the framework, use these emergent technologies "by design" to provide the necessary tools for advanced Training and support for Decision Making.

In many cases, this approach allows for a more efficient use of the functions, in some other cases it radically changes the way of approaching problems and provides new solutions through the functionalities of the framework. The Reference Architecture identifies the building blocks needed for the services, describing their tasks, internal and external relations, without however going into details on their realization. The outcome of the MSG-189 specialist team is intended as a first step for future working groups that, starting from the results described in the final report, can deeply define target architectures functional to specific areas.

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