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CENTRE OF EXCELLENCE

COMPUTER ASSISTED ANALYSIS, EXERCISE, EXPERIMENTATION

CA^{2}X^2 FORUM 2022

NATO's Digital Transformation, Now and Beyond

PAPERS COLLECTION

CA^{2}X^2 FORUM 2022

NATO's Digital Transformation, Now & Beyond

NATO Modelling & Simulation Centre of Excellence

This review is a collection of research papers and studies presented during the 2022 Forum.
These articles were selected based on the Forum presentation, the relevant topic and the quality of the information.

The NATO Modelling and Simulation Centre of Excellence team thanks you for participating in the 2022 Forum.

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Introduction

Dear M&S Community of Interest,

It is our great pleasure for the NATO M&S Centre of Excellence to present our 2022 CA2X2 Forum Review. This review is a collection of research papers and studies presented during the 2022 Forum. These articles were selected based on the Forum presentation, the relevant topic and the quality of the information in order to allow the reader a glimpse of the efforts within this community.

The CA2X2 Forum is an extremely fruitful annual event that brings members of the military, industry and academia together to share their ideas, projects and outlooks for the benefit of the NATO Alliance. After two years conducting the Forum online, the 2022 Forum was back in presence in beautiful Rome, Italy and saw the largest audience participation in its history. Although this Review contains only a sample of the projects presented, we hope it demonstrates the level of quality we see year after year in the Forum.

As a NATO accredited Centre of Excellence we strive to bring this group of experts together with the purpose of supporting NATO and the Nations as the Alliance goes through a Digital Transformation to outpace and outthink our adversaries. We are proud to bring this publication to life and share the devotion of the M&S community of interest.

Enjoy!

Best regards

Col. Francesco PACILLO

NATO M&S CoE Director

The CA²X² Forum 2022

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The NATO Modelling and Simulation Centre of Excellence wishes to thank the sponsors

for their contribution to this year's conference and for assisting with making it an incredible achievement.

Francesco Pacillo
Col. ITA Army
NATO M&S CoE Director

This book contains the proceedings of NATO M&S COE's Computer Assisted Analysis, Exercise, Experimentation Forum held from 27-29 September 2022 in Rome, Italy.

The principal theme for the conference was:

'NATO's Digital Transformation, Now & Beyond'

Through a team effort at the M&S COE we have captured many of the articles from the CA2X2 Forum allowing our readers to reference the great work done by some of the contributors. Please use these articles as inspiration for further collaboration and contributions to these important topics.

Thank you for the contributions to the forum,
the insightful questions and discussion to advance these topics.
For those that were unable to participate, this collection of articles will help you understand the level of expertise and professionalism that was displayed during the forum.
Enjoy.

If you wish to provide feedback, please send it to us at: info@mscoe.org.

Thank you and good reading!
The NATO Modelling and Simulation Centre of Excellence

Enhancing Wargames and Training Simulations with Accurate Logistics

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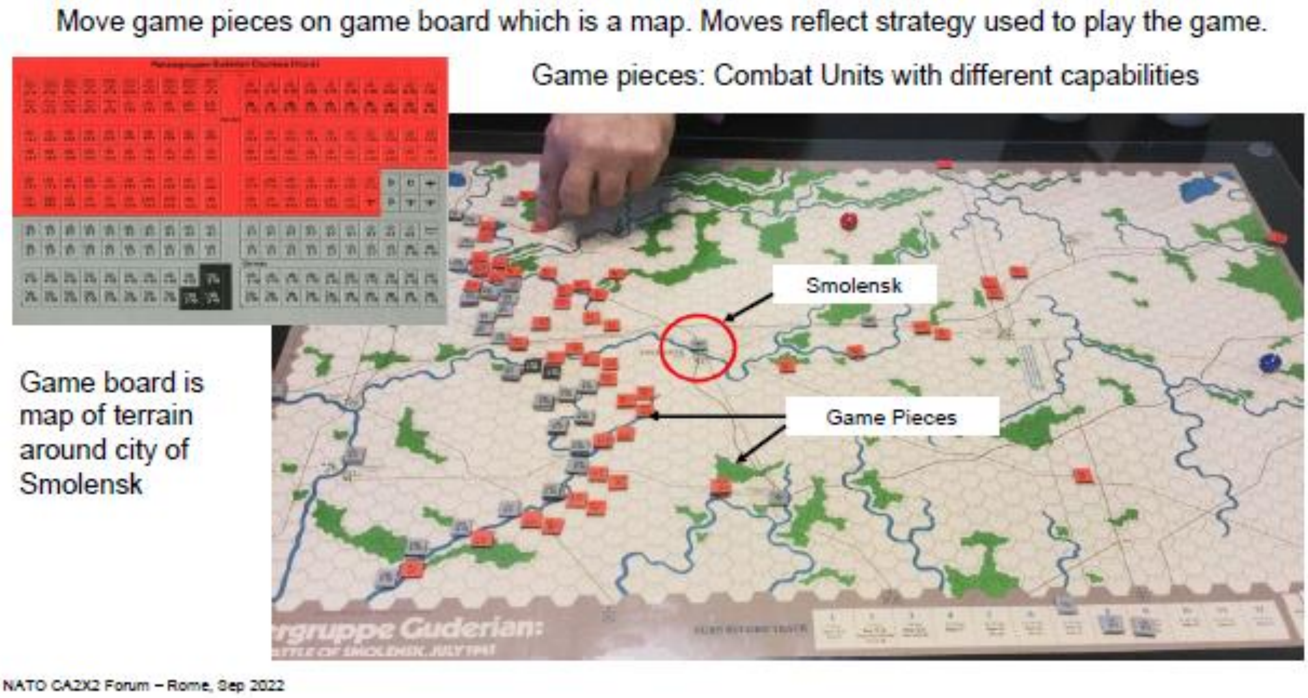
Abstract

Designers of wargames and VR training simulations are understandably reluctant to slow the pace of user interactions with complicated rules and calculations to address logistics that support the activities occurring in those simulations.

Wargames and training simulations therefore handle logistics only in the abstract. Yet, after the skill and bravery of the troops, logistics is perhaps the next most critical factor in the success of any mission.

We show how an accurate logistics dimension can be added wargames and VR training simulations or federations of simulations. A map-based supply chain modeling and simulation application can connect to a federation of other training simulations in a computer aided training exercise. This enables people to see, understand and manage the supply chains required to support operations happening in other training simulations. It adds a new layer of reality to other simulations, and enables realistic training of logistics personnel in a way not previously possible.

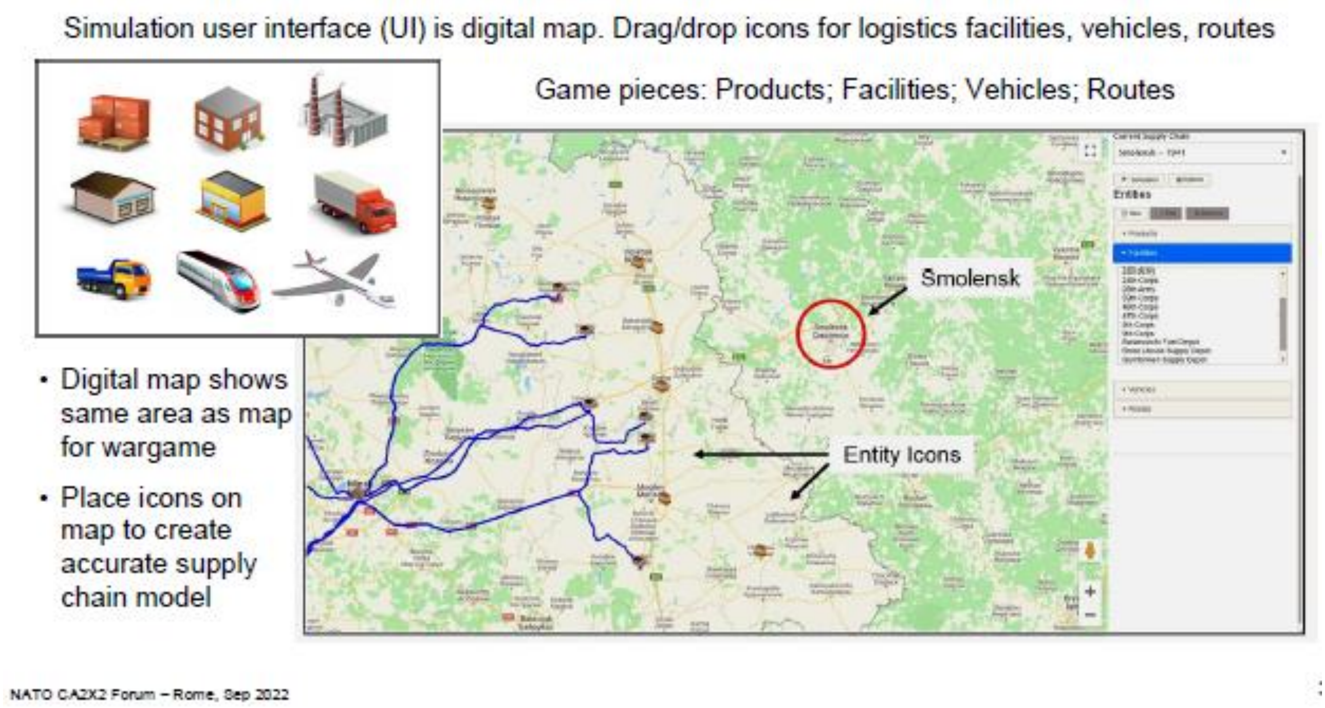
1 Wargame Example: Battle of Smolensk 1941



When game pieces are placed on a map of the battlefield the wargame begins. The placement of the game pieces and rules of the game determine the outcome of the individual moves made by the players in each round of game play.

Once outcomes from moves in the current round are determined that is the base from which players make their next moves in the following round of game play.

2 Add Logistics Dimension to this Wargame



When the game pieces in a supply chain (entity icons) are placed on the map they create a model of the supply chain and the simulation can begin. The simulation engine uses discrete event simulation (DES) with a deterministic, non-linear model. The simulations integrate agent-based modeling techniques with DES by using the four entity classes. This enables simulations to show both the overall state of an entire supply chain network as well as the state of each individual entity within the supply chain moment by moment as simulations play out over time.

Simulations track the flow of products through a network of facilities (a supply chain), and calculates related operating costs and key performance indicators over any number of hours, days, weeks or months. Supply chains and operations can be modeled and simulated at any level from global to regional and local. Simulations display the results of interactions over time between model agents in the four entity classes (products, facilities, vehicles, routes).

Simulations can be paused and re-started as needed to investigate specific developments in particular parts of a supply chain. Simulation data is saved and can be downloaded for further analysis and reporting purposes.

[Further discussion of modeling and simulation logic can be found at the SCM Globe website in the Online Guide section "Supply Chain Modeling and Simulation Logic" - https://www.scmglobe.com/online-guide/supply-chain-modeling-simulation-logic/]

3 Four Entities: Products; Facilities; Vehicles; Routes

A supply chain is modeled by combinations of four entities placed on the map.

Examples are shown here for: 1) Products; 2) Facilities; 3) Vehicles; and 4) Routes.

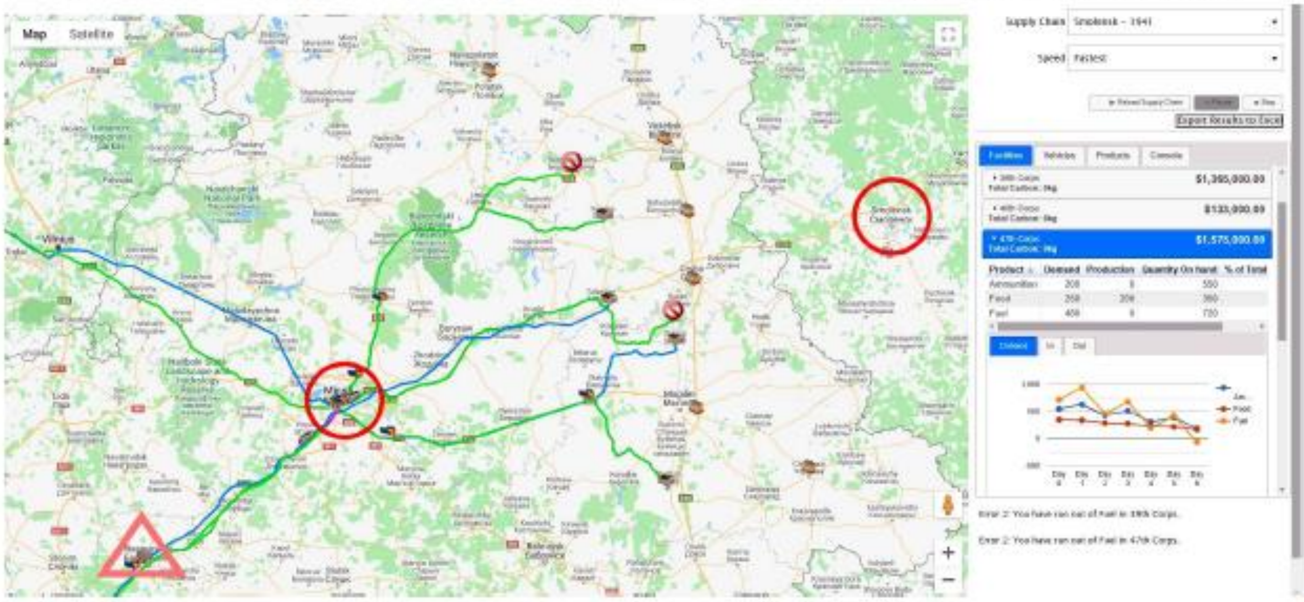
Data to define each entity is based on research – easy to change data as needed or as better data becomes available.

The screenshot shows data for a group of the four entities: (1) Products – size and weight of a shipping container of ammunition; (2) Facilities – storage capacity, internal product demand, and amounts on-hand at the Minsk Supply Depot (production of food at the depot represents food acquired locally); (3) Vehicles – cargo volume and weight, and speed of a vehicle representing 550 medium trucks; and (4) Routes – round trip time and distance on the route taken by those 550 trucks between Minsk and 5th Corps and the amounts of different products they drop off at 5th Corps.

Army group supply depots are shown with the depot icon, and army corps units are shown as warehouses placed where those units locate their main supply dumps. This model assumes each army corps has its own internal vehicles to move supplies from its main supply dumps to lower level units (divisions, regiments, etc). The daily product demand numbers shown for a corps represent the combined demand from all the divisions and regiments in that corps.

4 Simulations Show Points of Failure

Simulations show logistics operating costs, and where supplies run out, or accumulate too much



NATO CA2X2 Forum – Rome, Sep 2022

Once you define a supply chain model, then click on the "Simulation" button to see how well that supply chain works. See trucks and trains running on their routes, and see real time data displays on the right side of the screen showing day to day changes in inventory levels for different supplies at different facilities.

As the simulation is running click on some of those data displays for German supply depots and combat units to see the trends in the on-hand amounts of different supplies. You see various product inventories are trending up and others are trending down at different facilities representing army depots and combat units.

Day by day, as the simulation plays out, it will find and display the mismatches between demand for products at each facility, and the actual amounts of products delivered and onhand at each facility.

Keep trying things to see what works. When you get a simulation that runs for 15 – 30 days it means you have successfully created a logistics plan that will support Army Group Center in this battle for a couple of weeks or a month. Now download the simulation data and apply optimizing algorithms to improve the efficiency of this supply chain as best you can.

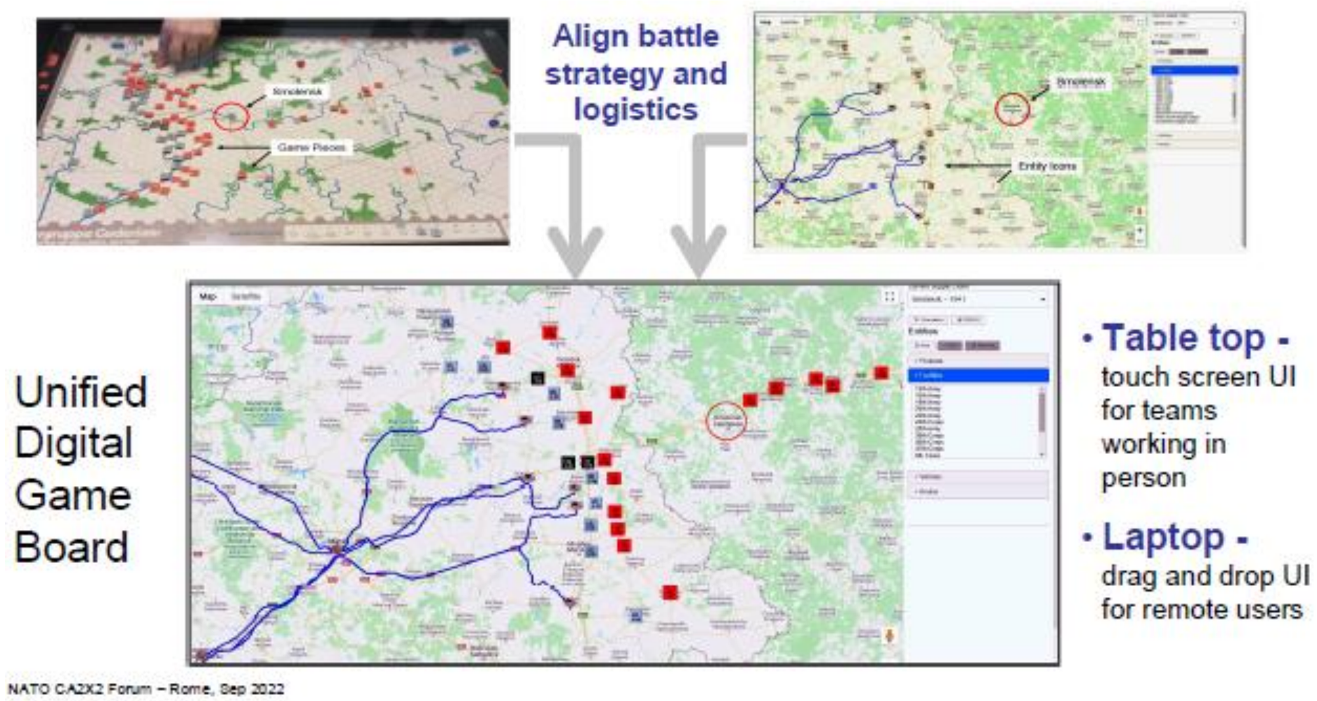
5 Find Best Facilities and Routes for Supply Chains

Assume that after the first 2 – 4 weeks, some of the combat units need to establish new supply dumps to support their advancing troops. Different corps will have different needs. In the real battle some corps traveled long distances (like the 39th Corps and the 47th Corps), and other corps (like the non-motorized 5th Corps and 9th Corps) did not travel so far. For corps that did not travel far, it may not be worth setting up new supply dumps. But for those motorized corps that did travel long distances, it is necessary to establish new supply dumps that are located half or even two thirds of the total distance those corps advanced over the course of the battle.

This means you need to find good locations for these new supply dumps – places well served by road and rail lines. Look for good locations on the map and zoom in and switch to satellite view to see more detail on specific locations. Select locations for the new supply dumps and create new facilities at those locations. Then re-route some portion of the vehicles delivering products to the old supply dumps to deliver products to the new supply dumps.

Then run simulations to see how well the new supply chain works. Get the new supply chain to run again for 15 — 30 days. It will take some experimenting and adjusting to get the new supply chain to work. As you figure these things out you will get an understanding of what is involved in supporting an army in the field. It's a lot harder than it might have seemed at first.

6 Operations Team Supported by Logistics Team



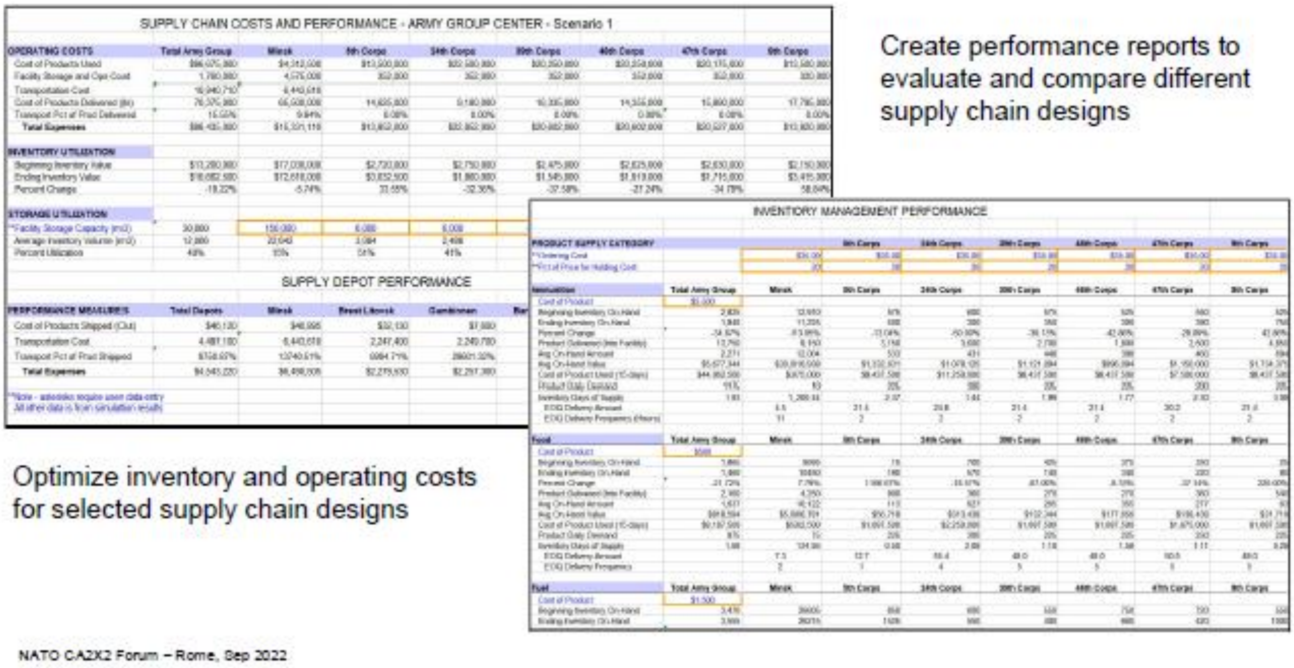
Unified Digital Game Board combines combat and logistics units. It enables operations and logistics teams to work together in the same room or from remote locations. And it leverages the strengths of humans and computers.

Humans do the thinking – they move combat and logistics units on the game board to model and simulate different options.

Computers do the calculations - run simulations, display results, apply AI and optimizing algorithms.

As operations team considers different options for offense and defense, the logistics team runs simulations to design supply chains needed to support those options. If available logistics capabilities cannot support a given battle operation, then it is modified to work within logistics constraints.

7 Simulations Generate Data for Reporting and Analysis



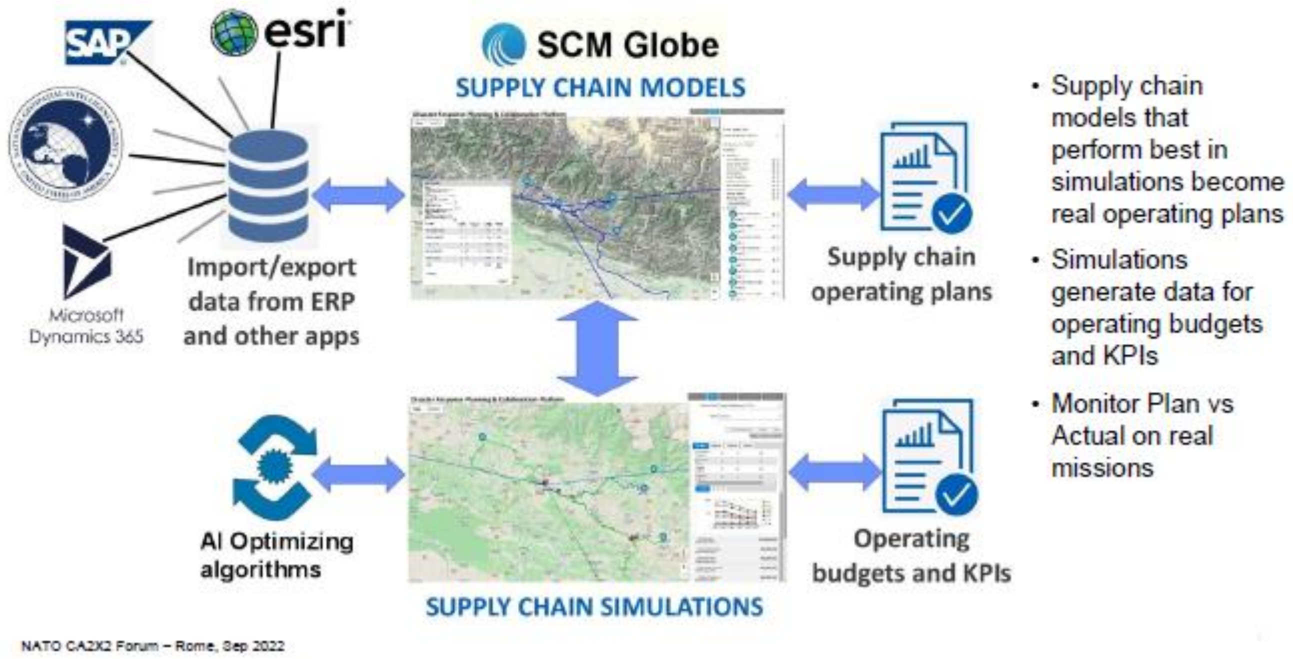
Simulation data can be downloaded and imported into a mission reporting template shown here.

The reporting template has an operations report and a performance dashboard for analyzing simulation data. This reporting template is built for a 15-day period and can be extended for further days as needed.

The operations report shows facility and product detail, and the dashboard shows where the best opportunities are for improvement. Use this reporting template to identify areas for improvement and make changes to your supply chain design based on what the reports show.

After 2 or 3 iterations you sill have a robust and cost effective design for your supply chain. That design becomes the logistics operating plan.

8 Import/Export Data and Optimize Supply Chain Designs

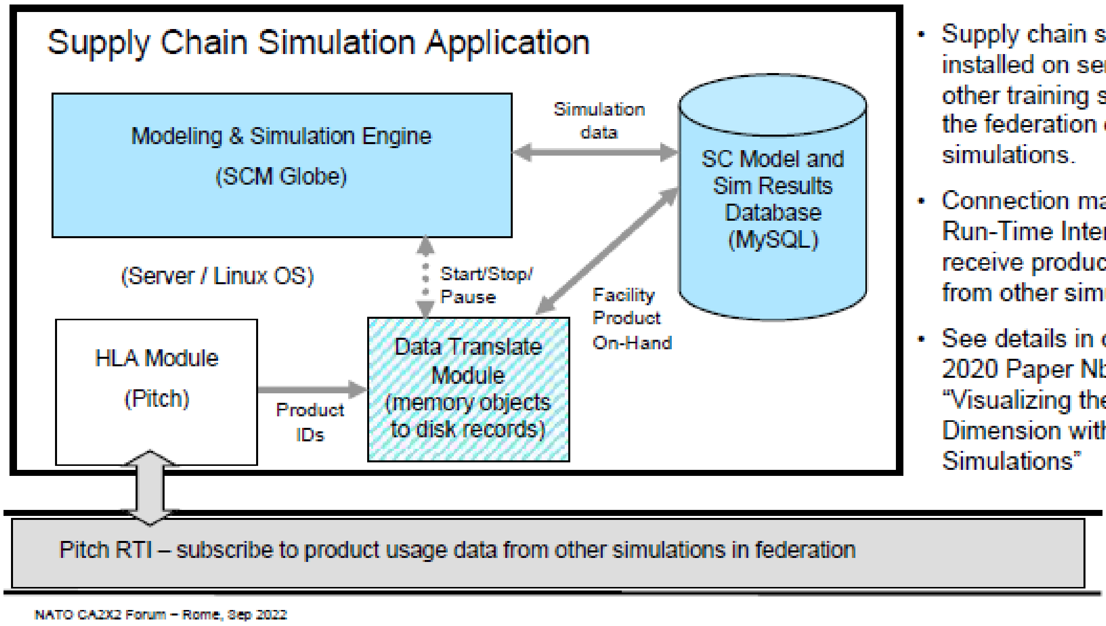


SCM Globe imports data from ERP, transportation management, and other sources to create supply chain models composed of products, facilities, vehicles, and delivery routes accurately placed on a map. Simulations do the thousands of calculations to reconcile mission demand plans with supply plans. Points of failure are found and fixed before those plans are implemented.

SCM Pro enables creation of continuously updated supply chain plans. Simulations generate data to run through optimizing algorithms and improve supply chain models. Models that run best in simulations become actual supply chain operating plans. Simulations also create operating budgets and key performance indicators (KPIs) for monitoring plan vs actual performance, and adjusting operations as needed.

SCM Globe Pro is designed for use by all levels of logistics and operations personnel in the field and at headquarters — not just small groups of experts. We combine a mathematically rigorous approach with an intuitive, engaging user interface to deliver ease of use and critical logistics insights and analytics.

9 Connect to a Federation of VR Training Sims: Technical Architecture

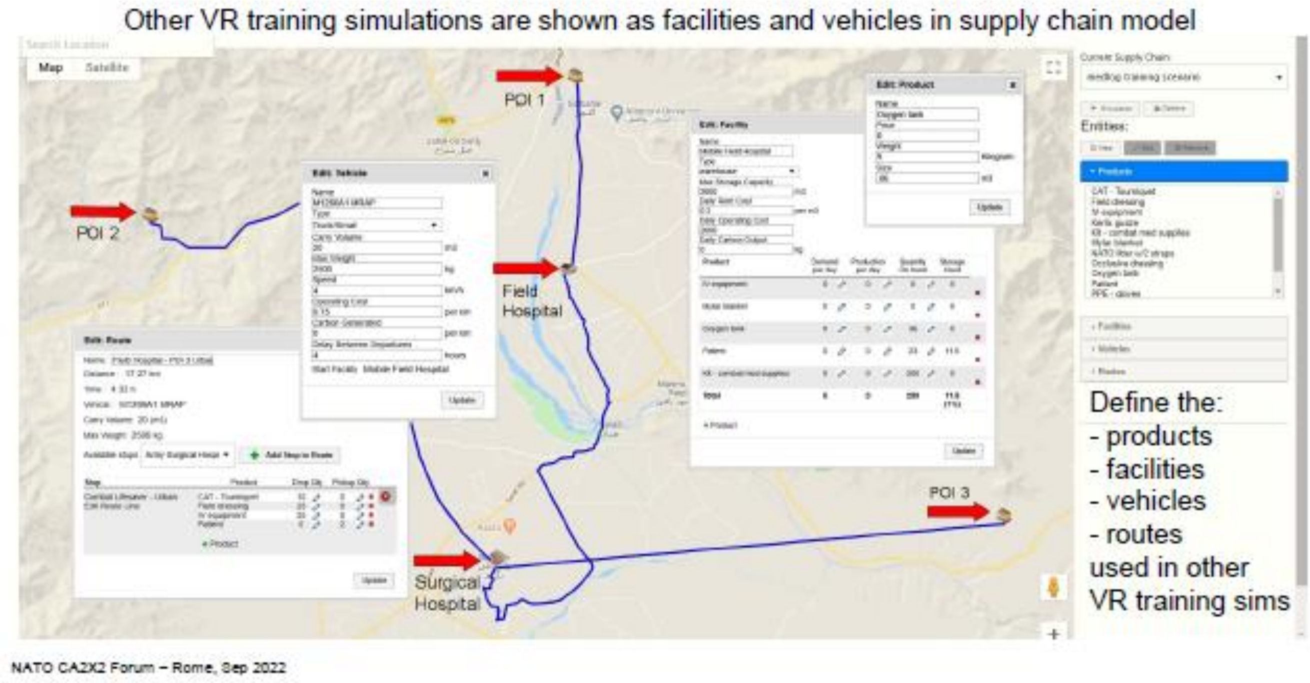


- Supply chain simulations installed on server running other training simulations in the federation of simulations.
- Connection made with Pitch Run-Time Interface (RTI) to receive product usage data from other simulations.
- See details in our I/ITSEC 2020 Paper Nbr 20488, "Visualizing the Logistics Dimension with Map-Based Simulations"

The simulation application was installed on a local server at the prime contractor's office. It connected with the federation of training simulations using a run-time interface (RTI) and high-level architecture (HLA) module developed specifically for the task of enabling different simulations to exchange data and commands (Pitch Technology).

A challenge for integrating this supply chain simulation with real-time 3D training simulations was the different ways data is handled in VR training simulations and in the supply chain simulations. This supply chain simulation software uses a relational database as the central data store. Model and simulation data is stored on disk not in memory. In real-time 3D training simulations data for product usage numbers are stored as objects in memory.

The data translate module (DTM) was created to handle data reformatting tasks. The DTM translates in real-time between in-memory objects and on-disk database records.



A map-based UI with entity icons enables addition of the logistics dimension to other training simulations. Facilities, vehicles and routes in the supply chain model represent other simulations in the federation. People in those simulations use products defined in the model.

Only a small dataset is needed to define each entity as shown in the four dialog boxes in the screenshot. As entities are defined, icons appear onscreen and users drag and drop them to place them on a smart map such as Google Maps. Users zoom in on the map and switch to satellite view to place existing facilities, vehicles and routes where they really are, and put new ones where they want them to be.

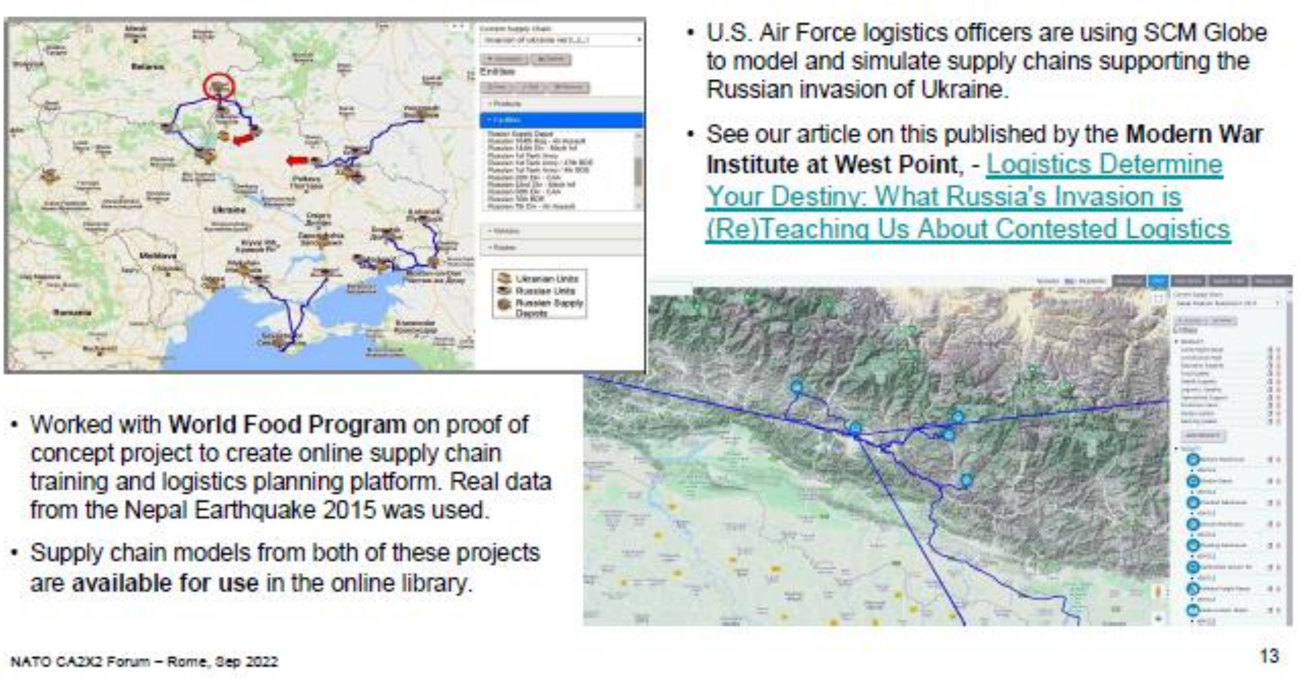
Simulations then show how these entities interact over time to make, deliver and consume products.

11 Show Logistics Operating Status for VR Sims in the Federation

As a subcontractor on this proof of concept project, we added and visualized the logistics dimension for a federation of medical training simulations used in the Point of Injury Training System (POINTS).

Two medical trainees work on a wounded soldier in a virtual reality simulation occurring at a POI. A patient is evacuated from POI to a surgical hospital. Surgical care is given in an operating room. These simulations are independent simulations running in a federation of simulations for this computer assisted medical training exercise.

When supplies are used by caregivers in the independent simulations it depletes the supply of those products available at that facility or vehicle. The supply chain simulation software keeps track of this and shows logisticians how much inventory is delivered and is on-hand at any location. If products run out in one of the simulations, the simulation is paused and logistics team is contacted.. Logisticians redesign supply chain to better support that facility or vehicle, and the simulation starts again.



We're working with instructors at the Air Force Institute of Technology (AFIT) to model and simulate supply chains supporting the Russian invasion of Ukraine. These supply chain models will be used by students studying military logistics at AFIT and the Air Force Logistics Officers School (AFLOS).

Versions of the model evolve as the Russian campaign strategy evolved. Models are available in the online library spanning the time between early March and late May. There are also other simulations: one models the supply chains used to attack Kyiv; another shows use of an airlift component, and another illustrates a plan to increase supply chain capacity and deliver 20 days of supplies.

The model created from data sent to us by the World Food Program is also available in the online library. Along with that model there is also a reporting template to use in creating performance reports from data generated by simulations of that model.

13 Conclusions & Lessons Learned

1) Integrate supply chain modeling & simulation with wargaming

- Both use map-based models to guide exploration of options and predict real world results
- Combine strengths of humans and computers:
  - **Humans:** creative problem solving based on critical thinking and intuitive leaps of imagination
  - **Computers:** ever more powerful for gathering data, scanning, optimizing, and visualizing results
- "Combined arms" approach to volatile, unpredictable, complex, and ambiguous environments

2) Use same platform for training, planning, and operations monitoring

- Map-based UI enables understanding and effective use by wide audience of operations, management, government, and academic people
- Real-time simulations let everyone see best responses to evolving situations, consensus happens faster, enabling decentralized command and control to guide group actions

3) Simulations + Wargaming = Radar - Probe the fog of uncertainty to find the best ways forward as events unfold, and the world changes in unexpected ways…

NATO CA2X2 Forum – Rome, Sep 2022

MICHAEL HUGOS – Co-founder of SCM Globe, providing cloud-based supply chain modeling and simulation applications for education and business. Designed and delivered supply chain applications for Microsoft Xbox, Starbucks Coffee, UN World Food Program, and US Navy Medical Logistics Command. Invited to brief commanding general and staff of USTRANSCOM on topics of resilience and command and control in global supply chains. Working with logistics instructors at U.S. Air Force Institute of Technology, and Air Force Logistics Officers School. Subcontracting on FEMA contract to create and teach training courses for disaster response supply chain planning and design.

Previously chief information officer for international distribution organization where he developed suite of supply chain and e-business systems transforming company's operations and revenue model. Received the CIO 100 Award for resourcefulness, the InformationWeek 500 Award for innovation and the Premier 100 Award for career achievement. Earned his MBA from Northwestern University's Kellogg School of Management. Author of several business and technical books including Essentials of Supply Chain Management, now in its fourth edition.

30-day evaluation accounts available at no cost to instructors and wargame designers who want to learn more about using SCM Globe to add realistic logistics to wargames and training simulations.

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The ValoRens Project - Predictive Analysis: Reading the Enemy's Mind

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Abstract

A major challenge for land forces is to gain an understanding of the tactical situation to a degree that probable future maneuvers can be foreseen. This project focuses on the ability to exploit more information over highly-restricted periods of time, in order to provide rapid decision-making elements for tactical leaders.

The ValoRens project is included in an operative context that started in 2021 with a study led by MASA Group and the French Digital office of the Army headquarters service (EMAT). This work aimed to produce a tool capable of estimating future enemy positions based on detection, and analysis of their goals, movement, and capabilities. Our project focuses mainly on battalion and company levels, and relies heavily on the SWORD simulation software package and artificial intelligence algorithms. Furthermore, it generates initial data and displays the analytic results used to test our solution.

In the near future this project is going to be integrated as an analytic component in the SCORPION combat information system.

In this paper we begin by describing the doctrinal bases, hypotheses, and use cases we have considered. We continue by providing a detailed description of the work accomplished and the results of our first evaluations. We then conclude by outlining what we see as the logical progression of the project, with emphasis placed on enemy ORBAT recognition and behavior analysis.

1 The ValoRens Project Regarding the Operational Environment

1.1 The Study of the Enemy: a Duty to Anticipate

He who studies the enemy is duty bound to attempt to foresee the next move.. The study of the enemy is based on a dilemma: while an enemy is often revealed by its actions, its study must necessarily precede the first direct manifestation of hostility.

Uncertain of an actor's hostile intentions before a threat, the decision-maker is therefore forced to study not a single clearly identified enemy, but rather potential threats that he considers to be a priority. This prioritization depends on the seriousness of the threats and the probability they will occur.

Once the threat has been defined and the strategic options have been validated by the government, the armed forces have a global view of the enemy. This is made possible by the leading national intelligence agencies. However, this vision is often too general to cover the needs, essentially local, of an operation. This is why, in the planning and conduct of operations, the military have their own intelligence methods and procedures. This military intelligence is a process of collection, analysis, dissemination and exploitation of diverse information. The military officer has to be able to describe, at each level of the chain of command, the corresponding enemy: its missions, its space-time framework and its situation. In short, what defines the enemy at each and every level.

At each level and within the strict framework defined by his superior, the military officer decides everything within his area of responsibility. According to the directives received and his tactical knowledge, he therefore makes a "bet" on the enemy (nature, volume, mode of operation, etc.) and decides what to take into account.

1.2 Doctrinal Working Hypotheses

As explained above, doctrinally speaking, an enemy can only be conceived within the framework defined by the mission received. This mission is formalized in the Operational Order (OPORD), which describes in detail the effect to be obtained, the conditions of success, the temporal and spatial limits and the enemy to face. A military entity does not have to confront all of the adversary's forces, but only one part: "its" enemy, "the one who can oppose the execution of its mission throughout the area of action and during the totality of the fixed time frame of its mission".

Within this framework, the analysis of the enemy must be based on "hypotheses conditioning the validity of the planning studied"[1]. Without them, no reasoning is possible. The most common principles are the following:

● *the primacy of superior intelligence*: the intelligence coming from the upper level is considered true *a priori*

● *the rational behavior of actors*: the enemy is considered to be acting consistently within its interests. It seeks to achieve its objective, despite the opponent's actions, by minimizing the means and maximizing its profits. In terms of operations, the enemy is considered neither suicidal nor stupid. From the description of the enemy to the definition of its objectives, and the estimation of its most plausible courses of action, everything is built on the assumption of the enemy's rational behavior.

● *the complementarity of objectives*: each actor at level N-1 contributes to the success of the actors at level N

All existing methods agree on the need to start from what we know in order to deduce what we do not know. Each element of information that modifies initial knowledge causes the cyclical process to start all over again. However, thanks to the stability of military intelligence, a certain amount of information about the enemy is always known and serves as a basis: its available forces, capabilities, doctrine and expected behavior.

1.3 The ValoRens Project

In order to facilitate the understanding of the enemy, the first step of the ValoRens project seeks to estimate future enemy positions. Joint teams from MASA Group, a French SME specialized in Modeling & Simulation and AI, and the Analysis and Operational Research Section of the French Army (SARO EMAT) have developed an algorithm based on artificial intelligence techniques and existing components. The goal is to be able to exploit all available digital data in near-real time. SWORD/SOULT, MASA Group's training software, has been used as a sandbox for this work, with a view to an integration of this component in the SCORPION combat information system.

The initial objective of this study was to estimate, up to 6 hours beforehand, the positions of detected enemy units. This estimation takes into account:

● enemy detection:

  ○ time and position

  ○ posture

  ○ direction and speed

● the behavior of equipment of similar enemy units

● the topography (roads, bridges, cities, type of terrain)

● the enemy's intentions and main objectives

[1] DC-004, Glossaire interarmées de terminologie opérationnelle, Ministère de la Défense, Paris, juin 2015, p119

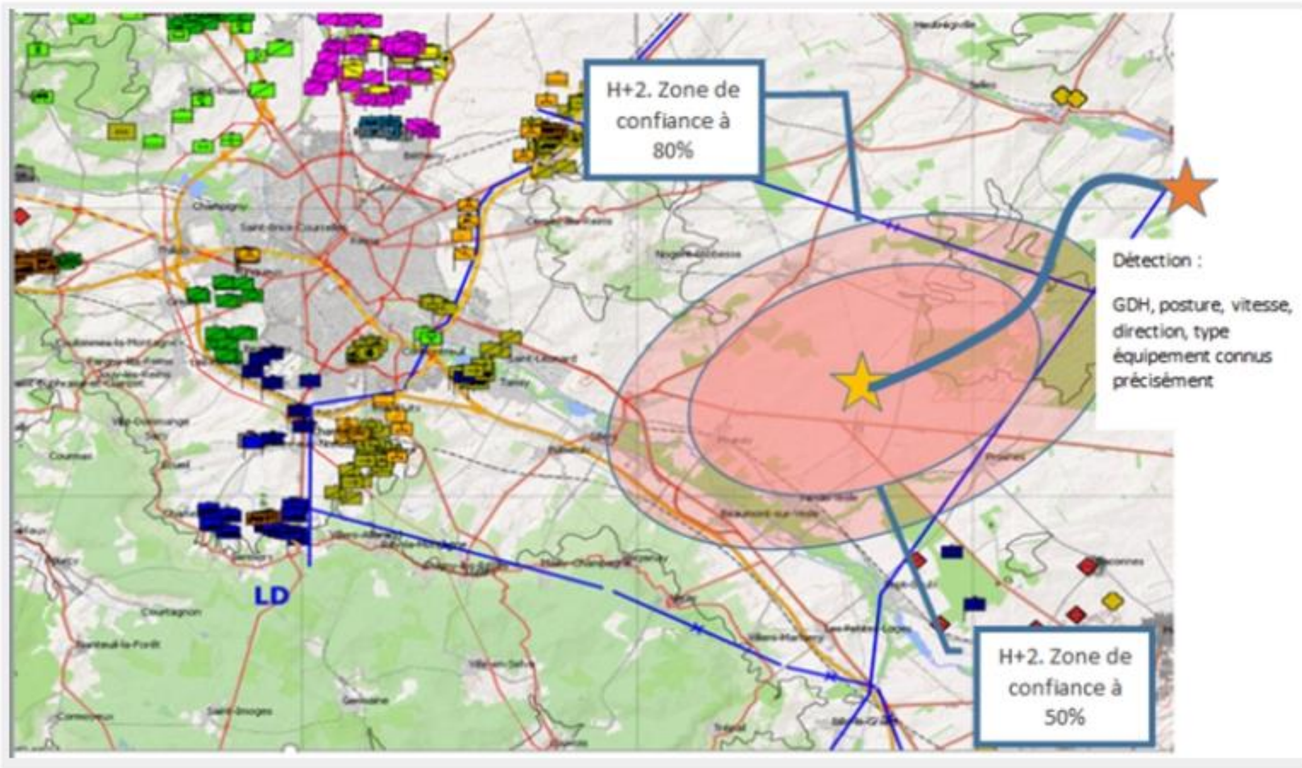

Figure 1 – ValoRens initial requirement

2 The ValoRens Demonstrator

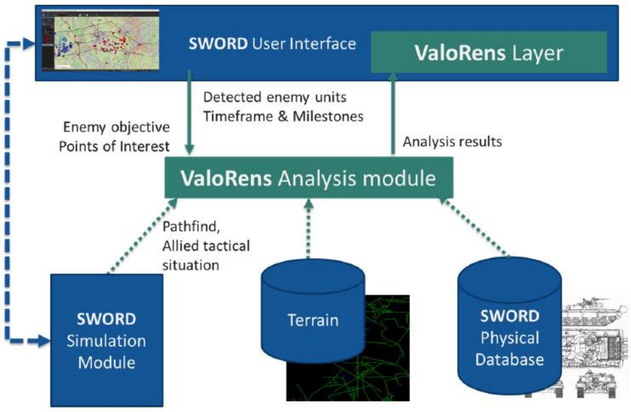

Figure 2 – ValoRens demonstrator architecture

The project estimated the enemy's future position based on the battlefield data generated by SWORD, a database containing known physical enemy capacities (defined inside SWORD) and an external analysis module. Results were displayed in a layer of the SWORD client interface.

2.1 Using SWORD Simulation to Generate Battlefield Data

In order to work on realistic data, we decided to use the data generated by SWORD during multiple dedicated simulation scenarios.

SWORD is based on a constructive simulation and is used for command staff training, operational analysis, doctrine design, etc. SWORD offers the simulation of large-scale conflict scenarios such as conventional warfare, destabilization operations, terrorist attacks, etc. SWORD is able to simulate those different scenarios in realistic environments, and allows trainees to lead thousands of autonomous units over virtual terrains.

The behavior of the autonomous units are modeled using MASA's Artificial Intelligence engine (Direct AI) and internal algorithms that allow agents to perceive, move, communicate, and open fire. The behaviors take into account the capabilities of the equipment involved, the characteristics of the terrain, the weather, etc.

Being part of the SWORD simulation, the allies' units havetheir own knowledge of the scenario and use it to generate intelligence reports. We decided to use these reports as operational intelligence sent directly from the battlefield.

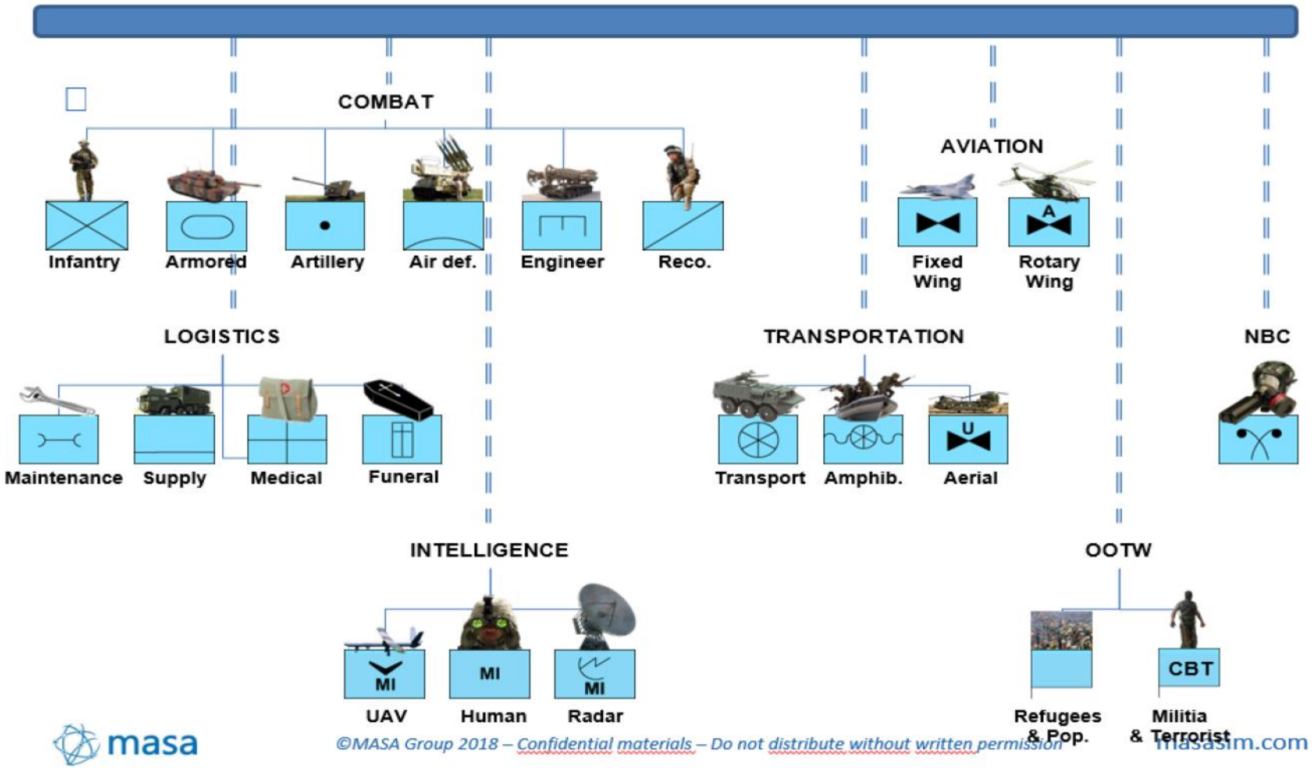

Figure 3 – SWORD generic physical and behavior database

2.2 OPORD Capitalization: Capabilities, Objectives and Points of Interest of the Enemy

<u>How can we exploit the known results of the enemy, terrain and mission analysis contained in the Operation Order (OPORD)?</u>

An Operation Order, often abbreviated to *OPORD*, is a plan format meant to assist subordinate units with the conduct of military operations. An OPORD describes the situation the unit faces, its mission, and the supporting activities the unit will have to conduct to attain the commander's desired end state.

More specifically, the first paragraph of the document analyzes the global situation and aims to provide information essential to subordinate leaders' understanding of the enemy's upper level knowledge: composition of enemy forces, known positions, supposed current activities (attacking, retreating, defending, patrolling, etc.), strength, morale, equipment, capabilities, and probable courses of action.

We decided to model this information as follows:

- *Enemy capacities*: the SWORD simulation contains a huge database of equipment, termed the *physical* database. It details the capacities of each equipment item and more specifically their maximum speed on each type of terrain.

- *Enemy probable courses of action*: in order to deploy and benefit from this information in the ValoRens analysis tool, we introduce two new notions:

    - the *Objective*, which represents the expected final destination of the enemy units under consideration

○ *Points of Interest (POI)*, which represent the tactical positions within the assumed area of responsibility of the enemy units: observation and firing positions, crossroads, bridges, avenues of approach, etc.

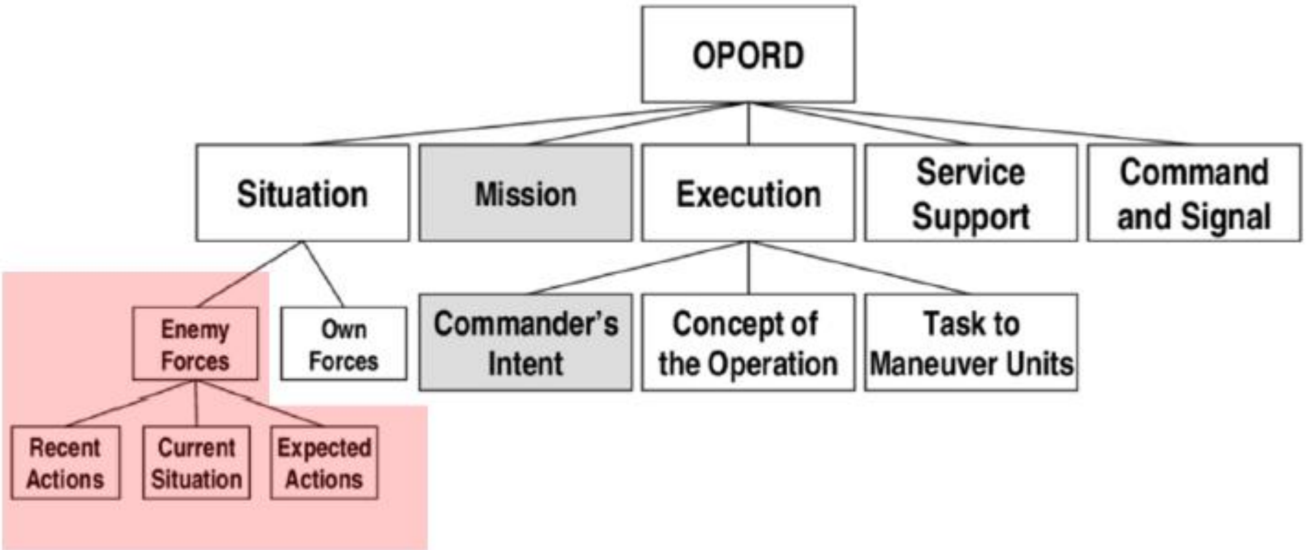

Figure 4 – OPORD Content

2.3 Algorithm of the Future Enemy Position Estimation

In the literature, *adversarial reasoning* is the term used to refer to algorithmic approaches for predicting the enemy's intentions or strategy. Traditionally, the theoretical framework for analyzing the strategy of an adversary is *game theory*. The need to find practical applications, essentially in the military domain, has seen the emergence of research programs such as those at DARPA which explore alternative approaches, such as statistical learning. Our approach makes extensive use of graph theory, while retaining a firm grounding in stochastic game theory.

2.3.1 Problem Definition

In the early stages, the problem of estimating future enemy positions may be approached as the physical problem of estimating the movement of mobile units on an actual physical terrain, where the physical characteristics of the mobile units (e.g., speed profiles according to the type of terrain, time of day, and weather conditions) have to be taken into account. We have not tried to reproduce the work of military experts, which would be unrealistic at best. Instead, we propose a decision support tool to allow them to quickly test different enemy movement hypotheses.

The goal of this work is to define an algorithm for estimating the future positions of enemy units; in our case, a set of geolocated positions, at [t+1, t+2, etc., t+h], where t denotes an *initial time*, and h an estimation *horizon*.

To make predictions, the algorithm takes as input the *observed* positions of enemy units detected in the past (before t). Other information from relevant intelligence reports is also considered (such as speed, direction, equipment capacities, etc.).

Although our approach can be applied, in principle, to any type of unit or terrain, this research focused mainly on *ground units*. For these types of units, the topographical features of the terrain facilitates, hinders, or prevents movement. When speaking about terrain we include infrastructures (roads, paths, bridges, etc.), urban and agricultural terrain areas, and any other topographical features having a military tactical interest. Since our algorithm is integrated in SWORD, we have naturally adopted the terrain capabilities used by SWORD to simulate the movement of units in a realistic manner.

The algorithm we propose here is based on the notion of *points of interest* (POIs). Instead of considering all possible positions, which is impractical, we only consider a small, discrete, subset of *points of interests*, which are points that have a tactical significance. For example, crossroads are considered points of interest as units may be expected to stop there. Observation

points, which are elevated points on the terrain, are also examples of POIs that have a role to play in reconnaissance missions.

What is interesting about the POIs approach, is that operational military experts already think about the terrain in terms of specific areas and points of tactical interest. Also, since we only consider a fairly limited number of points, our algorithm is able to analyze the data fairly rapidly (the goal was a less than 5 seconds analysis).

Ideally, it would be best to deduce the POIs automatically, given the available terrain data. Whether this is possible, and to what extent, represents a research topic in its own right. For this project, we assume that POIs are known, and that they are provided as input by the user.

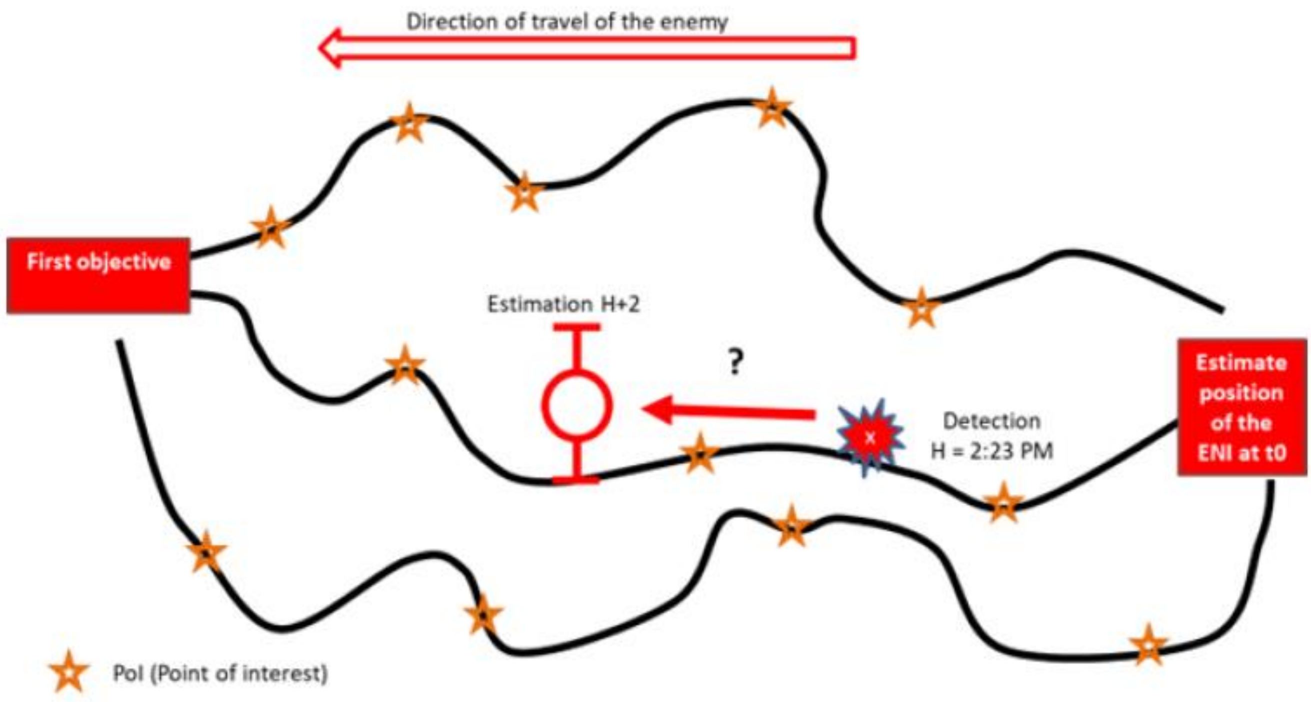

Figure 5 – Valo Rens Problem Definition

2.3.2 Prediction method

The basic principle of our prediction method assumes that an enemy unit *has* a specific goal. In other words, an enemy unit moves to reach one or more targets, in order to accomplish a mission (such as that of neutralizing objectives, monitoring an area, etc.). The goal of an enemy unit might be a unit on the allied side, a position near the allied line of contact, or some other position having a tactical significance. Since an allied unit is also defined by its position, the algorithm operates only on positions, or points, on the terrain.

The figure below illustrates a scenario where three enemy units (in red) advance northwards towards the allied units (in blue). They move along roads, where the crossroads (marked in yellow) are intermediate POIs.

Allied units are also POIs for the enemy. Generally, we cannot be certain of what the enemy *knows* about

the allied units, so we , conservatively, that the enemy has perfect knowledge of allied positions.
The algorithm takes the following inputs provided by the intelligence service:

● the *nature* of the observed unit (e.g., an artillery unit)
● the *initial position* of the unit (at the time of its detection), and
● the *position of its objective* (a point of interest)

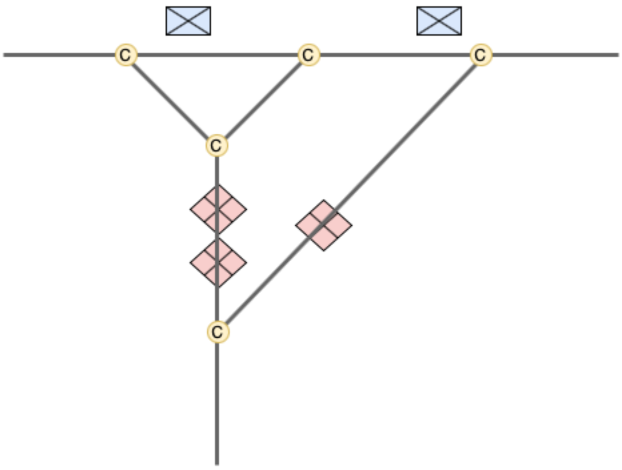

Figure 6 ValoRens algorithm step 1

To estimate the future positions of an enemy unit the algorithm computes *all* possible paths, where each path is defined as having the following properties:

● it has the position of its objective as its endpoint

● it passes through points of interest that enable the enemy unit to reach the end point

Formally, a *path* is a list of ordered points) associated with a total travel time, which is (p the sum of the time taken 1, $p2$, ..., pn to traverse each segment. To determine such a path, and also to ensure consistency with the outcome of our simulations, we use the *path-finding algorithm* integrated in SWORD. Given the initial and target positions, the path-finder computes a detailed path containing any relevant POI, such that the total travel time is *minimal*. Minimizing the travel time is akin to assuming that the enemy will *normally* take the fastest path to reach its goal, unless the path is tactically unsound. SWORD's path-finder takes into account the unit's capacities, and only considers paths that the unit can physically cross (e.g., without risking getting stuck).

For example, if the enemy unit in the following figure has the allied unit's position as its objective, the possible paths are: (2, 3, *f*), (2, 4, *f*), and (1, 5, 4, *f*), where *f* denotes the target allied unit.

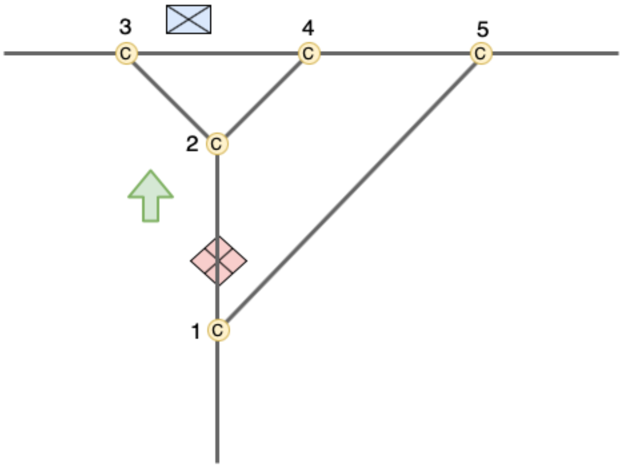

Figure 7 ValoRens algorithm step 2

Our description so far only takes into account the physical movement capabilities of the units along all possible routes. It does not yet take all the aspects of the tactical situation into account. When evaluating the set of paths considered by our algorithm, a military expert would immediately understand that some paths are not realistic, or very unlikely. To introduce this knowledge, an extended version of our algorithm should assign a probability to each path, following rules specified by the military operational military experts. These rules should be the result of empirical studies, military doctrine, and field experience. This idea is further developed in the Evaluation and Future Directions section.

Any paths having a low probability, less than 0.20, for instance, areby convention discarded. The remaining paths are used to estimate the set of future positions that will be envisioned. When assigning probabilities to the possible (or probable) paths, and in order to be able to interpret these values formally as probabilities, it is necessary to require that their sum does not exceed 1 (or 100%).

Using our previous example, if at each crossroads we assign a probability to each possible path, according to the values given in the following figure, the probabilities of the paths (2, 3, *f*), (2, 4, *f*), and (1, 5, 4, *f*), will be, respectively, 0.45, 0.45, and 0.1.

The value of 0.45 is obtained by multiplying the probability of continuing straight ahead (0.9), with the probability of approaching the target unit from the left or from the right. (Here, we deliberately use the vocabulary specific to game theory, where each crossroads is understood as a probability distribution on the outcome of choosing one of the paths.)

Note that the algorithm will discard the last path, with a probability of 0.10, where the enemy unit turns back to take a routethat leads it momentarily away from its target.

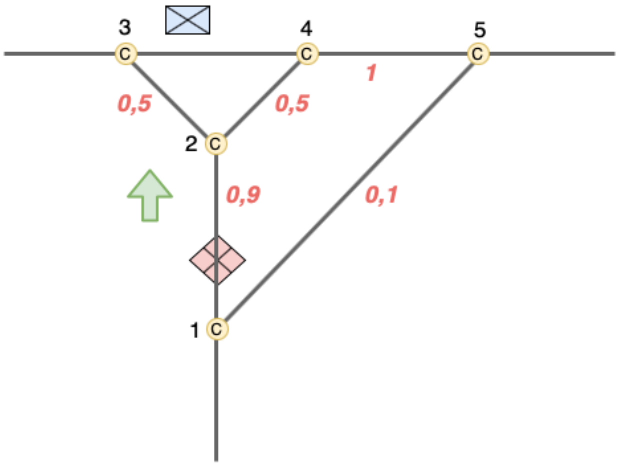

Figure 8 ValoRens algorithm step 3

2.4 Demonstration and Results

Figure 9 SWORD Scenario

In order to illustrate the work done, a tailored demonstration scenario has been created on French terrain. Two ORBATs were created:

● one for the allied team, made up of land forces (2 squadrons XL with 4 platoons, 1 CAC et, 1 SDTI et 1 Patroller) andtwo drones

● one for the enemy team, composed of armored vehicles and tanks ((1 company of 4 sections composed by 4 T72)

The enemy units approach their objective behind the allies with an offensive reconnaissance mission The allies have defense missions and their drones are on a recon mission.

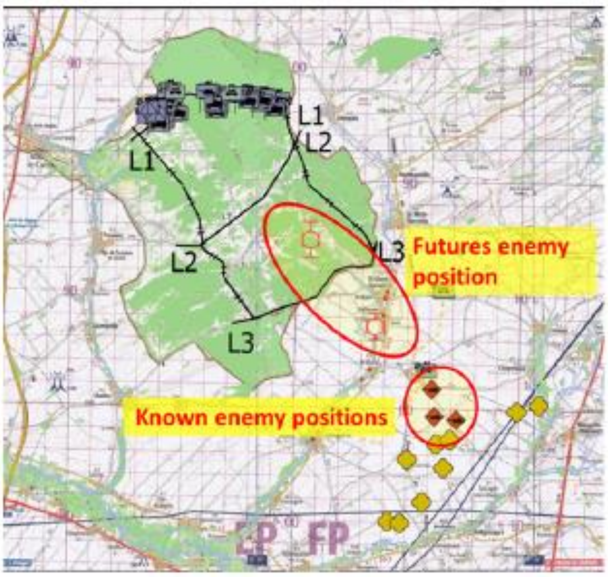

Figure 10 ValoRens Analysis results

Once the first enemy units have been detected, the analyst can open the ValoRens analysis window available in SWORD and fill in settings of the desired analysis.

The settings enter are :

● the targeted detected enemy units and the knowledge of them that we possess (position, date, speed, equipment, etc.)
● the main enemy objective
● enemy points of interests
● the time frame of the analysis
● A period of time between two date values in the time frame, termed a *milestone*

Figure 11 ValoRens Milestone marker

The analysis is almost instantaneous and the results are displayed in a dedicated layer on the SWORD terrain. Red markers indicate the future estimated enemy stroop positions. The segments delimit a rectangle that contains the estimated positions at each milestone (every 1 hour, 2 hours etc.).

3 Evaluation and Future Directions

The ValoRens Demonstrator has been shown in action at defense exhibitions (Journées Defense & IA, Defence Innovation Forum 2022, etc.) to many high ranking officers and industrial contractors, where their comments and descriptions of their needs proved extremely useful. On these occasions the operational need was validated and the proposed solution was considered promising.

Figure 12 ValoRens Booth at FID 2022

Some questions remain unanswered, such as:

● how can we utilize the enemy ETA (Estimated Time of Arrival) in the prediction algorithm?
● how can we better utilize the points of interest? Should we filter them? Should we prioritize them? How could we enhance their influence on the prediction algorithm? For example, a crossroads and a bridge should not be treated in the same way if one of the two is also an observation position.
● how can we modelize the knowledge the enemy has of the positions of allied units of allied units positions? What effect will this have on the algorithm?

In any case, this first version of the ValoRens project permitted to validate the following points:

● data generated by SWORD's simulation are exemplary operational data
● the game theory used produces excellent results and it allows you to accurately predict future enemy

positions
● the software architecture selected allowed us to propose near-real time analysis

Our intention now is to capitalize on this first phase by producing a more powerful tactical situation analysis tool , capable of estimating not only future enemy positions, the enemy ORBAT, and more generally, its overall intentions, all based on our initial partial knowledge of the said enemy. We then plan to integrate this new analysis tool in operational Command and Control (C2) systems.

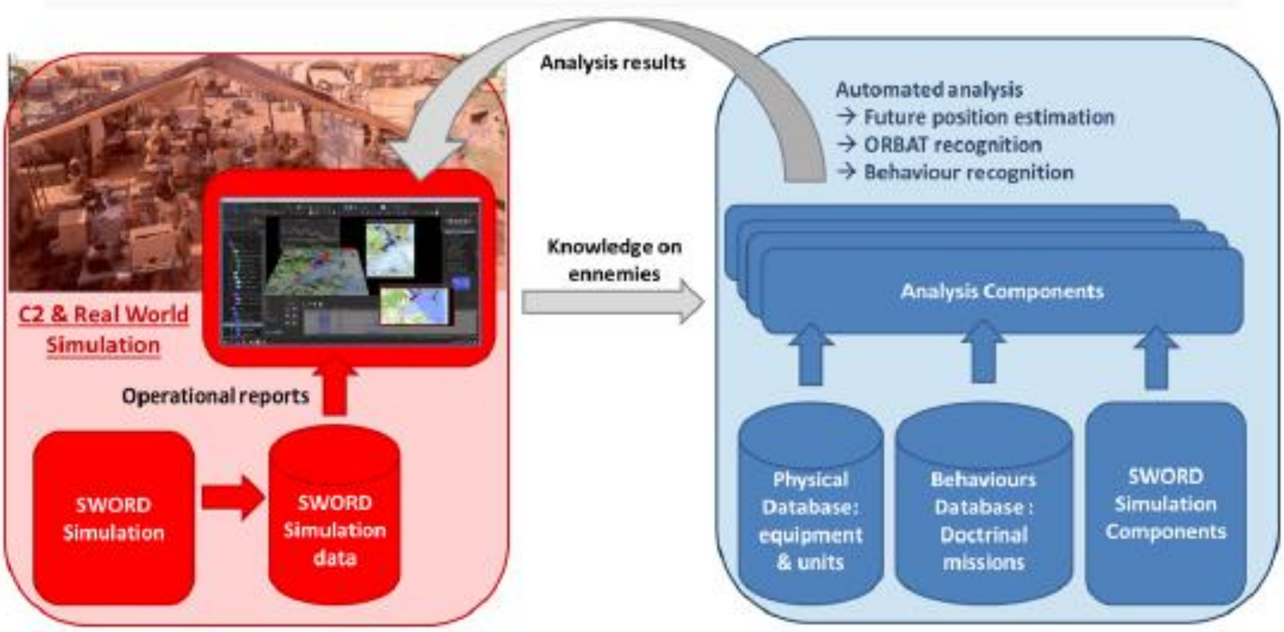

Figure 13 ValoRens Future Directions

This ambitious body of work has been divided into several sub-studies:

● Point of Interest computation: today all points of interest are entered by an operator. We would like to create a geographic analytical tool that calculates, filters and prioritizes the points of interest according to the assumed activities of selected enemy units.

● Estimation of the Enemy Orbat and Mission Nature: The new algorithm will estimage of the structure of the enemy ORBAT, and attempt to determine the nature of missions (defense, attack, control…) at a moment in time. t. To perform these tasks it will consider the positions and movements of the enemy units detected and will try to determine groups of units, termed spatio-temporal clustering. These groups will then be aggregated to form organizational hypotheses. To achieve this, it will be necessary to take into account the types of units encountered, and their operational roles (units specialized in reconnaissance, in direct combat, engineering, logistics, etc.). It is also necessary to determine the organization on the ground of units of the same type, for example by identifying a device at several levels. As a starting point, we plan to use both SWORD's physical database and behavior library:

○ the physical database contains the description of all units, their equipment, capacities, etc. It also describes the typical composition of companies, battalions, etc.
○ the behavior library includes a formal description of military missions at company and battalion level. This in particular describes the coordination between companies and their organization.

These databases will be formalised to serve as a reference point to allow us to obtain an estimation of the enemy ORBAT and its activities via missions.

● Enhancing the estimation of future enemy positions: in our initial approach, the enemy's objectives are always translated into a mouvement through tactical points of interest. In our new approach, we will also consider the *intentions* and actions of the enemy. An *intention* is formalized as a set of equivalence classes of possible paths to potential targets. Initially, without any information other than the position and type of a unit, the set of paths does not allow the military expert to identify a clear intention. However, the tactical information provided by intelligence, as well as the rules of military doctrine, and the nature of the terrain, make it possible to reduce the size of the set of possible paths sufficiently to identify an emerging strategy. The reduction of the number of paths will be done indirectly by assigning a greater or lesser probability to a path equivalence class. By adopting the vocabulary of game theory, the path segments can be interpreted as the branches of a stochastic decision tree, and the intermediate points of interest as decision nodes, where each sub-tree describes a distribution of probabilities. This approach can be further improved with the help of military experts.

● Integration in C2 systems: the future use case of ValoRens is a decision support tool that connects directly to a C2 system and the Intelligence Cell at headquarters (G2).

4. Conclusion

This first iteration of the ValoRens project was a positive proof of concept. Game theory offered the necessary scientific foundations and successfully provided the first elements of a solution that is capable of successfully identifying future enemy positions. Though many questions remain unanswered, we succeeded in validating the use of SWORD to simulate the battlefield, and the proposed architecture has proven effective and open. To move to the next level, we plan to produce a more complete decision support tool that is capable of building a global view of enemies, and furthermore can optimize the estimation of future force ratios.

"Quantum" Evolution in the Future of Telecommunications & Cybersecurity: A Dual Use Approach

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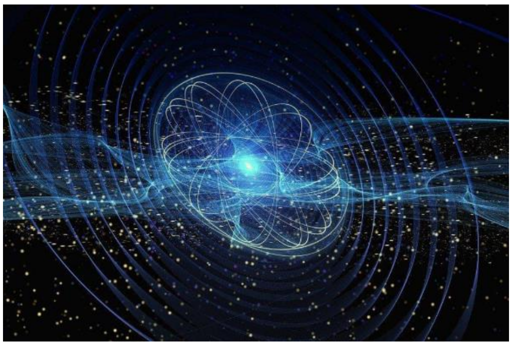


1 Introduction

Next generation "QUANTUM" technologies represent a revolution in military operations that will change in the future the way of operations, from cybersecurity to communications in tactics, operational and warfare strategies in modelling & simulation. Quantum technologies are dual-use technologies, and therefore are of interest to the defence and cyber security industry and military.

A fundamental role in this new scenario is "hyper connectivity" in the military framework as a digitization of the battlefield where all military elements are connected. The Defense Science Board (DSB), an independent Department of Defense (DOD) board of scientific advisors, has concluded that three applications of quantum technology hold the most promise for DOD: quantum sensing, quantum computers, and quantum communications. Today, European critical infrastructures and public safety communications and cloud are vulnerable to cyber-attacks. Today advances in supercomputing and the advent of quantum computing may soon undermine modern encryption systems, threatening the security of transmitted data and secure access to remotely cloud infrastructure.

2 "QUANTUM" Evolution in the Future of Telecommunications & Cybersecurity

The recent RADAR systems and the 5G and 6G antennas have contiguous or even overlapping operating principles that allow the development of solutions in a dual use perspective.

The convergence between radar and telecommunications can be glimpsed in the use of electronically scanned antennas that for 5G and 6G transmissions use "smart antennas" MIMO - Multiple Input Multiple Output. In the future, we begin to glimpse the evolution towards quantum radar while the "quantum" revolution in 6G with cognitive radio will be the next generation architecture thanks to quantum computers that already allow in 5G the optimal cellular planning of frequencies and transmission network. We are now working on the fusion of technologies with Quantum Machine Learning for 6G networks.

Quantum computers perform mathematical tasks thanks to Qbit. Quantum Computing will support the development of innovative services, and one of the new areas of research is the synergy of quantum computer with artificial intelligence (AI). The AI domain is a reality and therefore many applications will be deployed with AI to support next-generation wireless communications.

In fact, one of the industries that profit most from artificial intelligence technologies is that of wireless communications, as AI is incorporated into both smartphones and cellular architecture to control services and network resources..

The 6G network will manage billions of devices, thanks to quantum computing and artificial intelligence platforms. Digital technologies are also becoming a fundamental and essential means of guaranteeing the sovereignty of countries. The development of 6G infrastructure and solutions based in Europe is one of the keys to ensuring

European sovereignty in critical technologies and systems.

For this strategic and vital goal for the survival of the Industry, the EU has launched a first research program of 240 million euros for 6G, thus hoping to maintain technological sovereignty after 5G also in 6G.

Among the innovative hyper connectivity technologies, the Software Defined Radio and Cognitive Radio will be able to adapt to changes in the environment, interference and the availability of licensed and unlicensed frequencies.

Thus contributing to the management of traffic in communications between different systems, even in operational scenarios that provide more flexible spectrum management methodologies thanks to "cognitive radio" & "self-organizing functionalities".

Cognitive Radio is the intelligent technology that explores the spectrum by exploiting the holes of unlicensed or underused frequencies and their spatial availability. In the 6G communication network, devices such as smartphones are expected to interact with the base stations of the cellular network and receive indications on the portion of the spectrum in which they can find more favorable conditions in terms of greater availability for frequencies and bit rates..

This increases the complexity and the need for high computational capacity that can be met by Quantum Computing and Artificial Intelligence technologies. One of the main problems of a Cognitive Radio (CR) and SDR architecture for 5G systems is the enormous energy needs to support the cognitive capabilities of mobile devices. Cognitive Radio has a high complexity related to chip implementations and artificial intelligence applications. In addition, there are further limitations related to the realization of CRs that require devices with high computational complexities in order to analyse and perceive the entire spectrum range with good sensitivity and quality.

However, this evolution of 5G with the integration of SDR / CR in its 6G radio architecture even if now it appears an uphill road will become unavoidable.

The new "Next generation" 6G communication systems are already born intelligent, and will provide operators with a platform that will allow them to make the best use of the scarce resource of the spectrum thanks to an ethergeneous network architecture that requires cognitive radio to be realized.

The next decade will see 6G connect billions of device entities, sensors and connected vehicles, in a scenario where robots and drones will generate Zettabytes of digital information. 6G will improve 5G applications with more stringent requirements, such as holographic telepresence and immersive communication, and meet even stricter parameters than 5G.

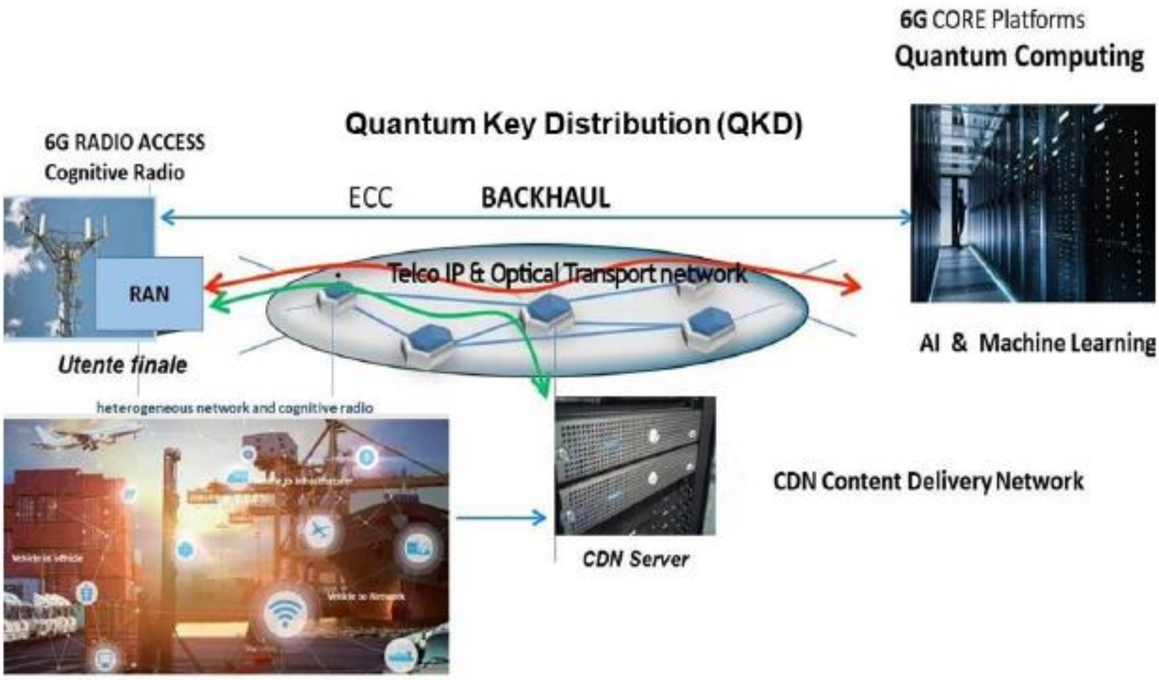
Starting from 2030, we could see the advent of the era in which the use of personal mobile robotics will interact with next-generation Artificial Intelligence platforms thanks to neuronal systems offered by the connectivity of the 6G network.

Artificial intelligence will be both local and distributed thanks to fog computing architectures and quantum computing capabilities. "AI everywhere" is the mantra of the new network.

At the following link, you can read an in-depth analysis on 6G:

https://www.agendadigitale.eu/infrastrutture/verso-il-6g-modelli-e-strategie-perlecosistemaitaliano-e-ue/

3 6G Architecture & Quantum Technologies



6G is the generation of mobile networks that will help us to face the socio-economic challenges in which the way of living and working will make a new paradigm shift compared to 5G.

6G will be an autonomous ecosystem based on artificial intelligence. 6G will offer complete wireless connectivity almost instantaneous and without restrictions thanks to the cognitive radio in which artificial intelligence falls both in the mobile device and in the management of radio interfaces.

A new landscape will also emerge for industries and companies always involved in digital transformation thanks to the convergence that 6G will enable in the fields of connectivity, robotics, cloud computing. This will radically reshape the way companies operate while also changing future social relationships. This exposes us to risks of lack of development of microchips with autonomous technology in Europe.

The topic is described in the article https://www.agendadigitale.eu/industry-4-0/microchip-5g-e-cloud-cosi-la-ue-accelera-sui-pilastridella-trasformazione-digitale/

Quantum Information Technology (QIT) has been evolving rapidly in recent years in terms of quantum communications and quantum computing.

It is envisioned that QIT will enable and boost future 6G systems from both communication and computing perspectives.

Secure quantum communications such as Quantum Key Distribution (QKD) can be leveraged to improve 6G security.

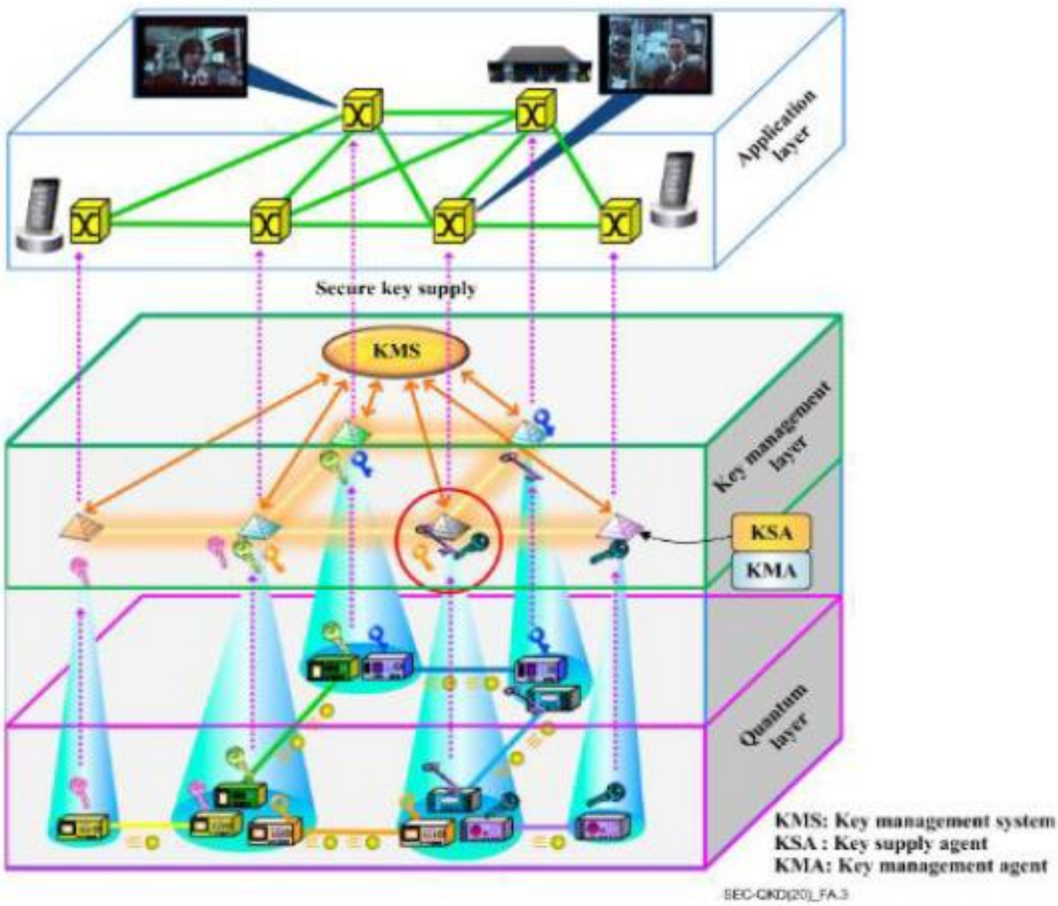
Standardization Activities

ITU-T Focus Group on Quantum Information Technology for Networks (FG-QIT4N)
https://www.itu.int/en/ITU-T/focusgroups/qit4n/Pages/default.aspx

IETF - Quantum Internet Research Group (qirg)
https://datatracker.ietf.org/group/qirg/about/

ETSI - Quantum Safe Cryptography
https://www.etsi.org/technologies/quantum-key-distribution

GSMA IG Work-item on Quantum Technologies and Services
https://www.gsma.com/



Source: https://www.itu.int/dms_pub/itu-t/opb/tut/T-TUT-QKD-2020-1-PDF-E.pdf

Modelling and Simulation Support to Geostrategic Analysis and Defense Planning

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Abstract

An extensive form Bayesian geostrategic game with imperfect information is used for quantifying the state vector (i.e., political, military, economic, social, infrastructure and information) and instruments (i.e., diplomatic, information, military, economic, financial, intelligence and law enforcement) of state and non-state actors. Strategies are wargamed for the actors. As new strategies are employed, the setting changes and when the conditions for predefined scenarios are met, the game generates warnings about the potential future scenarios, which become the input for a static and deterministic computer model that calculates the optimum set of military capability requirements to counter hostile capabilities. The methodology and the supporting tools are introduced.

1 Introduction

Many contemporary conflicts are in grey zone or in other words hybrid. Threats to societies come from multiple directions. Although they may be initiated by separate actors, their effects accumulate and create end states not as intuitive as it used to be. Therefore, we live in a setting characterized with volatility, complexity, uncertainty and ambiguity (VUCA). Timely, coordinated and comprehensive employment of all instruments, as well as innovative and adaptive concepts have become necessity to counter hybrid threats.

Breakthroughs in technology and international conjuncture imply a new generation of warfare. The instruments evolved within grey zone conflicts will need to be adapted for largely kinetic but hybrid confrontations. Current trends in emerging military strategic concepts indicates smaller, agile and more autonomous sensors and effectors engage with the scenarios in multiple domains including cognitive and social. New tools and approaches are required to forecast, to design, to integrate and to plan in the eve of such transition. Therefore, concept development and experimentation has emerged as a key function in strategic level military headquarters.

The bottom line is that VUCA and current trends in international politics have increased the need for big data processing, modelling, simulation and other means of computer assistance to military experimentation. Strategic headquarters can conduct computer assisted experimentations for geostrategic foresights, defense planning, all domain concept and doctrine development, capability design and integration, advance and response planning, military and nonmilitary response option testing. Note that we prefer using the term all domain instead of joint. Space and cyber space have been added to land, air and maritime domains of joint operations.

Military experimentation (Cayirci et al. 2022a; ETE 2022) typically implies an empirical study where you observe, collect data and deduct conclusions by analyzing the collected data, nevertheless, for us an experiment is also a methodology to discover and to validate via a formal approach, i.e., a stochastic or deterministic model (Cayirci et al. 2022b). Moreover, these models are validated by empirical studies, used in experimentations, and then the results of these experiments are subject to follow on empirical studies. Therefore, formal approaches are within the scope of military experimentations, and perhaps in the core.

We explain how Qatar Armed Forces Joint Warfare Training Center (JWTC) conducts geostrategic analysis and defense planning. Section 2 is about geostrategic analysis where we first introduce our perspective on geostrategic analysis and then the approach that we use for producing a geostrategic foresight. The setting and the scenarios that are parts of the foresight become a key set of inputs to our defense planning process. In Section 3, we explain the defense planning process (DPP), which is also called as strategic planning, and how JWTC supports DPP. Finally, we conclude our paper in Section 4.

2 Geostrategic Analysis

We follow a game theoretic approach to support the geostrategic foresight development process. In military circles, the status of a strategic actor is often modelled by the state vector, i.e., political, military, economic, social, information and infrastructure (PMESII). Actors influence the setting by employing their instruments, i.e., diplomacy, intelligence, military, economy, finance, information and law enforcement (DIMEFIL). Three instruments are also in the state vector as can be seen in Figure 1. We merge state vector with instruments and add technology as an additional instrument and end up with 11 geostrategic metrics in our game.

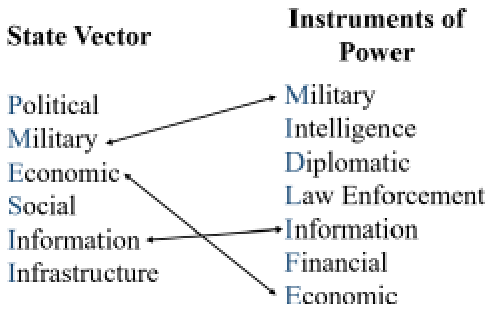

Figure 1 – State vector and instruments.

We quantify the geostrategic metrics by using models based on 41 parameters, such as gross domestic product per capita, and several hundred variables, such as the percentage of women with a university degree. Then, the metric and parameter values are normalized such that the best actor gets 100 and the others are assigned a value that represent their relative power comparing to the best actor as shown in Figure 2.

Figure 2 – hymots®g screen.

The complete list of geostrategic metrics and the parameters in the category of each metric is in Table 1. Please note that the metric and parameter values are not quantified based on only the parameters in their category. For example, public diplomacy parameter p11a of Actor a is a function of the parameters listed in Equation 1.

$$P11a = f\,(p31a, p21a, p22a, p32a, p33a, p72a, p73a, p74a) \quad (1)$$

Table 1 – Geostrategic Metrics and Parameters.

Geostrategic Metrics	Parameters
1. Diplomatic	p_{11}: public diplomacy
	p_{12}: official diplomacy
	p_{13}: clandestine diplomacy
2. Political	p_{21}: political system
	p_{22}: bureaucracy
	p_{23}: political code
3. Information	p_{31}: STRATCOM narrative
	p_{32}: awareness, misinformation, disinformation
	p_{33}: media engagement
4. Military	p_{41}: land
	p_{42}: air
	p_{43}: maritime
	p_{44}: space
5. Economic	p_{51}: current balance
	p_{52}: gross domestic product
	p_{53}: trade & tariff agreements
	p_{54}: ethics in economical interactions-anti corruption
6. Financial	p_{61}: public debt/GDP, loan currency
	p_{62}: private debt/GDP
	p_{63}: reserves
	p_{64}: savings
	p_{65}: yields
	p_{66}: tax income
	p_{67}: budget balance
7.Social	p_{71}: human resources
	p_{72}: social seams
	p_{73}: level of education
	p_{74}: social code

8. Intelligence	p_{81}: gathering
	p_{82}: utilization
9. Law Enforcement	p_{91}: legislative system and laws
	p_{92}: enforcement – policing and judicial system
10. Infrastructure	p_{101}: transportation and its independence
	p_{102}: communications and its independence
	p_{103}: medicine and its independence
	p_{104}: education and its independence
	p_{105}: production and its independence
	p_{106}: defense industry and its independence
	p_{107}: energy and its independence
11. Technological	p_{111}: R&D human resources
	p_{112}: R&D investments

In the geostrategic game (ETE 2022), there are a variety of strategic actors, such as, states, cooperates, international organizations, non-governmental organizations, mercenary firms, terror and criminal organizations. Strategic actors can be atomic, which means that they are alone, or composite, which means they are acting in alliance. Actors has relations, i.e., links with the other actors and through these links they may have also transient relations as depicted in Figure 3. Actors may have conflict of interest with some of the other actors.

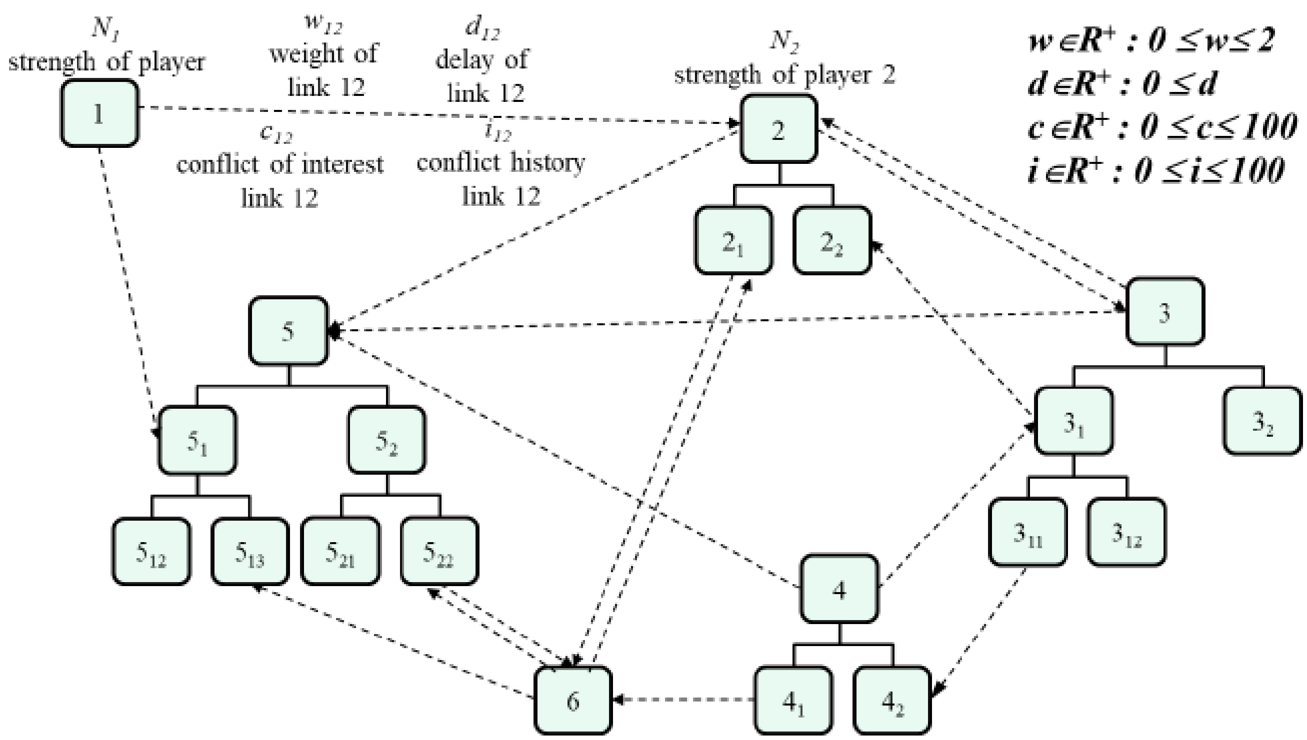

Figure 3 – The network of strategic actors.

Actors can implement strategies based on the projection of their 11 instruments and 41 parameters. Each strategy has preconditions, such as conditions related to a set of variable or parameter values, and in and out strategies (i.e., the set of strategies that must be implemented with the selected strategy, and the set of strategies that the strategy cannot be implemented together, respectively). The game is in the category of extensive form Bayesian game with imperfect information (Lasaulce 2011) and played though implementation of the strategies.

There are two ways to run the game. In **geostrategic turn games**, players select their strategies for the actors that they control, and the game is run to the next point in time. The results are received, new strategies are selected by the players and the next period is played. Iteration of this cycle repeats until the end of the game, which may be agreed by the players or decided by the referees based on the predefined end state. We call this turn game, nevertheless, players do not need to enter their commands in turn. They can enter their orders anytime before the next iteration starts. In **geostrategic interactive games**, the game continues until terminated by the referees. Players can enter their commands anytime while the game is running.

Scenarios are defined based on metrics, parameters, variables and network of relations. For example, if the military and diplomatic instruments of an actor is higher than another actor above a threshold and there is a conflict of interest between them, that implies a risk for an armed conflict. When the defined scenario conditions are fulfilled, the game generates warnings to the players. The scenarios can be created also based on environment and social related parameters and variables. Therefore, environmental crisis may also be detected.

The geostrategic gaming supports the strategic planners to develop a geostrategic foresight, in other words an insight into the future setting and scenarios, which become the basis for the requirement analysis. In other words, geostrategic gaming is used for generating scenarios as input for the defense planning process. It is critical to note that our geostrategic gaming approach is only an engineering support to geostrategic thinkers and planners. It is a tool for what if analysis.

3 Defense Planning

Defense planning process (DPP) is the key for proactively transforming the military structures for the future scenarios (Cayirci and Ozcakir 2016; Mazarr et al. 2019). In the post cold war era, many nations follow scenario-based defense planning approach as shown in Table 2. Therefore, DPP can start when a foresight for the future settings and contingencies is developed and an insight into the latest technological developments is gained. DPP is illustrated in Figure 4. After the political guidance, or in other words a strategic concept for the scenarios, is received, the transformational requirements are analyzed. The main objective is to elicit the capability requirements for future and to develop plans for their timely acquisition and integration to the military instrument. The main outputs of the DPP are the future scenarios that the military instrument is prepared for, the existing capabilities to be maintained, the new capabilities to be acquired, and the plan for acquiring and integrating new capabilities.

Orientation	**Organization**	**Threat**	**Scenario**
Period	Pre-Cold War	During Cold War	Post Cold War
Concept	Create and equip units/ organizations	Calculate forces to counter the enemy	Determine the capability shortfalls for a given scenario
Outcome	Units and weapons	Conventional and special forces	Joint, agile and expeditionary capabilities

Table 2 – Defense planning approaches.

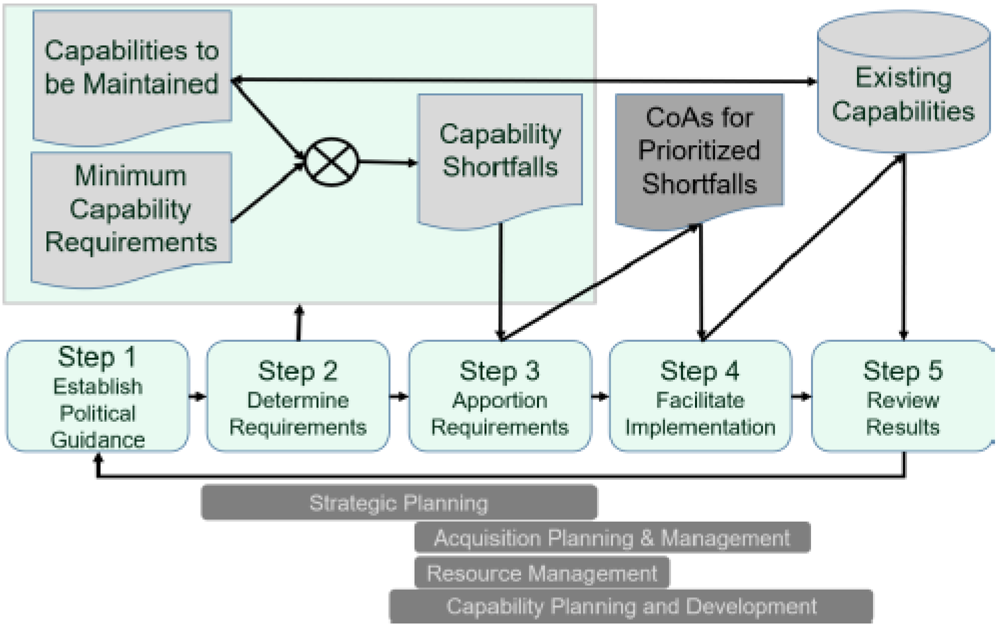

Figure 4 - Defense planning process.

We use a static and deterministic simulation-based optimization tool in Step 2 for determining the future requirements for the military instrument. The main aim of this tool is to figure out the optimum set of capabilities required to meet the political objectives in a given scenario following the process illustrated in Figure 5. The process starts with collecting and entering data into the system. The main part of these data is about the capabilities of the hostile actors, and both existing and designed capabilities that may be available to the own military instrument.

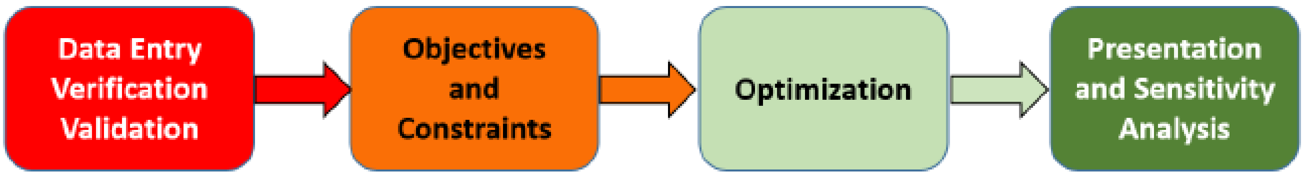

Figure 5 - Engineering support to defense planning process.

In the following stage, objectives and constraints for the optimization entered into the system. The optimization metrics can be various including minimizing the cost, the human casualties, the time to acquire the military capability shortfalls and maximizing the sustainability and practicality of the military instrument. Constraints may be related to politics, international law, ethics, economics, etc. When all the data are entered, the system is asked to produce the optimum set of capabilities that fulfill the objectives and constraints.

It is also critical that the experimentation audience can run a sensitivity analysis on the results because the optimum solution is often not followed due to the unquantifiable political and diplomatic constraints. A sensitivity analysis tool, showed in Figure 6, is used for this purpose.

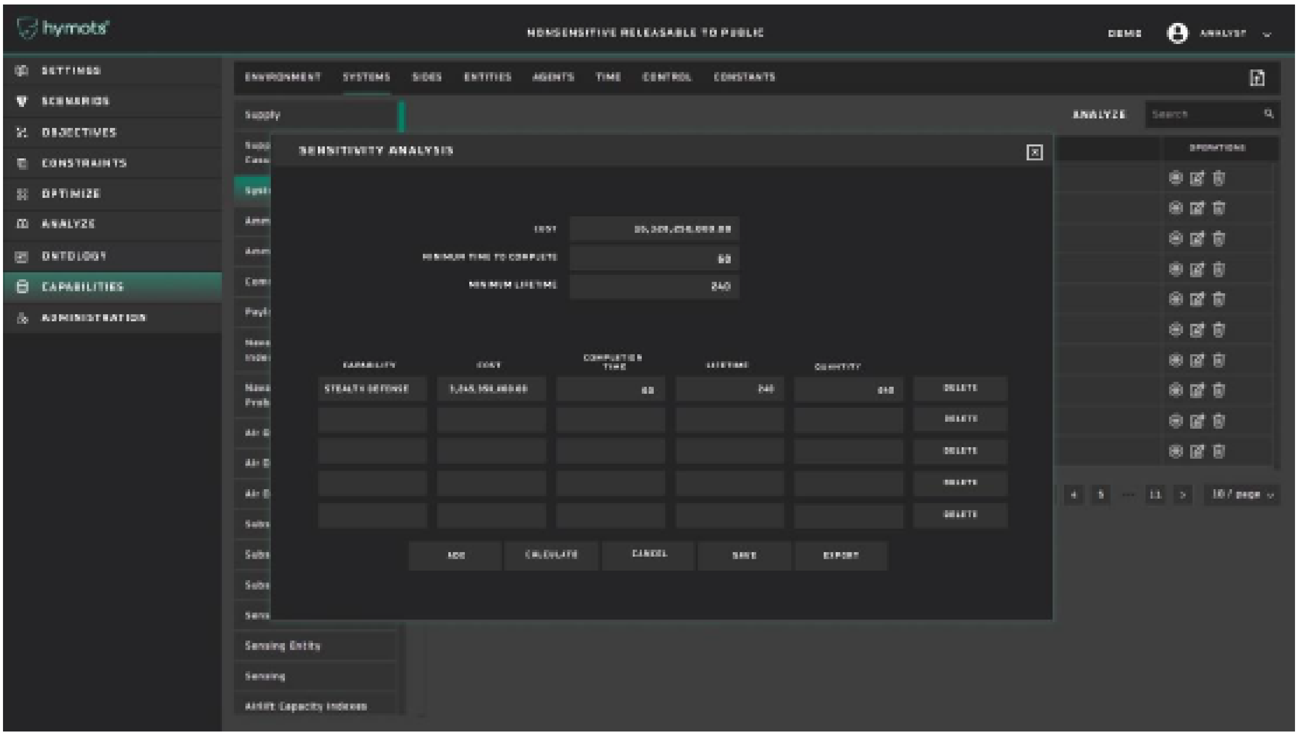

Figure 6 - Sensitivity analysis for defense planning.

4 Conclusions

The military instrument needs to be transformed continuously for the latest conjecture and setting to be mission prepared anytime. Transformation takes time and therefore it needs to be started proactively for the potential future scenarios. In the era of VUCA, this becomes more and more difficult a task. Therefore, the need for geostrategic forecasting tools is growing. We use an extensive form Bayesian game with imperfect information for gaining further insight into the future setting.

The geostrategic gaming supports developing a geostrategic foresight for the future scenarios. The political level guidance and the future scenarios become the inputs for DPP. A static and deterministic simulation tool is used to determine the optimum set of capabilities for the future scenarios. The players can run sensitivity analysis over the set of capabilities optimized according to the objectives and constraints given by the political level.

Acknowledgements

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Wargaming-Simulation Synthetic Environment SWORDOM (RAS use case)

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Abstract

Wargaming and Simulation are both methods to address a specific research problem even if they usually focus on different aspects of the research approach. This article aims to tackle the similarities and differences of these two methodologies; leveraging and capitalizing the experience of the Modelling & Simulation Centre of Excellence (M&S COE). Finally, a synthetic shared environment designed by the COE with the purpose to integrate the capabilities of Wargaming and Simulation on a common digital platform will be presented.

1 Introduction

Nowadays wargames still lack a clear, standardized and agreed process that define all the stages of the design and development. A standard process, on the other hand, is instead clearly stated for Modelling & Simulation i.e. DSEEP (Distributed Simulation Engineering and Execution Process). This is probably one of the most important aspects to consider when dealing with Wargaming and Simulation and it is indeed the main peculiarity that affects how to address a research method. This blurred situation can lead in misunderstanding what Wargaming and Simulation can be used for.

It is useful, therefore, to define what we mean for Simulation and what we mean for Wargaming in this article in order to declutter this ambiguity especially for the Wargaming side.

Simulation is the execution of a model (or set of models) through time. Largely speaking, simulation is usually based on computers and the computational capability that they can provide. We use simulation to represent entities and weapons systems on the battlefield and for accounting, with a high level of detail, physical phenomena aspects or for calculating lines of sight, fuel, ammunition or other logistical expenditures and eventually adjudicating the outcome of units in contact. This method can therefore provide and let us analyse multiple quantitative data with a certain degree of fidelity. Nevertheless, these simulation components are typically based on scripted behaviour/decisions ranging from a simplistic movement from waypoint to waypoint to a much more complex agent-based decision model; however, in both cases the human decision-making modelled is rarely sufficiently represented.

Wargaming can be roughly defined in three major branches: Experiential, Educational and Analytical. In this article with "wargaming" we will express the analytical one intended as a research method that addresses a specific research question. The most important figure of all Wargames is indeed the Sponsor (or Stakeholder) that has to address a problem that requires the answer. Wargaming can be considered as a tool to extract insights and findings from the participants in order to inform organizational challenges and complex problems. As it can be noticed from this last definition, the key aspect of a wargame is precisely represented by the participants (or players) of the wargame itself; they are the main source of collected data that is interpreted/analysed afterwards in order to answer the initial questions, which would fulfil the aim of the Wargame. This data is mostly qualitative.

2 Wargaming & Simulation

Based on the above definitions, we can identify some similarities and differences on these two research methods that can be useful in order to address an integration of these two fields in one common environment. For the sake of brevity, in the following picture only the key aspect details have been synthetically reported as an in-depth study would require a separate discussion.

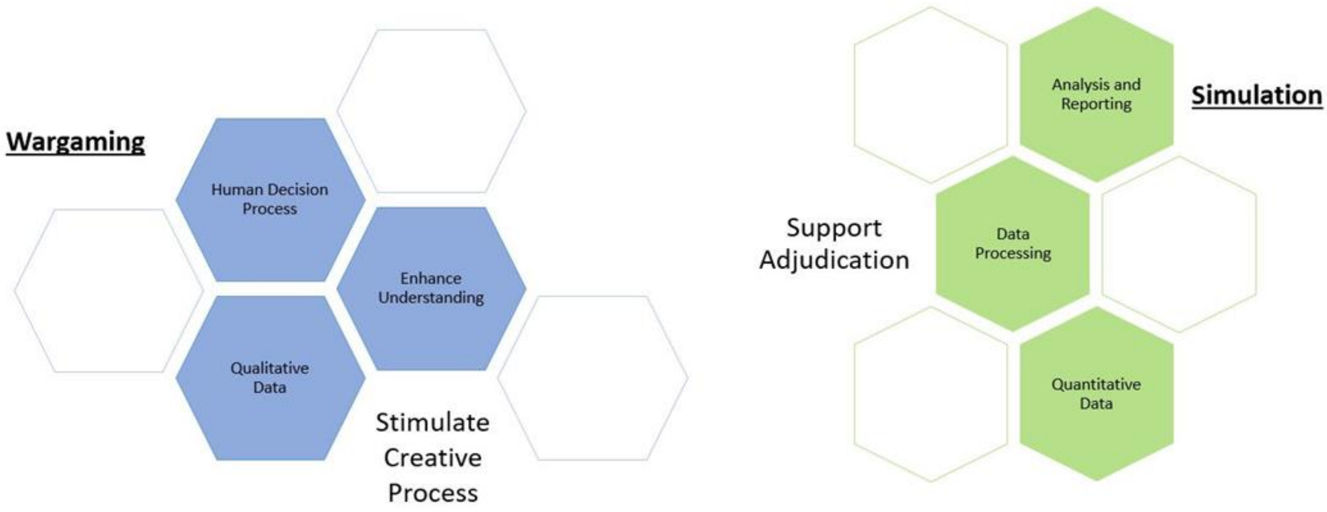

Figure 1 - Wargaming-Simulation fields of application

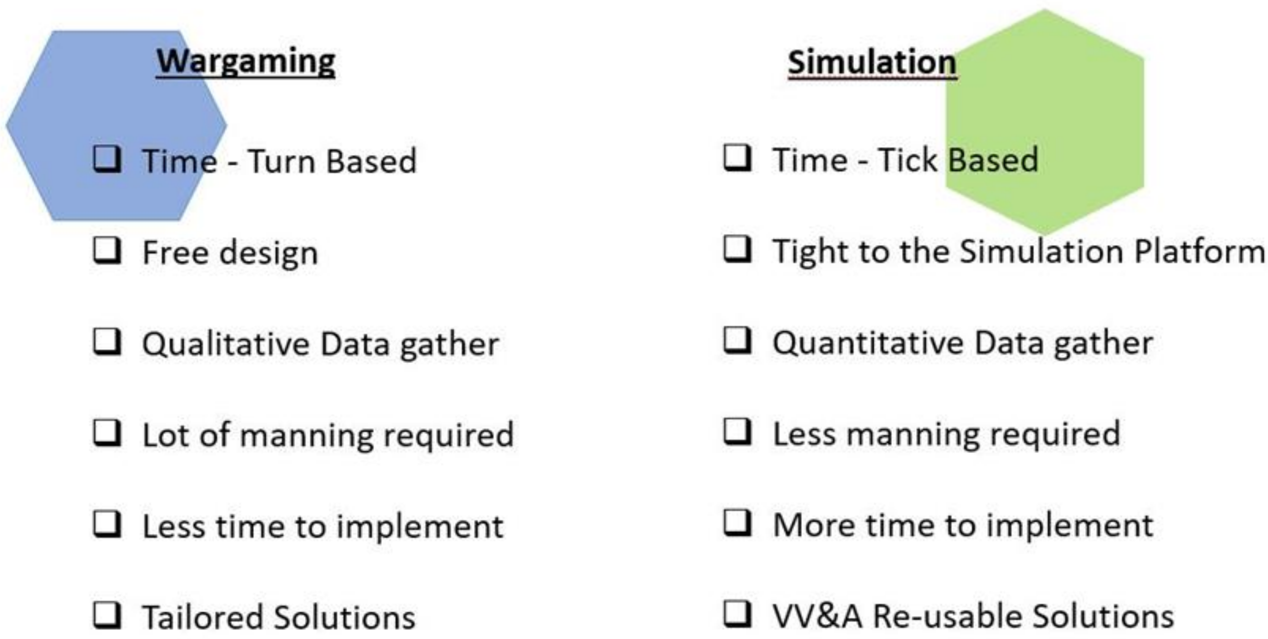

Figure 2 - Wargaming – Simulation differences

3 SWORDOM

The goal to integrate Wargaming and Simulation in one common synthetic environment is to provide a platform to the users that merges the capabilities of both fields, exploits the single benefits and minimizes the disadvantages. In order to create this environment, the M&S COE first identified the tools and the technical details needed to proceed with this integration.

The **tools** used for this Wargaming-Simulation integration are the Wargame-Interactive Scenario Digital Overlay Model (WISDOM) and MASA SWORD respectively. The following schema sums up the tools chosen to provide Wargaming and Simulation capabilities in its initial stage:.

WISDOM (Wargaming Capability)	MASA SWORD (Simulation Capability)
• **WISDOM** is a WebGIS based software platform, where it is possible to configure several different virtual geographic environments and complete wargaming scenarios. • The two main fundamental features of WISDOM are flexibility and modularity. Those characteristics can facilitate and allow swift adaptation to meet new challenging requirements. • Solution developped by the M&S COE and tailored for Wargaming activities.	• Detailed aggregate level Simulator software suite that simulates the interactions and actions of military or civil security units in their environment. • Provide detailed analysis capabilities and support the final wargame outcome. • high automatization degree process for a ready-to-use and realistic doctrine-compliant behaviour simulator.

Concerning the **technical** details to make this integration possible, three main "points of integration" have been identified and are briefly described as follow:

High Level Architecture (HLA). The leading standard for distributed simulation, the NATO Educational and Training Network Federation Object Model v3 (**NETN 3 FOM**) has been used for this integration project.

Application Programming Interfaces (API) are required when some specific capabilities are lacking from the NETN FOM especially for the analysis tool.

Specialists' Interoperability (SI). When not possible to fully automate, or when not cost effective, some actions in this integration have to be done by a specialist "behind the scenes" especially to initially set up the Wargaming environment.

3 SWORDOM

SWORDOM can be considered a platform with the main aim to free the Wargame participants from the burden of simulation complexity, allowing players to focus on what they are asked for i.e. understand, play and provide an answer of the wargame main problem while using simulation capabilities only when needed.

The final goal of SWORDOM is indeed to enable a better insight on Qualitative (provided by players) and Quantitative (mostly provided by simulation) data research on a specific wargame issue. This is supposed to help to understand the outcome data in a better manner and ultimately to provide the right answers in accordance with the stakeholder requirements.

Figure 3 – WISDOM and MASA SWORD integration conceptual architecture

The platform itself can also be considered as a permanent infrastructure that provides support for gathering both kind of data (Qualitative and Quantitative) in one comprehensive environment. This allows the Designers to boost the **Design & Development** process by using the wargame use cases available as a reference. Players can focus on the **Execution** and Analysts are facilitated in their **Analysis** with a wide range of organized and collected data if available.

Figure 4 - Where SWORDOM can be used

As we already mentioned, the main SWORDOM benefit is to create a user-friendly environment that can be used, to some extent, by all the wargame participants in order to facilitate the understanding of requirement and make considered choices to better achieve the analytical wargame objectives. The WISDOM interface can provide these features with an intuitive and distributed (internet based) access on the wargame instance, specifically tailored according to the needs of the designer/analysts. It follows therefore that the unwanted or unnecessary complexity of a simulation tool can be hidden or eliminated from the player's perspective and shifted to the technician that manages the SWORDOM's permanent infrastructure.

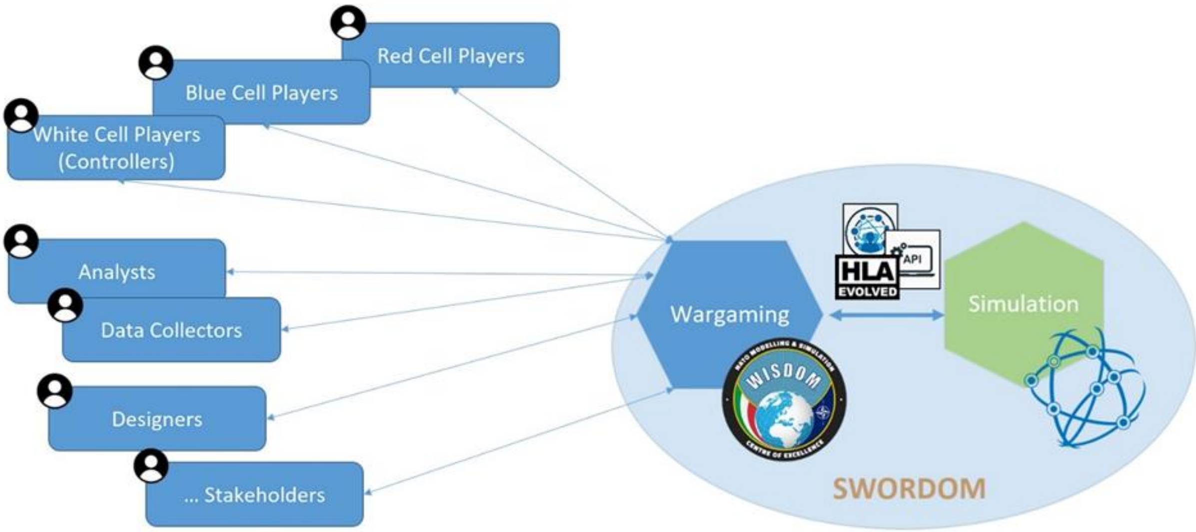

Figure 5: Wargaming Participants access to SWORDOM

One of the aspects that is worth noting is that SWORDOM can be used as a repository for Wargaming at all levels (Tactical, Operational, Strategic) and, to some extent, for all the warfare domains (Air, Land, Maritime, Space and Cyber). This reflects the agile and multipurpose concept of application of wargames. Without any doubts, if one would like to use simulation capabilities also for all level and domains, different simulators must be integrated. Currently, the MASA SWORD simulation database is more focused on Operational Level and Land Domain.

4 Data perspective

In order to provide a better understanding of the proposed SWORDOM platform conceptual framework, the following figure represents a bottom-up approach for the quality type of knowledge for data/models used in order to better define and understand SWORDOM.

Figure 6 - SWORDOM conceptual data model

The idea is to understand and leverage the data that each platform manages best. In this case, WISDOM can be considered solid on this diagram's lower-level providing Geo referenced data while any simulators are better on the upper level (i.e. providing simulation data). To be noted here that the "**High Level Intellect Data LAYER"** represents the conscious decisions made by humans (Wargame Participants) and the real aim of a wargame that has to be explored. These are provided by players and investigated by analysts and can be used to influence the development of the other level of data. Analytical Wargame models are meant to provide and enhance the gathering and exploration of this **High Level Intellect Data LAYER**, which can also be considered as a final/result Layer that influences the preparation and adaptation of the other lower Data Layers in order to boost further analysis, evaluation and interpretation.

5 SWORDOM Use Case

As anticipated, SWORDOM can provide a single synthetic environment for Wargaming and Simulation leveraging the specific positive aspects of both. The M&S COE identified five different use cases to be used for this platform:

1. ***Scenario Assessment and Design***. This is the case when simulation is not needed but you want to build your knowledge on a scenario or start to design and develop a new one. SWORDOM is used with the capabilities provided by WISDOM. It can be considered almost as a visual planning tool.

2. ***Traditional Analytical Wargame***. Use the platform to play an "old style wargame" but in a distributed fashion with support of other pieces of software for communication (i.e. Microsoft Teams, Discord, etc.). SWORDOM is used with the capabilities provided by WISDOM and thus this approach can be considered more qualitative data driven.

3. ***Wargaming Adjudication Advised***. The wargame can be played on the platform using WISDOM as a main framework, also in a distributed fashion, but with some simulation capabilities in the adjudication phase coming from SWORD for specific aspects (Movements, Attrition, ISR). This requires a challenging integration and some synchronization between a turn based environment and a continuous time environment. The idea here is to let the player do the wargaming actions in an intuitive and easy way, brief the controller by explaining their decisions, and then automatically play the simulation to evaluate the effects when needed.

4. ***Simulation Advised***. In this case the platform heavily uses simulation capabilities from SWORD but the visualized data is shared in WISDOM where you can access and enrich the visualization with other types of data (e.g. you can visualize that there is a densely populated area, or schools/hospital nearby the objective, therefore the players can decide to use another COA). This case could not be a turn based WG but it could depend on the simulation time.

5. ***Traditional Simulation Wargaming***. This last case uses mainly simulation capabilities from SWORD as a wargaming tool itself or just to see the result of a complete simulation. You can use WISDOM to visualize the simulation flow (reports and movements) or, with further development, use the MSaaS Cloud[1] paradigm to provide SWORD to every player.

[1] Modelling & Simulation as a Service (MSaaS) Cloud Based to provide on demand full access to simulation tools as a whole and not only some integrated capabilities.

6 Conclusions

SWORDOM can be considered a first step for the integration of Wargaming and Simulation capabilities in one comprehensive environment. Undoubtedly, in order to improve the ability to support evaluation and assessment of capability effectiveness across Domains (Land, Maritime, Air, Cyber, Space) and across levels (tactical through strategic) other specific simulation components focusing on these aspects have to be used/integrated in the same permanent environment. In order to achieve this and proceed with a better, easy and faster integration, standards must be used. In this regard the military industry must be pushed to develop the new simulation components to be fully compatible with HLA 4 and NETN v3; this will provide a great feat for the integration of Wargaming and Simulation in the future.

The real aim of SWORDOM is indeed to ensure a wargaming friendly environment for participants “shifting” the burden and complexity to automated procedures and technical administrators. This can help and facilitate wargaming through data layering, visualization, bookkeeping and adjudication simulation tools supporting quantitative analysis through analytical tools and qualitative analysis through Data Collection and Management Plan in one comprehensive platform.

Enhancing Resilience: Model-based Simulations[1]

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Abstract

Since several years, the fragility of global supply chains (GSCs) is at historically high levels. In the same time, the landscape of hybrid threats is expanding, e.g. the recent energy weaponisation. This study aims to assess the economies' foreign input reliance and foreign market reliance, identify possible vulnerabilities by simulating shocks to GSCs in presence of uncertainty. We stress test resilience by simulating most demanding circumstances and determine relevant, effective and efficient policy solutions. Conceptually, we employ a newly developed modelling framework, which is specially designed to account for the increasingly inter-dependent GSCs and study resilience and robustness in presence of hybrid threats as shocks. The scalable data model is parameterised by combining World-Input Output Tables with those from the Inter-Country Input-Output. Model-based simulations provide interoperable and directly comparable quantifications of positive and normative effects of counterfactual resilience and robustness policy choices and allow to identify policy solutions to meet the baseline resilience requirements.

1 Introduction

Two developments with a global character and dynamically interrelated across industries and countries have accelerated in recent years. One is an increasing vulnerability of global production networks. In the same time, the landscape of hybrid threats is expanding and the intensity accelerating (European Commission 2021). In the age of globalisation and widespread cross-border production, global production fragmentation increases foreign exposure of domestic industries, which participate extensively in global supply chains (GSCs). The specialisation and cost advantages for international companies that arise from involvement in GSCs are unavoidably associated with greater ambiguity and risks in the face of shocks, such as global pandemics, the climate crisis, hybrid attacks, such as Russia's energy weaponisation against Europe. These risks are acknowledged by the Secretary General Stoltenberg: "over-reliance on the import of key commodities, like energy [on the sourcing-side, and] exporting advanced technologies, like Artificial Intelligence [on the selling-side] can create vulnerabilities and weakened resilience". More than ever since the end of the Cold War, the last authoritarian regimes and strategic competitors test the Alliance's resilience and seek to exploit the openness, interconnectedness and digitalisation of free and open societies, interfere in democratic processes and institutions, and target the security of citizens through hybrid tactics.

The first line of Alliance's defence is resilience - ensuring that the socio-politico-economic fabric can function in the face of adversity.[2] Leveraging the strong commitment to action and achieving the desired resilience and robustness, requires a holistic, integrated and dynamically coordinated approach. On the policy side, political leaders need to take responsibility for being fully open with citizens about the changing character of hybrid threats. Achieving an enhanced socio-politico-economic resilience that meets the seven baseline requirements – which must be maintained under the most demanding circumstances – will require a mobilisation of resources. A full transparency is therefore important regarding the costs and sacrifices that will be needed, for example, to defend security in the face of Russia's

[1] The authors are solely responsible for the content of the study. The views expressed are purely those of the authors and may
not in any circumstances be regarded as stating an official position of the NATO, European Commission or the Latvian
National Armed Forces. Any remaining errors are solely ours.

[2] ww.nato.int/docu/review/articles/2019/02/27/resilience-the-first-line-of-defence

war on Democracy and possible future warfare. As noted by Secretary General Stoltenberg at the World Economic Forum 2022: "we should not trade long-term security needs for short-term economic interests"[3], which implies costs and sacrifices.

How to 'achieve the necessary resilience' while doing as little damage as possible to society's socio-politico-economic fabric'? Indeed, the challenge is to achieve long-term security goals without neglecting the shortand medium-term economic needs of society. In the context of our study, the challenge is to ensure resilient and diversified supply chains in place to allow for a continued flow of essential goods and avoid shortages in the short-, medium- and long-run. Our analysis investigates this trade-off formally by framing it as a constrained optimisation problem with two constraints – a resilience/robustness constraint on the one side and a resource mobilisation constraint on the other side. We simulate the optimal strategy of private sector firms in presence of shocks under uncertainty. Model-based simulations provide interoperable and directly comparable quantifications of positive and normative effects of counterfactual resilience and robustness policy choices in critical and non-critical sectors. Further, the scalable data model we employ allows to identify strategies for addressing Alliance's vulnerabilities arising from societies' openness and economies' interconnectedness in international trade and global production networks.

The present study builds on and complements the existing Science & Technology Organisation (STO) strategic analytical support, including the Multi-Dimensional Data Farming, Causal Reasoning, the Resilience Data Analytics Tool of the ACT's Innovation Hub and the Aggregated Resilience Model. The Resilience Model provides a holistic framework for simulating a wide range of Political, Military, Economic, Social, Information, and Infrastructure (PMESII) shocks (e.g. electricity blackout, cyber attack, martial law enforcement, big human movement, state of war, armed conflict), and allows assessing both resilience domains (civil support to the military, continuity of government, and continuity of essential services) as well as risk (command and control, protection, movement/maneuver, and sustain) (Hodicky et al. 2020). The Joint Warfare Centre (JWC) leverages the Joint Theatre Level Simulation (JTLS). The Resilience Data Analytics Tool can be used, among others, to assess the levels of resilience by leveraging open-source data, big data analytics, machine learning, and data visualization and allows the identification of potential shocks to the Alliance's resilience. Our modelling framework - which is based on Antras and de Gortari (2020) and Jiang et al. (2022) - is complementary to the existing resilience modelling and simulation tools, as it is specifically designed to account for the asymmetric exposure of domestic industries, and to study the allies' resilience and robustness in the presence of exogenous shocks under uncertainty causing, for example, supply ruptures, demand ruptures/surges or transportation ruptures.

2 Global Supply Chains and Foreign Dependence

Because of outsourcing, off-shoring and often insufficient investment in resilience, many global production networks have become excessively complex and fragile. The GSCs of 2020s are efficient but brittle – vulnerable to breaking down in the face of a pandemic, a war or a natural disaster. The GSC-disruption-caused losses are escalating and the frequency and intensity of hybrid threats is increasing, particularly during the last years. These developments are important to understand, as the increasing fragility of GSCs may have implications for the vulnerability of critical sectors and essential services as well as implications for the entire Alliance's security and defence.

Different metrics and indices have been developed to monitor and track the state of GSCs. The Global Supply Chain Pressure Index (GSCPI) is one of such indices; it is being deployed by the Federal Reserve Bank of New York. GSCPI measures a common

[3] www.nato.int/cps/en/natohq/opinions_195755.htm

factor of several cross-country and global indicators of supply chain pressures (e.g., delays in shipments and delivery times and shipping costs after purging these from demand measured by new orders). As illustrated in Figure 1, the GSC pressure is at historically high levels since 2020, which is signalling an escalating probability of GSC ruptures. Already the World Economic Forum (2021) was explicit about the increasing vulnerability of GSCs to shocks: "The increasing frequency of supply-driven disruptions – ranging from global pandemics and the climate crisis to cyber threats and geopolitical tensions – combined with an ever intensifying set of demand-driven disruptions – including the rise of new consumer channels, pent-up demand and a fragmented reopening of the global economy – will continue to destabilise global value chains."

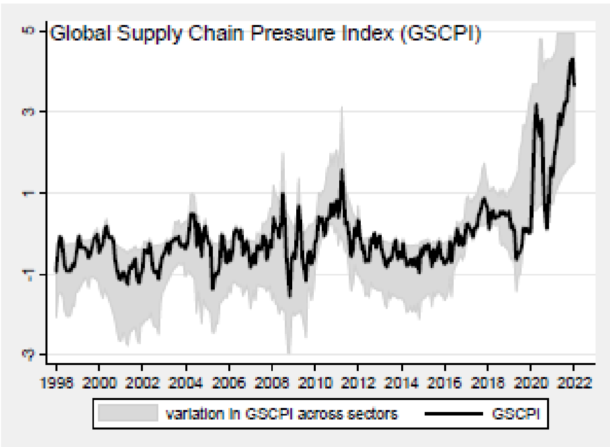

Figure 1 - Firms' efficiency-robustness trade-off, externalities and market failures
Source: www.newyorkfed.org/research/policy/gscpi

In light of the increasing fragility of GSCs and expanding hybrid threats, in this study we are interested in understanding the domestic industries' foreign reliance. Knowing economies' international exposure is important to identify potential vulnerabilities and allow for policy actions where needed before major GSCdisruptions occur. We approach this question by querying recent statistical data through different levels of aggregation. First, we employ a value-added (macro) approach by looking how the industrial production is allocated internationally and how each stage of production contributes to the final product. This approach concentrates on countries and industries as the unit of analysis. The macro-approach to measuring GVCs connects national IO tables across borders using bilateral trade data to construct a World Input-Output Tables. These data are applied to measure trade in value added, as well as the length and location of producers in GVCs. Second, a firm-level perspective provides an alternative to the aggregate view of the former approach. The micro-approach uses firm-level data to understand firms' input sourcing and outpur market decisions, how import and export participations are linked, and how globally operating firms organise their production networks. Both in the value-added approach and firm-level approach an understanding of the domestic economy's foreign exposure via the GSC channel requires to know where are goods made? This core question is approached from different sides (location of output, inputs) and by viewing through different lenses (micro, macro).

2.1 Micro perspective: Firm-level foreign reliance

In the micro approach, the firms are the unit of analysis; they are the ones that decide whether to participate in GSCs. Firms upstream and downstream face contracting problems – moral hazard or incomplete contracts. Integrating internationally and vertically help to solve the informational problem. Considering international trade statistics, the observed world trade flows are best understood as the aggregation of individual firm-level decisions related to the destinations to which firms export their products, but also the origin countries from which they source intermediate inputs, or the 'platform' countries from which they assemble goods for distant destination countries. Inspired by the theoretical "micro" literature (Antras and Chor 2022), which is largely concerned with developing tools to solve the complex problems that firms face when designing their optimal global production decisions - forward GSC participation, backward GSC participation, centralised versus lead-firm approaches - the underlying conceptual framework which builds on Antras and de Gortari (2020) and Jiang et al. (2022) is introduced graphically by focusing on the key decisions of a firm. For the sake of brevity, in the graphical analysis we abstract from other GSC-related decision of firms, such as staggered GSC participation, buyer-supplier matching, relational nature within GSCs.[4]

We start with the cost versus resilience/robustness trade-off already mentioned in section 1. Profit maximising companies (participating or not in GSCs) aim to ensure a certain resilience/robustness of the production process while keeping the cost optimisation and customer satisfaction in mind. Formally, the riskreward trade-off refers to a decision process of firms which typically care about both uncertainty (i.e. they value resilience/robustness) as well as the reward from cost savings (e.g. Lettau and Ludvigson 2003). In the context of GSCs, a key trade-off in both resilience and robustness decisions at the firm level involves diversification of risks versus lower cost and higher quality inputs. Lower cost is usually associated with economies of scale in input sourcing, whereas higher quality inputs tend to be found in markets with niche expertise – both implying a higher participation in GSCs. The trade-off between the uncertainty (in form of risk and ambiguity) that comes with GSCs (vertical axis) and the rewards (horizontal axis) is illustrated in Figure 2. The solid line represents the uncertainty-reward frontier; everywhere on this line the firms' willingness to substitute one unit of uncertainty for reward is constant. Uncertainty is assumed to increase as manufacturers concentrate production of a particular input in the single cheapest location. Diversification of sources reduces risk and ambiguity but at a diminishing rate. Solving the underlying mathematical model, the equilibrium solution is found at the tangency of the indifference curves and the uncertainty-reward frontier, represented by point P in Figure 2.

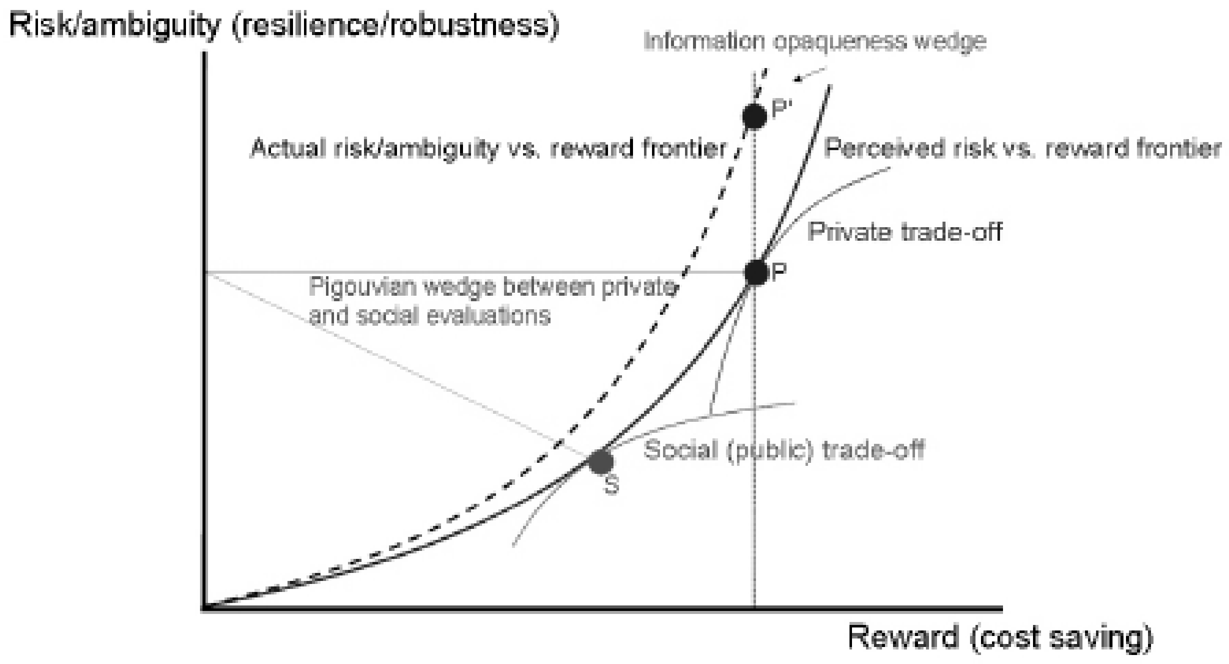

Figure 2 – Firms' efficiency-robustness trade-off, externalities and market failures

[4] For more complete theoretical foundations of these channels of adjustment, we refer to Antras and de Gortari (2020).

Although optimal from the perspective of a single firm, the equilibrium efficiency-robustness outcomes may be inefficient socially in the presence of externalities and market failures (Baldwin and Freeman 2022). First, social evaluation of the uncertainty-reward trade-off may put a greater stress on uncertainty than private evaluation. Private companies may prefer more risk/ambiguity (resilience/robustness) for any given level of reward. In contrast, the public usually cares relatively more about risk/ambiguity (resilience/robustness). The indifference curve shapes reflect that firms would agree with more risk/ambiguity for any given level of reward (curve 'Private trade-off'), but the public cares relatively more about risk/ambiguity (curve 'Social (public) trade-off'). In equilibrium, the public is desiring a lower level of d, point S, than the private sector, point P in Figure 2. This wedge between the public and private evaluation for risk ('Pigouvian wedge') is an externality that is not internalised by economic actors in their optimisation decisions leading to a market failure. As became evident during the recent GSC ruptures, markets for medical supplies share features of the public-private wedge, as do other 'strategic' inputs such as semiconductors.

Second, the equilibrium efficiency-robustness outcome is likely to be socially inefficient also in markets where a collective action problem creates information asymmetries that force companies to act without a full information. In 2020s, GSCs are characterised by complexity, non-transparency and opaqueness. Even large, sophisticated companies do not know all their suppliers and the suppliers of their suppliers, and even seemingly 'purely domestic companies' might not appreciate being part of a global network. The general lack of firms' understanding of where they sit in their own supply chains - supply chain opaqueness - implies that companies may be sub-optimally making decision with respect to the risk-reward trade-off and misaligning their sourcing and supply chains. The Russia's war on Ukraine and the implications on global food and energy supplies visibly demonstrate how this lack of information about where domestic company inputs and input-inputs are actually sourced results in private misjudgements as to how uncertain a GSC actually may be in critical sectors, leading to a misperception of actual vulnerability. In Figure 2, the supply chain opaqueness-caused externalities are shown on curve 'Actual risk vs. reward frontier', which is above the 'Perceived risk vs. reward frontier' curve. We refer to the gap between the two curves as the 'Information opaqueness wedge' in Figure 2. Since GSCs are highly interwoven and generally not fully contained within the boundaries of a single firm, information about them has public good features. This information is costly to collect, cheap to share, and provides value to many.

How exposed are domestic companies to foreign input supplies and output markets? This question can be answered at several levels. When a product rolls off the Airbus Defence and Space assembly line in Stevenage, UK, we can say it was made in Stevenage. This is the first-level truth, but it is not the whole truth. The second level recognises that the Stevenage plant buys inputs from other sectors located at home and abroad. Tracing the first-level production location of inputs gives us the second-level answer; this provides a directly observable dependence on foreign inputs. The intermediate import measure is directly observable in standard trade databases, and it has many merits. However, this measure of intermediate imports is not the whole truth either because purchased foreign inputs also use inputs. The third-level answer, the whole truth of foreign input reliance, takes account of the recursive sequence of all the inputs into all the inputs. According to Lund et al. (2020), Airbus has 1,676 publicly disclosed tier-one suppliers. In the same time, Airbus works with over 12,000 tier-two suppliers and below worldwide. This implies that Airbus has more than 10 times as many total suppliers as in tier one. Figure 3 provides another example from the semiconductor industry, where the global supply chains of Dell [Military and Defence] are depicted. According to the Bloomberg Global Supply Chain Data, Dell has nearly 5,000 worldwide tier-one and tier-two suppliers. The fact that the total number of actual global input suppliers are not exactly known even to these large public companies illustrates well the complexity, non-transparency and opaqueness of GSCs at the firm level.

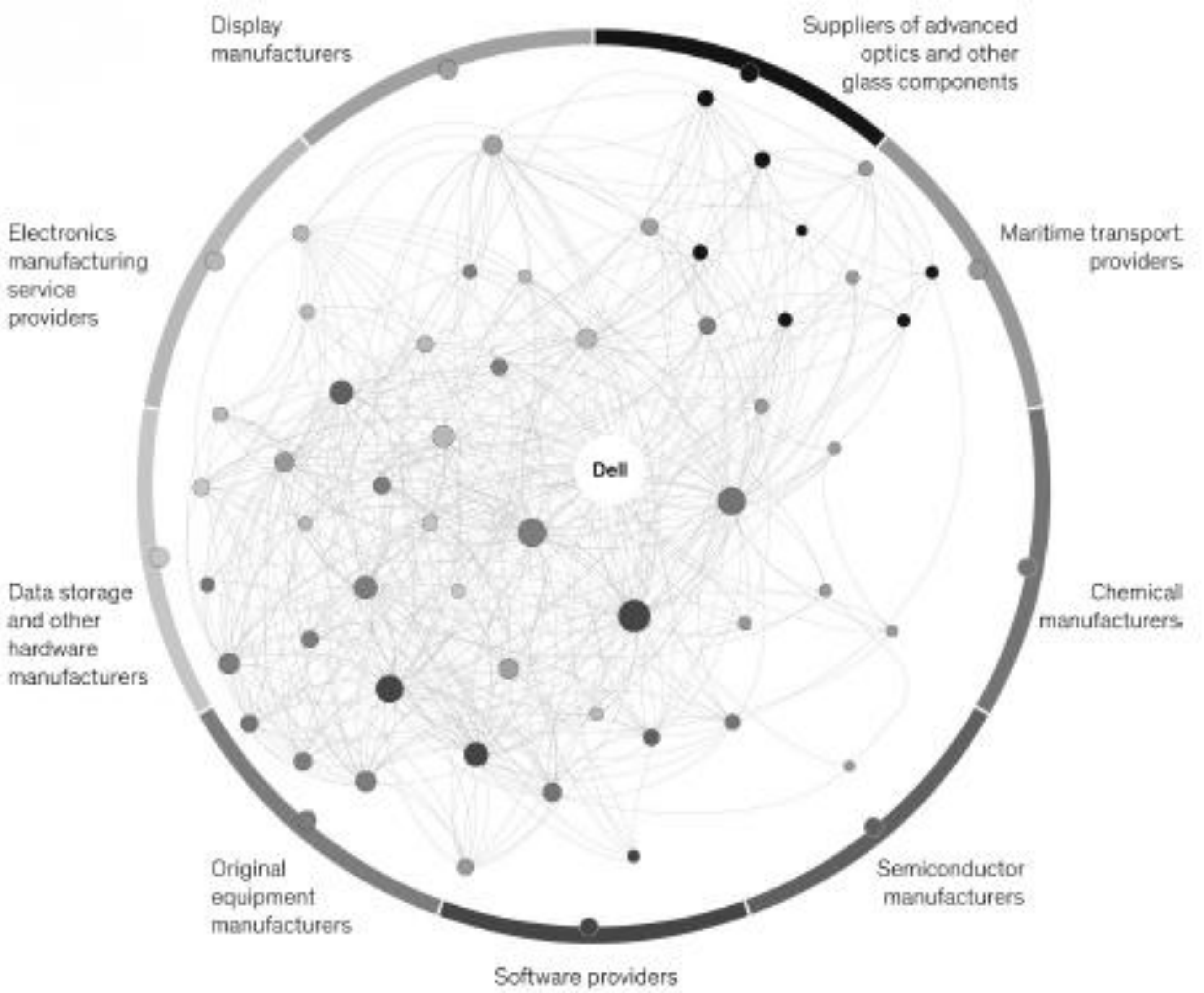

Figure 3 – Dell [Military and Defence] exposure to GSCs
Source: Computed based on www.dell.com/en-us/dt/oem/military.htm; Bloomberg Global Supply Chain Data; and www.dell.com/en-ca/dt/oem/defence.htm data.

Why is the domestic company supply chain foreign exposure important after all? Summarising the insights from the perspective of a single firm, the equilibrium efficiency-robustness allocation may be inefficient socially in the presence of externalities and market failures. Typically, the efficiency-robustness allocation of private sector firms is skewed toward efficiency more than it would be socially optimal, and private misjudgements as to how uncertain a GSC actually are, may lead to a misperception of the actual vulnerability. An even more important argument for a policy intervention is given by the increasing deployment of foreign supply dependence as a hybrid threat by adversaries (European Commission 2021). A recent example is the Russia's energy supply stop to EU Member States in 2022.

2.2 Macro perspective: Foreign exposure at the aggregate level

In our second - the value-added (macro) approach - the unit of analysis is a country or an industry. We look how production is allocated internationally and how each stage of production contributes to the final product. Combining international trade data with national Input-Output tables yields cross-country or

World Input- Output Tables (WIOT). Information contained in these tables allow to shed light on value-added trade flows across countries and the implied degree to which production processes have become globalised. We will draw on insights from the theoretical "macro" literature, which mostly focuses on the development of structural interpretations of the WIOT, with the ultimate goal of constructing reliable tools for counterfactual analysis by acknowledging the relevance of GSCs in the world trade (Antras and Chor 2022).

A variety of metrics has been developed to assess the foreign exposure of a sector or economy as a whole (see e.g. Johnson 2018). For example, the content of value added in final goods, value added in gross exports, positioning in GSCs. As in the firm-level analysis, it is useful to think about the domestic industries' exposure to GSCs by attempting to answer the same key question - where are things made? As noted above, the domestic industry's foreign dependence can viewed from different sides. For example, this core question can be answered by evaluating the input-side foreign exposure or the output-side foreign exposure. The magnitude of foreign exposure can also be measured by the total foreign exposure of domestic producers yielding a more complete empirical portrait of GSC exposure.

Foreign Input Reliance (FIR) measures the sourcing-side exposure of a sector or the entire economy. We use the Inter-Country Input-Output (ICIO) data from the OECD to compute FIR for G7 economies and China in 2019 (the most recent available data). The computed FIR corresponds to the share of foreign sources used as intermediate inputs into domestic production. Table 1, panel (a) reports row nations' reliance on inputs from column nation for manufacturing production. Cell shades are indexed to share sizes; darker shades indicate higher FIR.[5] For example, the 11.8 in the row for Canada (CAN) and column for the China (CHN) indicates that 11.8% of Canadian manufacturing production was made using inputs sourced directly and indirectly from the China. The global dominance of China in intermediate input trade can be seen by the fact that CHN column is highlighted primarily in shaded. The fact that CHN column is relatively dark indicates that China is important supplier of inputs to manufacturing industries of all analysed G7 economies. It is also worth noting the asymmetry between the USA manufacturing production's reliance on Chinese inputs, 9.9%, whereas China's manufacturing production's reliance on US inputs, 3.7%.

Next, we investigate how Foreign Input Reliance has changed during the last two decades by comparing FIR in 2019 with FIR in 2000. Table 1, panel (b) reports change in row nations' reliance on inputs from column nation for manufacturing production between 2000 and 2019. Darker-shaded cells indicate larger changes in FIR. For most countries the bilateral FIR matrix with respect to China was considerably larger in 2019 than it was in 2000. In panel (b), the figures in the China column are all positive and all significantly different from zero, indicating that the G7 industries' input dependence on China has increased. In contrast, the figures in the USA column are small, mostly, under 1ppt, and some figures are even negative (e.g. China). Most of the panel (b) entries for other countries are negative. Overall, the reliance of G7 economies on Chinese inputs has increased substantially between 2000 and 2019, whereas the opposite is observed for Chinas reliance on inputs from G7 (last row in Table 1, panel (b)).

Industries participating in GSCs are exposed also to sales-side shocks. Therefore, it is not less important to understand domestic industries' foreign dependence on the output side. Conceptually similar to the FIR index - which measures countries' total reliance on foreign production on the sourcing side - the Foreign Market Reliance (FMR) index measures

[5] The matrix diagonal elements are suppressed, as we are interested in foreign inputs and foreign exposure. The diagonal elements would show a nation's input reliance on itself - both in terms of direct domestic sourcing and indirect sourcing through the re-import of previously exported inputs.

(a)	USA	CAN	GER	GBR	FRA	ITA	JPN	CHN	ROW
USA		5.4	1.8	1.0	0.7	0.8	2.1	9.9	13.0
CAN	32.5		2.1	1.5	0.9	0.9	2.0	11.8	21.1
GER	4.6	0.5		3.2	4.7	3.8	1.6	6.9	42.0
GBR	6.2	1.4	6.9		4.1	2.6	1.3	7.7	29.5
FRA	5.6	0.7	10.1	3.8		4.7	1.2	6.4	35.3
ITA	3.5	0.5	8.9	2.6	5.8		0.9	7.6	39.6
JPN	4.1	0.7	1.3	0.7	0.6	0.4		10.7	26.0
CHN	3.7	0.8	1.7	0.6	0.7	0.6	3.2		24.6

(c)	USA	CAN	GER	GBR	FRA	ITA	JPN	CHN	ROW
USA		3.2	1.0	0.8	0.7	0.4	1.3	5.6	9.6
CAN	31.9		0.8	1.3	0.6	0.3	1.7	10.8	9.3
GER	7.1	0.8		3.8	5.1	4.2	1.6	10.0	41.0
GBR	7.0	0.9	4.7		2.9	2.1	1.2	5.5	25.8
FRA	5.2	0.7	8.4	3.9		5.1	1.4	8.0	33.1
ITA	5.9	0.7	6.7	2.6	4.6		1.3	5.4	31.9
JPN	5.7	0.6	1.1	0.6	0.5	0.4		14.4	16.8
CHN	8.0	0.8	1.3	0.9	0.7	0.7	2.8		15.7

(b)	USA	CAN	GER	GBR	FRA	ITA	JPN	CHN	ROW
USA		-1.4	-0.6	-0.5	-0.2	-0.2	-1.8	6.0	-3.9
CAN	-1.1		-0.2	-0.8	-0.2	-0.1	-1.6	6.1	2.0
GER	0.7	-0.2		-0.5	-0.3	-0.1	-0.3	4.9	5.0
GBR	1.0	0.1	0.4		-0.7	-0.4	-0.7	4.9	0.1
FRA	1.4	0.1	1.1	-0.2		-1.1	-0.5	4.0	0.2
ITA	0.4	-0.1	0.1	-0.4	-0.8		-0.3	5.0	3.9
JPN	0.4	0.1	0.1	0.1	0.1	0.1		5.6	5.7
CHN	-1.3	-0.1	-0.7	-0.2	-0.4	-0.4	-6.1		-8.2

(d)	USA	CAN	GER	GBR	FRA	ITA	JPN	CHN	ROW
USA		-0.5	0.1	0.1	0.1	-0.1	-0.3	3.8	1.4
CAN	-17.6		-0.1	0.1	-0.1	-0.2	-1.1	8.3	-0.2
GER	-1.5	0.1		0.3	0.1	-0.8	0.1	6.5	6.0
GBR	-0.8	0.1	0.1		-0.4	-0.8	-0.1	3.9	2.1
FRA	-0.1	0.1	1.2	-0.2		-0.9	-0.1	5.7	4.0
ITA	0.3	0.1	1.8	0.1	-0.1		0.1	3.9	6.6
JPN	-2.3	-0.2	0.1	-0.1	-0.1	-0.1		7.5	3.3
CHN	-3.9	-0.8	-0.4	-0.5	-0.5	-0.6	-3.2		-0.8

Table 1: Panel (a): Foreign Input Reliance in 2019 (FIR, %); Panel (b): Change in Foreign Input Reliance between 2000 and 2019 (ppt); Panel (c): Foreign Market Reliance in 2019 (FMR, %); Panel (d): Change in Foreign Market Reliance between 2000 and 2019 (ppt). Source: Authors' computations based on Inter-Country Input-Output (ICIO) Tables http://oe.cd/icio. Notes: ROW denotes the Rest of the World.

countries' reliance on foreign markets on the sales side. Table 1, panel (c) reports row nations' total input sales to column nations' manufacturing industries for G7 economies and China in 2019, again based on the Inter-Country Input-Output (ICIO) data from the OECD. As before, cell shades are indexed to share sizes; darker shades indicate higher FMR. Overall, the G7 economies' foreign market exposure with respect to China is high (higher than the bilateral foreign exposure between most G7 country pairs). Second, the global importance of the USA and China stand out from the rest, as the respective columns are primarily shaded dark. However, the bilateral US-China asymmetry is less marked and reversed since China's sales-side reliance on the US is 8.0% while that of the US on China's market is only 5.6%.

Finally, as for the input sourcing side, we also compute change in Foreign Market Reliance between 2000 and 2019. Table 1, panel (d) reports change in row nations' total input sales to column nations' manufacturing industries, 2019 vs. 2000. Dark-shaded cells indicate large FMR decreases or increases. Overall, panel (c) suggests that the G7 economies' FMR has been further increasing with respect to China during the last two decades. These findings apply both to the input sourcing side as well to the sales side. Given that the foreign exposure is an inverse measure of the domestic industries' resilience and robustness (see trade-off in Figure 1) with respect to GSC shocks, our results imply that the increasing dependence on intermediate inputs from China and market sales in China may contribute negatively to the G7 economies' resilience and robustness.

3 Simulation-Based Decision Support

What exactly does it imply a robust/resilient supply chain? Model-based simulations and GSC stress-tests should help us answer this question. In particular, we are interested in understanding the potential consequences of extreme events - like natural disasters, pandemics, military and hybrid aggression - on GSCs and the involved domestic industry resilience and robustness. We undertake GSC stress tests by simulating counterfactual shock scenarios. According to our modelling framework, the optimal firm efficiency-robustness strategy depends on the institutional framework (policy constraints) and the nature of expected shocks (frequency, idiosyncrasy, distribution).

3.1 Modelling framework and policy constraints

In order to study the challenge of "not trading long-term security needs for short-term economic interests" in a formal model, we frame it as a constrained optimisation with two constraints: a robustness/resilience constraint and a resource mobilisation constraint. We aim to formally address the trade-off by achieving the baseline resilience while doing as little damage as possible to the society's socio-politico-economic fabric. The robustness constraint ensures that the baseline resilience requirements with respect to foreign input sourcing and output sales are fulfilled. The resource mobilisation constraint implies that governments do not ask the impossible of domestic economy and society. While private sector firms may be willing to temporarily forgo possible gains or even accept losses, especially when it is in the name of a good cause, profit maximising firms' tolerance of forgoing profits is not infinite and should be taken into account.

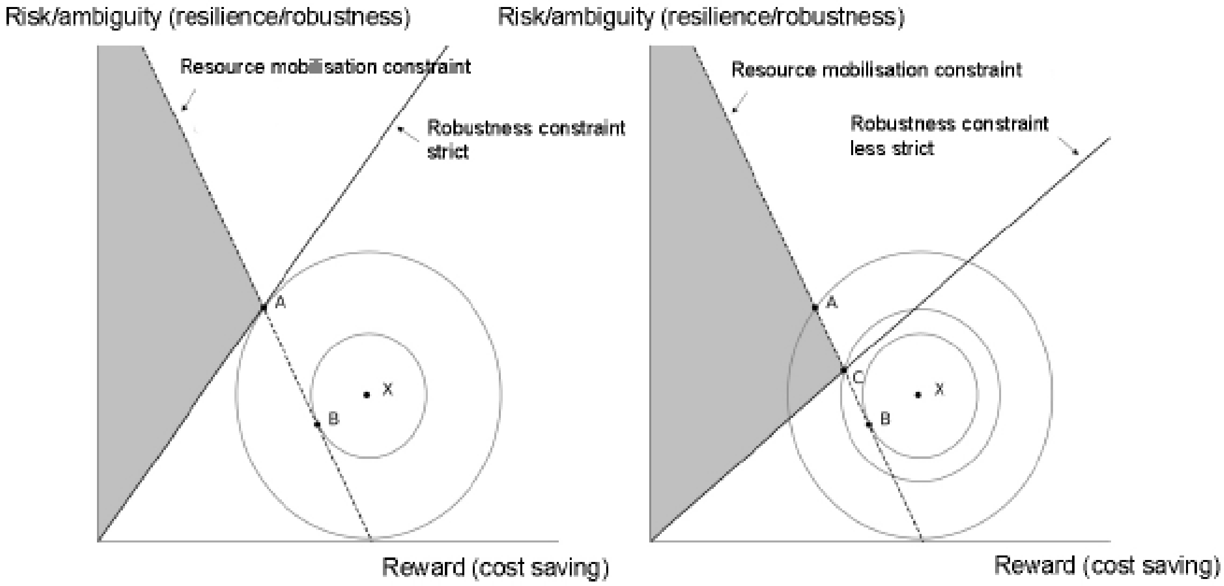

Figure 4: Welfare maximisation and constrained policy optimisation

Figure 4 shows the key intuition of the constrained optimisation problem in a static setup graphically.[6] The aggregate welfare is represented by indifference curves (circles), with each circle representing a different level of welfare. The optimal welfare in absence of shocks and policies (and abstracting from other factors such as externalities and market imperfections) is represented by point X. The solid line represents the uncertainty-reward frontier (as in Figure 2); everywhere on this frontier the domestic industries' robustness/resilience to GSC shocks is constant. Solving the underlying mathematical model, the equilibrium solution after the implementation of the robustness/resilience constraint is found at the tangency of the indifference curves and the uncertainty-reward frontier, represented by point A in the left panel of Figure 4. The other boundary condition is represented by the resource mobilisation (tolerability) constraint – the dashed line in Figure 4. Under these two constraints, the new equilibrium state of the economy would be represented by the solution to the welfare maximisation problem subject to both constraints, which would occur at point A in the left panel. Note that the grey shaded area represents the feasibility region of all possible combinations. Figure 4 also illustrates a scenario with less stringent resilience requirements (right panel). The robustness/resilience constraint is less steep, implying that the new equilibrium is now at point C. The level of welfare

[6] The solution of the full simulation model is more complex, with heterogeneous firms choosing optimal strategy in a dynamic general equilibrium (for details, see Antras and de Gortari 2020 and Jiang et al. 2022).

resulting from these minimum resilience standards (represented by the circle going through point C) is not as high as under the optimal resilience strategy (the circle going through point B) but it is closer to the optimal than the welfare achieved under the alternative strategy (the circle going through point A). The right panel of Figure 4 demonstrates that this strategy represents a more efficient outcome (higher welfare).

3.2 Shocks and simulation scenarios

Our point of departure is a decentralised supply chain (in absence of policy) which in the pursuit of efficiency could become vulnerable to extreme events/shocks. In line with the Alliance's resilience strategy,[7] we have constructed three simulation scenarios: a no-shock Baseline (S0) and two scenarios with exogenous shocks to GSCs. Scenario (S1) 'Demanding circumstances' corresponds to the standard approach in the GSC literature. In S1, the expected GSC shocks are frequent, idiosyncratic (shocks to the firm) with a priori known distribution. In scenario (S2) 'Most demanding circumstances', we study an environment in which the expected GSC shocks are infrequent, aggregate with an unknown distribution. Particularly, the S2 scenario will challenge the baseline robustness requirements regarding the core functions of continuity of government, essential services to the population and civil support to the military – which must be maintained under the most demanding circumstances.

Scenario Firm response	Baseline (S0)	Demanding circumstances (S1)	Most demanding circumstances (S2)
optimal firm strategy	'Just-in-Time'	'Just-in-Case'	'Just-in-Worst-Case'
efficiency-robustness trade-off	maximise efficiency	maximise efficiency under risk	maximise efficiency under ambiguity
robust decision rule	inefficiency aversion: the stock at firm held to a minimum	risk aversion: amount of inventory that maximises profit	ambiguity aversion: maximise payoff in the worst-case scen.
excess capacity/ cost in normal times	zero/ zero	half the time/ medium	all the time/ high

Table 3: Summary of differences in the optimal firm strategy under the simulated scenarios

The optimal firm response strategy illustrated in the top right panel in Figure 5 corresponds to a resilient supply chain which can optimally deal with risk and function under demanding circumstances in the medium- to long-run. From a policy perspective, facilitating reasonable minimum resilience/robustness standards to non-critical sectors may provide both a resilient from a security perspective and sustainable from an economic perspective solution in the medium- and long-run. The situation illustrated in the bottom left panel in Figure 5 corresponds to a robust supply chain, which can optimally deal with ambiguity, and function under most demanding circumstances in the medium- to long-run. From a policy perspective, implementing such a policy with the highest minimum resilience/robustness standards to critical sectors of the economy may be the most GSC-shock-prove and robust strategy. Given differences and the societal sacrifices and resource mobilisation costs across scenarios, a distinction between 'critical sectors' and 'noncritical sectors' is important to manage the load to domestic producers and possible adverse effects on the tolerability constraint. Resilience baseline requirements determine the critical sectors and essential services, which must be maintained under the most demanding circumstances.

7

The optimal resilience strategy will certainly depend on political priorities - "we should not trade long-term security needs for short-term economic interests" (Secretary General Jens Stoltenberg, World Economic Forum 2022), and political feasibility constraints (robustness/resilience constraint and resource mobilisation constraint). Since GSC disruptions may have catastrophic impacts on the socio-politico-economic fabric, and the probability of such disruptions is not accurately known, uncertainty and robust decision rules are the proper tools for analysis and resilience-enhancing policy recommendations. The difference between the public and private evaluation for risk and ambiguity ('Pigouvian wedge') implies that governments and the private sector might experience risk differently; whereas a social evaluation of the risk-reward trade-off will likely put a greater stress on the risk than a private evaluation. Given that in most cases governments are the residual claimants in case of natural disasters, global financial crisis or other system-wide shocks, governments are more likely to prefer a more 'robust approach' than the private sector would. For instance, if the cost of a natural disaster is very asymmetric, the government is more likely to pay attention to the worstcase than the private sector. We have demonstrated in simulations that the government can align private incentives by imposing minimum resilience/robustness standards or by providing a subsidy to relocation from riskier locations in the GSCs. For example, Japan did so as a response to COVID-19. In August of 2020, Japan set up a fund to compensate firms that diversify out of China (Jiang et al. 2022).

4 Conclusion

The landscape of hybrid threats is expanding and production processes are increasingly fragmented across borders. Because of outsourcing, off-shoring and insufficient investment in resilience, many supply chains across the globe have become highly complex and fragile. GSC vulnerabilities are important to understand, address and monitor, as the escalating fragility of GSCs may have severe implications for the functioning of critical sectors and essential services, such as energy supplies, food and water, communication networks and transport systems under the most demanding circumstances, as well as implications for the entire Alliance's security and defence.

The presented model-based simulations provide an interoperable and directly comparable conceptualisation of positive and normative effects of counterfactual resilience and robustness policy choices in GSCs. The current work adds value and contributes along a number of dimensions to the existing modelling and simulation exercises at the Alliance's and Member State levels. First, it integrates several horizontal crosscutting PMESII elements in one global modelling framework. Indeed, many supply chains are essential to everyday life for the functioning of the entire socio-politico-economic fabric. Second, a particular attention is paid to critical sectors, potential vulnerabilities are assessed based on the severity and likelihood of their disruption against a range of stress test scenarios. Data from Inter-Country Input-Output and World Input-Output Tables reveal that in a number of highly specialised industry-country pairs on the sourcing/selling side even a small shock to supply/demand can have major ramifications on the entire socio-politico-economic fabric. Third, model-based simulations enable a better understanding of the complexities underlying GSCs and provide a scientific evidence base to a resilience-enhancing decision support. To answer the simple question 'where are things made?' comprehensively – as increasingly needed by defence decision makers – one needs to look at foreign input reliance by taking into account the entire recursive sequence of all inputs and all inputs of inputs, not just the first-tier inputs.

Results of our simulations allow the vulnerability source identification and assessment of possible mitigation strategies that could strengthen supply chains in an effective and efficient manner. The decision maker choice of the most suitable strategy in each particular domain and sector should depend on the nature of the shocks, source of vulnerability, strategic priorities and resource mobilisation possibilities. Our results have also practical implications and suggestions for decision makers. First, we urge for an Alliance-wide assessment of the key capability areas and economy sub-sectors that the

Alliance's security relies upon, including the mapping of critical sectors' vulnerabilities in GSCs. Model-based simulations can provide the necessary evidence base. Second, a stock taking exercise is needed to identify what is directly available within the Alliance (including its strategic partners) to meet the seven baseline resilience requirements under the most demanding circumstances – such as a complete input sourcing cut-off from authoritarian regimes – and what is needed in the short-, medium- and long-run to achieve the baseline resilience requirements. Third, a strategic framework for addressing the identified vulnerabilities have to be developed, to identify relevant, effective and efficient mitigations for enhancing the resilience and robustness of supply chains, particularly in critical sectors. Finally, a continuous real-time uncertainty assessment and monitoring, collating intelligence across allies and partners will be utmost important in the face of the rapidly growing and dynamically changing hybrid threats. It is important to establish a shared oversight of the most critical sectors, allowing the Alliance to respond quickly when new risks and ambiguities – such as the energy weaponisation against Europe by Russia – emerge.

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Intelligent Operational Decision Support for the Military Engineer

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Abstract

This paper describes a proof-of-concept application that aims at providing timely decision support for the military engineer. Abstracting the characteristics of the terrain and integrating these elements into a simulation environment enables the use of AI methods such as genetic algorithms and Monte-Carlo simulations for finding courses of action that perform well. The experiments show that a good obstacle effect location strategy can be found that exploits weaknesses of the opponent.

1 Introduction

A commander that has to decide upon a course of action (COA) uses the Military Decision Making Process (MDMP) to help structure this task (Department of the Army, 2003). Many facets of the COA are taken into account, such as unit composition, terrain study, enemy intelligence, unit placement and orders, and more. One of these facets is the placements of obstacles, or to be more precise, the effects that a set of obstacles should achieve on the battle field. The military engineer fulfils various tasks during military operations (Department of the Army, 1994), one of which is the creation of effects aimed at delaying the advancement of the opposing force (counter mobility). With limited time and resources, possibly in unfamiliar territory, the maximum delay has to be achieved. The (dynamic) behaviour of the opponent has to be taken into account, and the behaviour is adapted in response to the encountered conditions. It has to be said that the military engineer does not develop such a plan in solitude, but the military engineer is in constant collaboration with other roles of the planning process, such as manoeuvre and air defence, in order to create a well-coordinated course of action.

During the creation of the course of action for obstacle effects, the military engineer performs three major tasks. (1) The terrain is analysed, (2) opposing courses of action (OCOA) are drafted, and (3) a counter mobility advice is developed. These steps are mostly performed manually. For automatic terrain analysis, various techniques already exist (Richbourg & Olson, 1996; Grindle, et al., 2004). In order to draft OCOAs, the gathered enemy intelligence is used to create predictions of future behaviour of the opponent. After knowing where effects can be achieved (Sycara, et al., 2009), the challenge is to decide on what combination of effects delays the enemy the most.

In order to abstract the wide range of possible future behaviours of the opponent, usually two OCOAs are considered, the most dangerous (MDOCOA) and most likely opposing course of action (MLOCOA). A counter mobility advise that is robust against these two OCOAs is manually created for the commander. If a wide range of OCOAs is possible due to incomplete enemy intelligence, then the real behaviour of the opponent may not resemble the MDOCOA or the MLOCOA. The OCOA should also not be regarded as static, as the enemy behaviour is likely to adapt to the chosen effect placement. OCOAs can be formalized to allow reasoning (Ulicny, Kokar, Matheus, & Powell, 2008).

The manual process of analysing the terrain, thinking about OCOAs and finding a robust plan that works in various conditions is not something which should be completely automated. Only when the engineer created a mental model of the situation, can he/she react quickly in unexpected conditions. Therefore, future AI systems should rather support the military engineer by automating simple tasks, perform data fusion and analysis, and be a sparring partner. Once this is achieved, the engineer can create stronger plans in the already limited timeframe of a military planning setting. Either being quicker while keeping the quality the same, or increasing the quality in the same time frame, can make the difference between losing and winning in the battle field.

There are many steps in the analysis process of the military engineer. From terrain analysis to OCOA estimation to obstacle effect placement. In the present study we focus on the last step in this analysis process, namely the use of AI methods such as genetic algorithms and Monte-Carlo simulations for finding a robust obstacle effects advise against a wide range of static and non-static elements of OCOAs. The opponent force can be simulated with various intentions, taking into account the expected knowledge and skills of the opponent. The developed prototype can be seen as a glimpse on the potential of future decision support systems for military missionplanning support applications. This prototype is developed in collaboration with the Dutch Ministry of Defence (MoD) and the knowledge gained helps in prioritizing innovation projects for the MoD in the near future.

In order to explain and understand the approach that is presented in this study, we first present the steps that a military engineer is currently performing manually. Thereafter we discuss relevant parameters which should ideally be derived automatically from terrain analysis methods. We then present our approach and initial results.

2 The work of the military engineer

The first step in the analysis process of the military engineer is the creation of the so-called Combined Obstacle Overlay (COO). In this map overlay, terrain characteristics are marked. Important elements are forests, lakes, rivers, bridges and cities. Depending on the size of the operation, the military engineer does this on different granularities. The larger the operation, the more zoomed out the analysis gets. The military engineer mainly uses maps and satellite images for this analysis. When there is internet available, even google street view may be used. Given enough time, a field investigation may be performed for the most relevant areas. The finished product from this analysis step is a map overlay with marked polygons for forests, lakes and cities, line elements for rivers and point element for bridges. For each polygon the military engineer needs to decide whether it is a slow-go or a nogo area. The difference is that a slow-go area can be crossed by a military unit, but it takes additional time, while a no-go area is so inaccessible that it does not make sense to cross it within the current mission parameters. Figure 1 shows an example of such a COO with several no-go areas which are marked with diagonal lines in two directions, while slow-go areas only have diagonal lines in one direction. As you can see in Figure 1, the line that represents a river does not exactly follow the flow of the river. For the purpose of the COO in this mission, a straight line is sufficiently accurate for the military engineer to base the planning on.

Figure 1: An example combined obstacle overlay with no-go forests (green), no-go cities (black), a river (blue) and a bridge (black).

Once the COO has been assembled, it is used as input for the Modified Combined Obstacle Overlay (MCOO). In the MCOO, possible *Avenues of Approach* are entered. These avenues of approach are typically located in the areas that have not been marked in the COO. These avenues take the expected arrival direction of the enemy forces into account, as well as the size of the enemy forces. The larger the unit, the wider the size of the avenue has to be. A unit that moves in battle formation requires a certain width to do so in a safe manner. Figure 2 shows an example of avenues of approach.

Figure 2: Avenues of approach have been created in the MCOO.

These avenues of approach are similar to a navigation graph. Navigation graphs are frequently used in simulators to restrict the movement of simulated forces in an open terrain. The MCOO in essence describes all possible routes the enemy forces may take during the mission.

The third step in the analysis chain of the military engineer is the creation of OCOAs. Based on enemy intelligence gathered by the intelligence cell and the MCOO, the military engineer devises a most-likely and most dangerous OCOA (called the MLOCOA and the MDOCOA). In these OCOAs, the engineer decides upon a logical route of approach of all enemy forces, as well as other aspects (e.g., whether an armoured vehicle-launched bridge is available).

Now the engineer devises a plan which can delay the enemy forces in both the MLOCOA and the MDOCOA. For this, obstacles are placed in the terrain to create a certain effect. The four possible effects are shown in Figure 3.

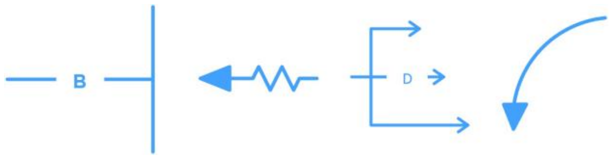

Figure 3: The four possible obstacle effects. From left to right: Block, Fix, Disrupt and Turn.

With a block effect, the opponent is hindered so much that the avenue is completely inaccessible and clearing the obstacle is unrealistic in the mission timeframe. A fix effect tries to fix the enemy forces at the current position for a certain period of time. The enemy forces are however able to continue their route with some delay. A disrupt effect tries to disrupt the opponents movement and create confusion. The opponent is however expected to continue their journey quickly. With a turn effect, the enemy is coerced into taking a for us desired route by blocking the alternatives (i.e., on a road crossing). The delay potential of these effects is increased when the effect location can be reached with direct or indirect fire. It is therefore important to closely collaborate with different roles of the planning cell to create a good overall plan.

Each of these effects costs a certain amount of resources. Examples of such resources are time, manpower, explosives, mines, diggers, concertina wire, amongst others. Such resources are scarce. The military engineer has to estimate how much of these resources are needed to create each effect on each location. For example, a blocking effect is more expensive on a wider road, as more of the street has to be destroyed with explosives. Some effects may not even be possible depending on the terrain, such as blocking the opponent in a wide open area. How much resources are needed depending on terrain characteristics is already known (approximately) and described in handbooks (Opleidings- en Trainingscentrum Genie, 2017).

For each avenue of approach the engineer looks for locations in which the minimum amount of resources is needed to achieve each of the effects. Once these are known, the engineer creates combinations of obstacle effects that together may achieve the mission goal, which is to delay the opponent a certain amount of time. It is important that the chosen plan works for both the MLOCOA and the MDOCOA. The plan is shared and coordinated with the other roles in the planning and presented to the commander.

3 Relevant research

There have been developed plenty of decision support tools and prototypes for various roles in the military (Davis, Kulick, & Egner, 2005; Van Den Bosch & Bronkhorst, 2018). Also, the use of optimization techniques such as genetic algorithms, reinforcement learning and approximate dynamic programming is not new in the military setting (Rempel, 2021). We however focus on planning support for the military engineer in this section.

(Butler, Boggess, & Bridges, 1999) created a knowledge-based planning approach for military engineering tasks. In this study, a genetic algorithm is used to draft COAs that optimize a commanders intent. They are able to schedule tasks in much detail, such as the movement of units based on expected speed. The main difference with our approach is that in their study the behaviour of the opponent is fixed, leading to a wellworking COA when the opponent behaves as expected, but it is questionable whether the COA is robust if the opponent deviates.

(Jang & Lee, 2017) considered the optimization of artillery positions. The military engineer supports in the smooth operation of the artillery. This study considers how equipment and personnel can be scheduled to maximize the engineers capacity. The aspect of fire support is one that we do not address in the current study.

(Kopuletý & Palasiewicz, 2017) considered the use of autonomous systems to support the engineer reconnaissance. A COA developed by the engineer may work well when certain assumptions of the terrain prove correct (e.g., a forest is dense enough so that you cannot pass). However, in case the assumption process is wrong, the entire COA may be invalid or suboptimal. Therefore engineers need to validate the most critical assumptions, if there is sufficient time in the mission context. In our study we assume that the terrain analysis produced accurate and realistic results. Planning with uncertainty in those assumptions is an interesting topic, which we would like to address in future research.

4 Model Parameters

Each of the steps that the military engineer performs during the analysis can be supported by terrain analysis and smart algorithms. In our research we focus on the final step of this analysis chain, which is the choice of obstacle effect locations. This implies that all earlier steps already have been executed and can be used as input parameters. This section describes all the input parameters that the current version of the models requires in order to calculate well-performing obstacle effect plans.

The first input feature is a navigation graph, which is derived based on the avenues of approach of the MCOO. This graph describes all legal movements of enemy units in the scenario. The second input feature is possible obstacle effect locations. These essentially are the nodes of the navigation graph. In case an obstacle can be placed on a location which is not an intersection, then the corresponding edge can simply be divided into two elements with a node in between. Not all nodes of the navigation graph are eligible obstacle effect locations. Each node holds a list of possible effects for that location. This list may be empty, or hold any number of effects. For example may two different turn effects be part of the list, in order to force the opponent in either of two directions.

For each possible combination of effect and location, the resources that are needed to create the effect are parameters as well. The resources that currently are part of the model are: (1) manpower, (2) needed time for placing the obstacle, (3) the amount of mines needed, (4) the amount of explosives needed, (5) the number of rolls of concertina wire, and (6) whether an excavator is needed for placing the obstacle effect. Given these resources on the corresponding location, a specific delay can be expected. The current model allows for placing the same effect multiple times on the same location, so that a different amount of invested resources may result in different expected delays. In this way the optimization algorithm may choose to invest additional resources on a certain location to generate a larger delay of the opponents forces.

Last but not least, a list of opponent behaviour models is required. These behaviour models command the opponents units during the simulation. Not every soldier is simulated in detail, but larger military units are modelled as a single entity. This is similar to what modern computer generated forces (CGF) simulators call the aggregate level (VT MAK, 2015). The two behaviour models that are obviously required are the ones that correspond to the MLOCOA and the MDOCOA. We are however free to add more opponent models. By adding more models the algorithm will attempt to find well working obstacle effect plans that are robust against all of the specified models. So may hundreds of route variations be tested, as well as different capability combinations. This is a significant difference to the manner in which human military engineers devise their plans, as they only plan against two of such models.

To make the behaviour of the enemy dynamic and intelligent, simulation techniques such as Monte-Carlo Tree Search (Browne, et al., 2012) can be used to create intelligent behaviour for never before encountered conditions. These condition may arise from the large amount of combinations of own choices with a wide range of OCOAs. Handcrafting behaviour with scripting by Blue force experts is not feasible for millions of combinations, and generalizing behaviour potentially leads to unrealistic behaviour in various situations. Any uncertain information from the intel cell can be modelled as probabilities as well (e.g. 40% chance of route A, 30% of route B, ad 30% of route C).

5 COA optimization

The challenge we are facing is to find a counter mobility effect placement that is robust against a wide range of opponent behaviour, such as the chosen route of approach. As there exist too many combinations, testing each counter mobility option against each OCOA is not possible. We choose a genetic algorithm (Coello, Van Veldhuizen, & Lamont, 2002) in the hope of finding good effect locations without testing each permutation.

In the genetic algorithm, individual genes represent effect locations for the military engineer. A set of genes forms the chromosome and represents the entire plan on where to place effects. Each generation of chromosomes is evaluated against OCAOs that are sampled out of the range of possible OCOAs. Also adaptive OCOAs can be used, such as changing the route when encountering effects.

An important aspect of the optimization is the evaluation function which describes the effectiveness of the proposed obstacle effect plan. The military term for such a function is *measure of success*. It is of grave importance to define this function adequately, as an optimization algorithm will generate wild solutions as long as these solutions increase the evaluation function by a tiny amount. We have seen such behaviour in other applications, for example an optimization that learns to run away infinitely when playing hide and seek (Baker, et al., 2019). While such an evaluation function typically is defined in code, in the future a military commander might be able to explain his/her intent in natural language, and the intent can then be used as evaluation function (Schadd, Sternheim, Blankendaal, Van Der Kaaij, & Visker, 2022).

In the scenario that we have chosen for this prototype, two enemy companies approach an important city with bridges. In a battle, a force ratio of 3 to 1 is needed to make gains. In an urban environment such as a city, force ratios of up to 9 to 1 are needed. We therefore decided that a single enemy company has not sufficient force to capture the bridges, but only once the second company arrives is the necessary strength accumulated. The score of an obstacle effect placement is determined by the time step that the second enemy company arrives at the target node of the graph. This implies that the optimization algorithm may choose to focus all obstacles effects on one company, and ignore the other. As military units get assigned each their own corridor, and rarely enter the movement corridor of a neighbouring unit (to avoid friendly fire), it becomes straightforward to place obstacle effects that focus on a single unit (i.e., by placing effects in the corridor that that units travels in).

6 Experiments

In order to validate that the genetic algorithm is indeed working as intended, we executed a baseline experiment. In this baseline, three variants of the opponent are simulated. In *Static Route*, the opponent has a single battalion that always follows the same path. The optimal solution is rather easy to find, as only obstacle effects on the chosen route have any effect. In *Quickest Route*, the opponent is allowed to plan a new route to the target location as soon as new information becomes available. For example when a turn effect is placed, the blocked route is not accessible and a route replanning occurs. In *Two Battalions* approach with the quickest route setting. Figure 2 shows the learning process against these three variants. The x-axis shows each subsequent generation, and the yaxis the performance of the generation. A value of 1 indicates the achievable delay when Red takes the static route and is maximally delayed.

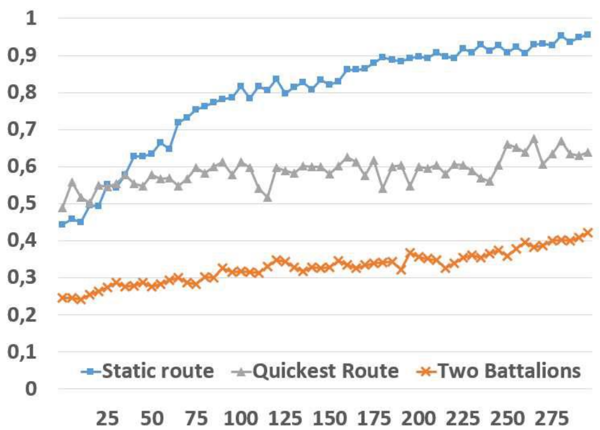

Figure 4: Learning optimal effect locations against various opponent behaviours.

The experiments show that a good effect location strategy can be found that exploits weaknesses of the opponent and results in high opponent delay. As the algorithm is limited in the amount of resources available, it is not possible to achieve a high delay for the smarter *Quickest Route* opponent behaviour as well as for the *Two Battalions* opponent behaviour. We therefore cannot expect that the achieved delay approaches the value 1 on the y axis.

This initial experiment showed that the genetic algorithm gradually finds better solutions. We could manually validate that the generated solutions are logical within the scenario. So did the best solution for the *Static Route* opponent only place obstacle effects on the route that opponent takes. With this affirmation, we confidently can increase the complexity of the scenario.

Figure 5 shows an overview of the fictional scenario. An MCOO has been created, but the possible avenues of approach are not shown to make the visualization readable. The arrows represent the routes that the two enemy battalions will take if they encounter no obstacle effects.

Figure 5: A fictional scenario. Two red battalions are approaching from the south west towards an import town. The blue arrows are the shortest routes within their own corridor.

We let the genetic algorithm optimize obstacle effects, given limited resources. The enemy battalions will replan their route when encountering obstacles. The chosen obstacle effect locations, as well as the (dynamic) reaction of the enemy battalions are shown in Figure 6.

What this solution shows is that the genetic algorithm focused its resources on delaying the northern battalion. The southern battalion is allowed to arrive at the city without any delay. The algorithm chose this because of the way the evaluation function works. Only when the second battalion arrives does the opponent have enough force to take the bridge. An interesting detail is that the algorithm used a turn effect (the third effect on the northern route). The enemy battalion is turn towards a road leading south, but as this crosses a unit corridor border, the unit is not allowed to go there, and has to turn around. A block effect would yield the same result, but a block effect is more expensive than a turn. In reality the northern battalion would communicate to the southern battalion that it will enter their corridor for a short while to avoid such a large delay, and adding such behaviour is left for future improvements.

Figure 6: A well-working obstacle effect setup against two battalions that look for the shortest route. The chosen effects are indicated with red icons, and the blue arrows are the routes the enemy battalions take.

In the next experiment we increase the capabilities of the opposing battalions. They are now equipped with a reconnaissance unit, and can now detect obstacle effects on neighbouring nodes of the navigation network. As the battalions perform path planning, they are now able to plan their route around obstacles without triggering a delay by entering a node with an obstacle effect. A unit can of course intentionally navigate through an obstacle effect in case that the route with expected delay is still quicker than a large detour. A well performing obstacle effect plan for such an opponent is given in Figure 7.

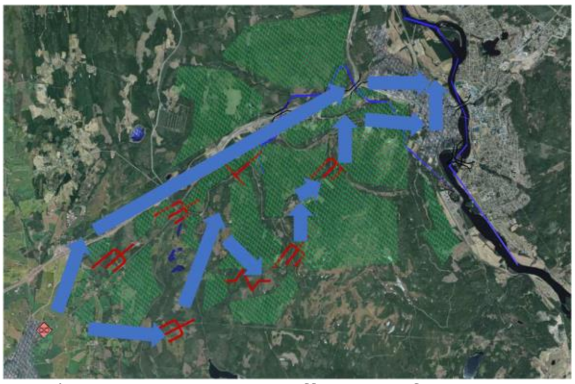

Figure 7: An obstacle effect plan for a smart opponent that has a reconnaissance capability. Obstacles effects on neighbouring nodes of the navigation network can be detected.

Interestingly, letting the opponent have the reconnaissance capability resulted in an entirely different obstacle effect plan. Instead of delaying the battalion in the north, now the southern battalion is delayed. The algorithm is able to let the southern battalion make a small detour (the second arrow). The block effect in the middle of the figure is seen too late by the battalion, and a new route has to be planned. If the battalion knew of the obstacle effect earlier, then a different route would have been chosen earlier.

In the next experiment we increased the reconnaissance capability of the battalions even more. In this variant, both battalions know the locations of all obstacle effects beforehand. This means that it is not possible to surprise the opponent. Both battalions are able to plan an optimal route at the beginning of the scenario, taking all obstacle effects into account. This can be regarded as a MDECOA, as the opponent is well informed. A well working effect placement against such a powerful adversary is presented in Figure 8.

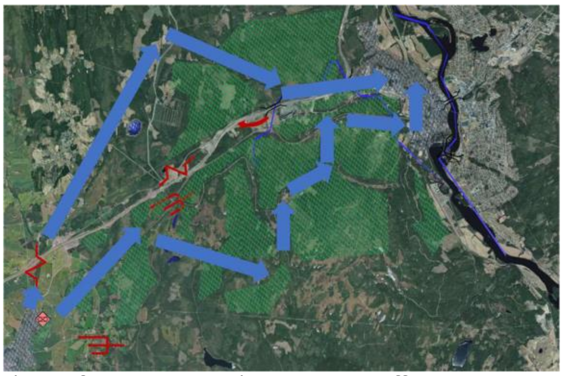

Figure 8: A well-working obstacle effect placement against two battalions that have complete knowledge of all obstacle effect locations.

In this last obstacle effect plan we can see that obstacle effects are now placed in such a manner that the northern battalion is mainly delayed. The delay is however limited, as the battalion directly bypasses the main road where the obstacle effects are placed.

7 Conclusions and discussion

We demonstrated a proof-of-concept application that aims at providing timely decision support for the military engineer. This type of decision support is essential in the field to support the military engineer. It may inspire new ideas and avoid tunnel vision in stressful situations. The technology is also valuable as a future tool for training purposes and has great potential towards developing more accurate behaviour models for simulated entities.

Although promising, there are still many areas in which the prototype currently is making assumptions. In order to make the approach usable, an automatic terrain analysis, which generates a MCOO, is required (de Reus, Kerbusch, & Schadd). Also a variety of other parameters have to be set, such as required resources and expected delays for each combination of location, effect, and enemy unit. Such parameters possibly can be gathered in a data-driven approach (Schadd, de Reus, Uilkema, & Voogd, 2022). A great promise of the current approach is that a well working solution can be evaluated against a pool of opponent variants. The score of an obstacle effect placement then becomes (for example) the average of all achieved scores against the tested opponent variants. Testing plans against such a large opponent pool is something that currently cannot be done by hand.

Another aspect which needs additional attention is that a good course of action requires more disciplines than only the military engineer. An obstacle effect is much more effective when it can be supported by indirect fire (e.g., artillery), and direct fire (e.g. infantry). A future tool could for example also look for good positions with line of sight on the obstacle effect location, including a suitable retreat route for the infantry unit that provides direct fire. This will increase the number of parameters and the underlying simulation model, but it is required to increase the realism and feasibility of the proposed solutions.

Next to only create a well-performing plan, the question of why this solution performs well deserved investigation. As long as the military engineer cannot understand the solution, the solution is essentially worthless. The future tool should include features that address the understanding of the problem, for example a what-if functionality.

Last but not least, a major assumption of the current prototype is that the terrain analysis was accurate. Creating obstacle effect plans, that take into account such uncertainties, will be more robust in practice.

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Unmanned Aircraft System, Command and Staff Training via Modelling and Simulation in Support of Military Exercises

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1 Introduction

Training for military Exercises in the 21st century requires robust technologies that expose techniques to facilitate trainee immersion, high fidelity modelling and high graphics resolution to support training via simulation. Using these techniques, stand-alone as well as collaborative and collective training is achievable, now more than ever before. This paper will discuss discovered and utilized simulation methodologies in support of military Exercises for individual and partner nations (a corresponding presentation and video will be utilized during the briefing at NATO CA2X2).

2 Standards

Paramount to any successful simulation Exercise is the incorporation and adherence to agreed upon standards. Requirements and the subsequent decomposition of the same are essential to the success of a viable modelling and simulation training solution. In terms of Unmanned Aircraft Systems (UAS), Products such as National Imagery Transmission Format (NITF) – STANAG 4545, Full Motion Video (FMV) - STANAG 4609, with embedded Key Length Value (KLV) metadata, Ground Moving Target Indicator (GMTI) - STANAG 4607, and Command and Control (C2) - STANAG 4586 are standard products and protocols that should optimally be utilized to facilitate training. In addition, the desired solution should have the ability to execute in stand-alone mode and in a networked environment such that training can occur at remote locations without diminished capabilities nor results. There must also be domain knowledge concerning Graphics Processing Units (GPUs), Network Interface Cards (NICs) and computational bandwidth of Central Processing Units (CPUs). Since at times, not only the software solution is deployed, but in addition the hardware platform that the software will be executed on, it is essential that the appropriate hardware, with high Mean Time Between Failure (MTBF) rates, is selected since availability and sustainability are typically Key Performance Parameters (KPPs) of any system performing simulation.

From a technical perspective, the challenge of producing a acceptable product such that the trainee is immersed can be a daunting task. One of the earliest items that must be addressed is to define interfaces such that the software can communicate items such as status. Typically, the approach is taken to examine the required data to be known and build an interface accordingly. The interfaces are the “bible” for communications, internal and external to the system. Structures, indigenous protocols, etc. are defined, then Interface Control Documents (ICDs) generated, versioned then disseminated to all appropriate stakeholders. The ICDs expose the proper methodology of how to communicate with other models in the system to obtain data or send data (e.g. – altitude, velocity).

3 Network Protocols

A successful collaborative training solution must address which transport protocol to use. For example, if a sample rate of 30 Hertz (Hz) is required, then exploiting the User Datagram Protocol (UDP) would be appropriate since it is a connectionless transport that won’t impede other packetized traffic on the network. Even though all of the packets, sent via UDP, may not make it to the destination, this is acceptable since, at 30 Hz, another packet is in the pipe to be processed right after the one that was dropped off of the network. Conversely, if the data to be processed requires guaranteed packet delivery, then the Transmission Control Protocol (TCP) would be the transport of choice. However, when using TCP, care must be taken to ensure that the network has sufficient resources to accommodate the additional ACK/NAK traffic (inherent in the TCP protocol) that assists with ensuring delivery of the data. Using TCP on a dirty network could negatively impact both the network and the algorithmic models since the models depend on the arrival of the data to execute properly; some of which must be in sequence.

4 Visualization

In order to properly train UAS, some data must manifest via applications that support two and three dimensional (2D/3D) views. Three high-level requirement items are terrain, textured models (tanks, trucks, etc.) and Heads Up Displays (HUDs) on Unmanned Aerial Vehicles (UAVs) / Remotely Piloted Aircraft (RPA). Typically, when mission planning for a UAV / RPA, a 2D application is used. Waypoints are generated that determine where the asset will fly. If the platform asset is analogous to a Global Hawk or U2, then planning for collection of certain sensor shots, resulting in NITF imagery, is required for the mission and the application must be able to display the waypoints, the SAR collection points and the lines that indicate the flight plan and the sensor view(s). Terrain creation, terrain population and providing the ability to view the terrain from a platform with associated payloads are tasks to complete for UAS training as well. Typically, high-resolution terrain is built, with the correlating Digital Elevation Model (DEM) for the training audience prior to the event. Creating terrain is typically the long lead item since downloading satellite imagery of increased resolution takes significant time due to the size of the imagery, then the processing of the downloaded images to remove anomalies must occur (e.g. – clouds). Suffice it to say that the region that will be used to train should be selected early to provide ample time for the terrain builders to download and build the appropriate terrain. Populating the terrain refers to placement of textured models, represented by entity state data, in the 3D space of the Image Generator (IG). Multiple sensor modes must be provided such that the user can effortlessly and seamlessly switch between views such as, Day TV, Infrared (White Hot/Black Hot), etc.

The 3D processing and displaying of data is typically utilized to train responses to FMV. Entity state data used to manifest textured models in the scene must contain at a minimum, position, orientation, and type information. The uniqueness of the textured model represented is accomplished by assigning an instance identifier, which makes it indigenous in the training environment (not just a tank but which tank). In addition, damage states must be part of an entity's representation. The training solution must be able to appropriately display detonations, then support subsequent Battle Damage Assessment (BDA) in the form of a damaged textured model (given the munition is sufficient to effect damage on the target). The damaged model would need to be observable using the sensor(s) on platforms that are airborne and in range.

5 Ease of Use

An item that is commonly overlooked when developing systems that require software is Ease of Use. There are times when the software solution must look identical to the already fielded tactical asset. Other times, liberties can be taken to provide the user with a "User-Friendly" Graphical User Interface (GUI). This is an area that has received far less attention than necessary. It can be troubling to the training audience when the simulation solution provided is complex. Care must be taken to consistently identify opportunities to improve the user experience such that, if possible, training can be performed without the need to invoke the assistance of engineers. In other words, if engineers were funded to create the solution for the training audience, it shouldn't take engineers to operate the solution for the training audience. More time should be spent training utilizing the simulation tools, as opposed to more time learning the simulation tools in order to train.

6 Scalability and Redundancy

Over time, Exercise data loads will invariably grow. Items such as the sensor count per platform, the weapons load out count per platform or platforms with associated FMV counts can and typically do increase over time. This necessitates the need to design with growth in mind. Monolithic approaches to software design typically will not suffice when scale becomes a requirement. Hardware is also a factor due to 32 and 64-bit architectures. Characterization of bus speeds on the motherboard and the Network Interface Controller (NIC) are also essential since having a fast CPU alone will not suffice in reading the data off of the wire (Ethernet) and getting it processed in a timely manner. Thought must be given to incorporating the ability to employ load distribution mechanisms to mitigate federation and data load increase. Redundancy for power and machine must also be addressed since, with all of the data stored in memory during system operation, a power outage or the failure of a machine could be catastrophic to the training event. The ability to restore the system back to a given point such that training could continue from the federation SAVE point must also be a consideration. Vignettes/scenarios should have the ability to be played multiple times with identical behaviours, thus providing an repeatable objective mechanism with which to evaluate trainees.

7 Interoperability

Typically, DIS and/or HLA are used to populate the 3D applications that serves as the Image Generators (IGs). By using HLA, interface compliance by all M&S algorithmic models participating in the Exercise is organically achieved. This is accomplished by a Federation Object Model (FOM) being mandated to all federates (those algorithmic models that will Join the federation). If an algorithmic model is DIS enabled and not HLA enabled, then the DIS enabled Model has the option to send its DIS feed to an HLA federate and that federate will publish the status of the DIS Model to the Run-time Infrastructure (RTI). In Figure 4-1, Federate F3 receives the Platform DIS PDU from the Platform & Sensor Model. Federate F3 in turn, converts the Platform PDU to an HLA object and publishes it to the RTI. This is the power and benefit of utilizing standards in the M&S domain. The UAV Platform Model produces a DIS PDU that can then be seen by other Models that are a part of the federation that are HLA compliant, joined to the federation and have subscribed to the appropriate object(s).

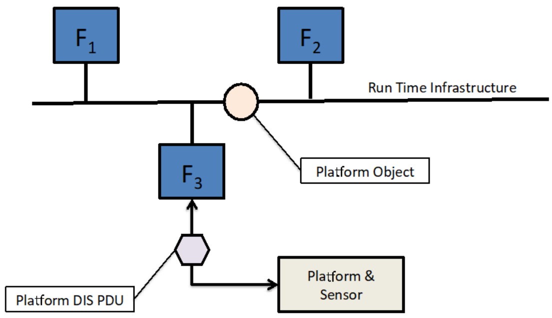

Figure 1: HLA to DIS and Visa Versa Architecture

8 Modular Open Systems Approach (MOSA)

In terms of software design that facilitates efficient collective training simulation solutions, a MOSA is recommended. Success has been realized by architecting in three phases. First, identify atomic units of capability that can be used across the software baseline and/or enterprise; i.e. - components. Second, incorporate the well-vetted componentized capabilities into services. Thirdly, access the services via GUI applications, Web applications, etc. This methodology supports an extensible, scalable architecture that facilitates load distribution both local and remote. For example, in Figure 4-2, let's identify Component 3 (C3) as a DIS parser.

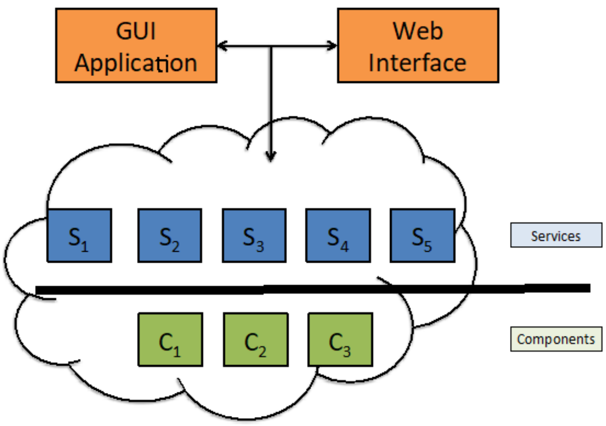

Figure 2: Service Oriented Architecture Implementation

This component is responsible for encoding and decoding DIS. Once the C3 Component is created, it would be used throughout the baseline and/or enterprise since an interface would be available to access its capabilities. Next, C3 could be used in services (S1 – S5) that are created for access by other applications. A by-product of this approach is that there is potential for extracting out a Software Development Kit (SDK) for use by external customers/organizations. As the component count grows, the extensibility grows. In the event that additional requirements are levied, once fleshed out, an examination of current components can be evaluated to determine what is already available to leverage, hence reducing cost and time to delivery. Figure 4-4 is an example of how applications, all of which adhere to the MOSA construct, allow for DIS PDU data to be distributed across multiple machines, thereby negating a computational bottleneck which would be counterproductive to an Exercise/Training Event (this architecture is currently used in multiple Exercises using the Government off the Shelf (GOTS) applications shown).

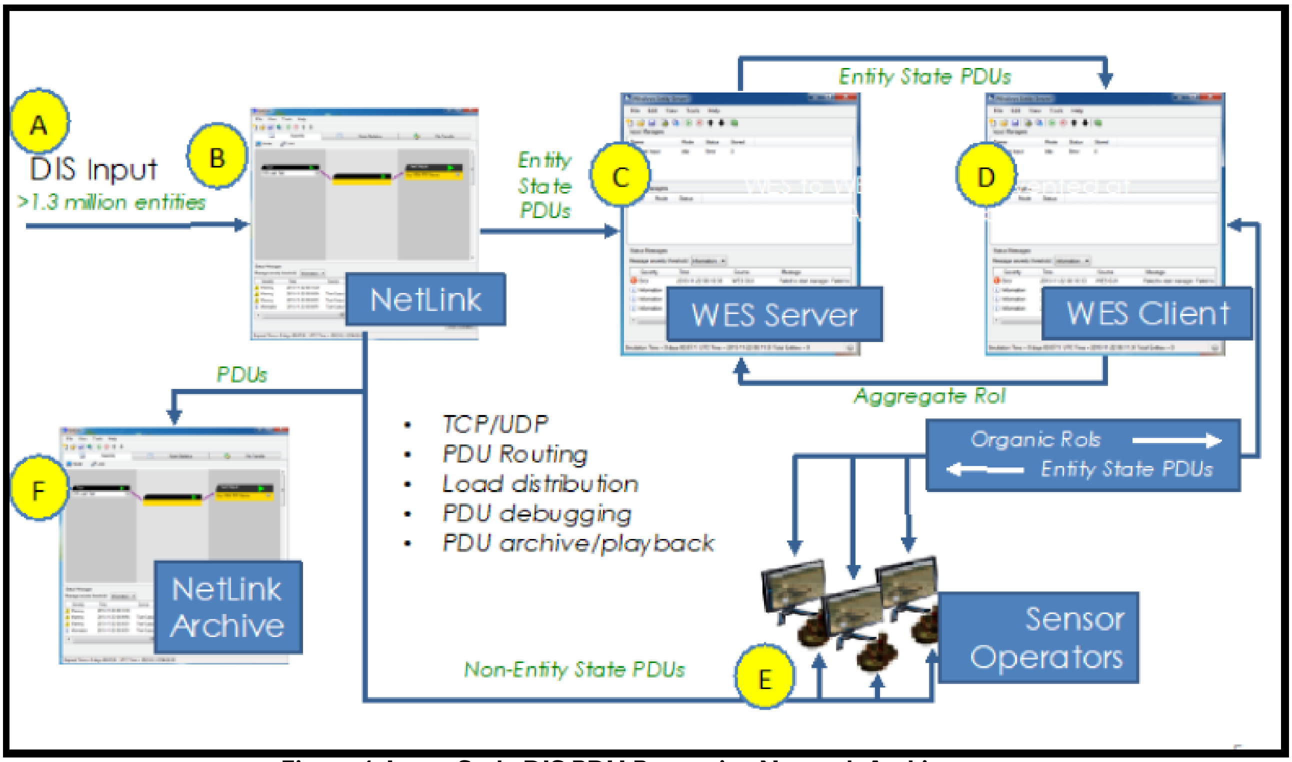

Figure 4: Large Scale DIS PDU Processing Network Architecture

The architecture demonstrates a tiered approach that negates the need to have the entire execution data on one machine.

The data flow of Figure 4-4 is characterized as follows:

1. Starting at A (DIS Input):

   a. >1.3M PDUs are sent to B (NetLink) via TCP (typically DIS utilizes UDP but since the data set is so large, TCP is used so that on a connection, all PDUs are delivered). Subsequent to the initial delivery, deltas only (this single architecture modification alone, reduced bandwidth consumption from approximately 92% to approximately 21%.

2. B (NetLink):

   a. Receives DIS PDUs from A (DIS Input).
   b. Sends all DIS PDUs to F (NetLink Archive), for archival such that all PDUs received could be played back, with appropriate timestamp, to debug anomalous data feeds (PCAP file generated).
   c. Sends non-Entity State PDUs such as Detonate or Designate to E (IGs – Sensor Operators).
   d. Sends Entity State PDUs to C (Windows Entity Server – WES Server), to store all Entity State PDUs (which are the majority of the PDUs).

3. C (WES Server):

   a. Receives and stores, into volatile memory, all Entity State PDUs received from B (NetLink).

b. Receives aggregate Regions of Interest (RoI) from D (WES Client).
c. Sends Entity State PDUs to D (WES Client), per the aggregate RoI received.

4. D (WES Client)

a. Receives and stores into memory, Entity State PDUs, received from C (WES Server).
b. Sends aggregate RoIs to C (WES Server).
c. Sends Entity State PDUs, based on organic Platform RoI, to the appropriate IG (representing a sensor).

5. E (IGs - Sensor Operators)

a. Receives non-Entity State PDUs (e.g. – Detonate, Designate) from B (NetLink).
b. Receives Entity State PDUs from D (WES Client).
c. Sends organic RoI to D (WES Client).

In conclusion, the key concepts to deploying an efficient, cost effective, extensible, scalable architecture, for a modelling and solution to support military Exercises are to develop a set of tenets that guide the development of the system. A recommended set of tenets would be, ease of use, open architecture (MOSA), utilize standards when appropriate, design for load distribution (scalability) and leverage existing code by reusing components.

Technology, Gameplay and Human Streams; a Framework to Support the Development of Simulation-based Wargames

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Abstract

The Dynamic Messenger (DYMS) operational experimentation exercise, scheduled September 2022, marks a new era in NATO's approach to assessing the effectiveness of emerging and disruptive technologies. As part of this new approach, DYMS22 will utilise the latest version NATO's Disruptive Technology EXperimentation (DTEX) approach to provide an immersive, scalable and adaptable M&S based wargaming capability to support decision making in complex and uncertain environments by blending human, technology and data aspects.

DTEX's ability to be rapidly configured, deployed and made available to support wargaming in DYMS22 stems directly from the project's long-term focus; to reduce configuration time while increasing scalability. This paper documents the design, development, implementation and refinement of a versatile framework that supports the rapid deployment of M&S based wargames in NATO.

The development framework focuses on three parallel lines of effort; the technology stream, the gameplay stream and the human stream. The technology stream focuses on the implementation of toolsets that not only allow the technologies of interest to be simulated, but also on the agile and incremental design and development of scalable interfaces that allow the players to configure the scenario and analyse data in a range of formats. The gameplay stream focuses on providing players with the right information at the right time, balancing motivation and a desire to win with the need to encourage discussion and elicit insights into the decision making process. Finally, the human stream recognises the fact that the motivational and communication elements of each event need to be tailored to optimise engagement among diverse player communities.

Using DYMS22 as an example of the latest application of the DTEX in NATO, the structure, content and observations that led to the development of a robust wargaming development framework will be presented, discussed and made available to enhance the wider field of M&S based wargaming in NATO.

Keywords. *Modelling and simulation, wargaming, M&S lessons learned, emerging technologies, capability development and experimentation.*

1 Introduction

Wargaming is well established as a core component of military planning, decision-making and operations [1]. As wargames continue to develop, NATO has begun to identify best practices in how to support wargames with computer-based simulation environments [2].

Set against this wider trend, NATO's Innovation Hub is supportining the analysis of new and emerging technologies in a series of gamified Disruptive Technology Experiment (DTEX) events [3]. The latest DTEX in this successful series of gamified events investigates the future role of potentially disruptive autonomous systems technologies in maritime operations as part of the 2022 NATO Dynamic Messenger (DYMS) exercise in Portugal.

Despite the recognition of the effectiveness of simulation to support a wide spectrum of wargaming events, there remains a lack of standardised frameworks that support the development and effective integration of computer-based simulation ecosystems into gamified events.

This paper presents a standardised framework that has been developed in parallel to recent DTEX events with the aim of efficiently developing simulation based wargaming capabilities and, more importantly, effectively integrating them into wargame events. The identified framework consists of three parallel incremental development streams: gameplay, technology and human.

This paper describes the motivation for a framework to support the development of simulation environments to support wargame events in section 2. Section 3 presents the proposed framework elements individually. Section 4 describes their application in support of DYMS 22. Finally, section 5 contains the conclusions and next steps for the DTEX synthetic environment.

2 The need for a framework to support distributed, incremental development

The history of wargames is almost as old as history itself [1]. In the modern era, typically executed as table-top exercise with paper and card, wargaming was introduced into military activities in the 19th century as a method to simulate warfare in order to improve military planning and responses [4]. Due to its wellknown and accepted benefits, NATO is investigating wargaming as a methodology to encourage alternative thinking for planning and assessment. The potential of wargaming has been well recognized within NATO, allowing the exploration of operational possibilities and discovering unintended consequences in a safe-to-fail environment [1]. In recent years, NATO has been investigating the enhancement of wargaming with computer based simulation aids to support the human analysis of ever-increasing data sets [2] [5]. While this work has led to the identification of best practices in how to wargame with simulation-based capabilities, approaches to how best develop the simulation capabilities to support events have not yet been widely agreed upon [6].

Typical simulation development approaches, such as the Recommended Practice for Distributed Simulation Engineering and Execution Process (DSEEP) [7], encourage a staged approach to the development of simulation capabilities. Activities within DSEEP start with the identification of end user needs and objectives which are often linked to the need to model, understand and investigate a particular problem, system or specialised area within a structured set of research or engineering business processes [8] [9].

When developing simulation capabilities to support wargames, two development challenges are amplified when compared to traditional applications:

1. The need for a very wide group of users to interact with the simulation environment; in a wargame environment, users may span from knowledgeable and specialised subject matter experts to members of the general public. Despite the fact that the simulation environment designers will not know the players before the game starts, all players must all be able to obtain a benefit from interacting with the simulation environment.

2. The need for the simulation environment to seamlessly integrate with the information flow of the wargame event; a vital aspect of the wargame event is to encourage the players to understand, discuss and debate the wargame subject matter. The use of a simulation environment must not interfere, disrupt or distract from this core task.

Due to the additional emphasis on the human and integration aspects, traditional simulation development frameworks such as DSEEP must be augmented or replaced to support the creation of a wargame synthetic environment [10].

3 A development framework for M&S-based wargames

To address the current lack of a reusable framework to support the development of wargame simulation environments, the authors of this paper have designed, implemented and tested a comprehensive framework in recent years. An overview of the resulting framework, comprised of parallel and incremental gameplay, human and technology development streams, is presented in Figure 1 and described in the remainder of this paper.

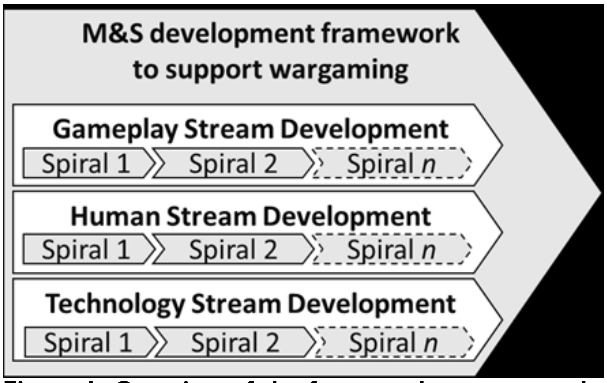

Figure 1: Overview of the framework to support the development of simulation application to support wargaming

3.1 The Gameplay Stream

Gameplay is a core element in the design of any wargame, creating an environment in which players remain informed, motivated and engaged. Development activities within the gameplay stream relate to supporting and enhancing the wargame's information flow, gamification and user interactions.

The design of the wargame's simulation capabilities information flow forms a foundational starting point for all of the required development activities, typically focussing on three key gameplay stream elements;

1) Presenting background information behind the challenge, setting the scene and allowing players to make choice that they believe will improve the situation.

2) Using simulation to further communicate the impact of the player's choices and generate data based on the new situation.

3) Present information generated by the simulation data to allow players to investigate the effects of their choices, understand their current game score and, ultimately, be better informed in the next iteration of the game and beat their current score.

Understanding these three typical gameplay elements and the information flow among them is a vital area of knowledge that need to be clearly defined in order to support the development of the remaining simulation capability streams.

3.2 The Human Stream

A truly fundamental aspect of any wargame are the players that will contribute to it. The central value of a wargame is in effectively eliciting and capturing knowledge and ideas from a diverse range of player types. Specifically, development activities within the human stream focuses on understanding key stakeholders, attendees and optimising their roles.

The design of information presentation and interaction capabilities within the simulation environment can again be considered in three key elemental areas;

1) What information is to be presented to, and elicited from, the wargame players? This element considers aspects such as, should a facilitator lead the players through the event or should the progression through the wargame be fully player-led.

2) When the information is to be presented and elicited? Wargame events can often present players with large quantities of information, that may not be in the player's normal field of expertise, in a short space of time. Development activities in this area may wish to consider the timing of information delivery and the importance of discussion or reflection time.

3) How the information should be presented to, and elicited from, the players? The background, experience and role that each player is used to may vary greatly throughout a diverse range of players in a single wargame event. Development activities should consider how to maximise the effectiveness of each player interaction with the simulation

capability by always presenting information in a format or style that's intuitive to each player group.

Consideration each of these human elements throughout the development of the simulation capability is vital to the engagement, contribution and value of each player in the wargame event.

3.3 The Technology Stream

Whereas a common route in integrating simulation environments into wargames begins with a focus on the technical aspects [11] [12], the proposed framework addresses the technology stream as a final development area that allows the creation of M&S-based software and services to augment, support and facilitate the wargame events. Specific development elements that are typically considered as part of the technology stream include:

1) Standards-based architectures and interfaces allow simulators and other synthetic environment toolsets to be rapidly expanded, reconfigured and reused as lessons from a series of wargame events are observed and learnt.

2) The use of immersive and interactive technologies allow the synthetic environment to support the wargame event to its full potential. These environments may allow players to interact with the wargame elements with a wide range of physical devices, from touch-screen phones and tablets to 3D augmented and virtual reality (AR/VR) systems.

3) The use of distributed and web-based approaches is a key enabler to increase participation reduce planning times for each wargame event. In addition to using these features to improve the quality of the wargame event, agile and distributed wargame events also supports the iterative development of the supporting simulation environment.

By implementing the designs developed to support the gameplay and human streams, the technology stream creates the configuration and debate tools, simulation environments and interactive data presentation toolsets required to validate the designs in each of the framework streams and, ultimately, support each wargame event.

3.4 The importance of incremental development

By design, multiple dependencies exist among each of the framework's three development streams as they progress in unison to augment wargaming with a comprehensive simulation capability. To manage these dependences, it is essential that the project's development activities maintain an agile and incremental approach to development. The incremental development spirals typically begin with minimum viable product (MVP) developments in each of the three framework streams that are trailed and tested in wargame events, allowing framework dependencies to be identified and incorporated into subsequent development spirals.

An additional goal may be to align the incremental development spirals with a longer term or multi-project roadmap of capability development, allowing the resulting simulation-based framework to be incrementally developed and refined over extended periods of time.

4 The application of the framework in DTEX to support DYMS22

To further illustrate and benchmark the development streams and elements described in section 3, their application to support a series of DTEX events in support of NATO's DYMS '22 exercise will be presented and discussed.

The NATO Innovation Hub developed DTEX as a tool aiming at test and assess new technologies and concepts in gamified settings [3]. In support of this, DTEX assesses the opportunities and challenges associated with emerging and disruptive technologies in a rapid and efficient way through the innovative use of simulation and open innovation. Typical inputs at the start of a DTEX are a problem statement and a set of potential solutions (usually sourced through open innovation techniques such as challenges, hackathons, etc.) The gamified DTEX events typically involve endusers and operators to make sure the ideas are evaluated by those who will actually use the new concepts and technologies in operations. DTEX events also include subject matter experts, students and others with diverse backgrounds to blend different ideas and approaches throughout the series of events. The value of a DTEX is the creation of a ranked list of technology solutions, as well as technology combinations, that is supported by the knowledge of how they solve the problem at hand. One line of DTEX investigation in 2022 is analysing the effectiveness of innovative and emerging autonomous systems technologies in maritime operations, as part of the 2022 NATO Dynamic Messenger (DYMS) exercise in Portugal.

DYMS 22 is a Joint Force Development Operational Experiment Exercise [13]. As part of this exercise, NATO operational communities are working together with partners from industry and academia to promote the operational integration of Maritime Unmanned Systems (MUS) into NATO operations through extensive experimentation. Live, multi-domain exercises will take place from 23rd to 30th September in the Portuguese North Atlantic exercise areas close to the Troia peninsular. Specifically, the DTEX will support the post DYMS 22 analysis of the naval mine warfare (NMW) MUS operations.

To support the post-DYMS NMW analysis activities, the DTEX project began its incremental development activities in the event's planning conferences, beginning in May 2022. In the first of these planning conferences, human stream development activities began with an interactive workshop with the DYMS NMW syndicate's end user community. With the aim of analysing the experiment's emerging and disruptive MUS technologies, the workshop allowed the DTEX project team to work with the end user community to identify the potential areas of value offered by a wargame event:

> DTEX Objective 1) Augmenting the DYMS scenarios with additional harsh, hostile and red-force features.
>
> DTEX Objective 2) Communicating the capabilities and limitations of MUStechnologies to non-MCM experts.
>
> DTEX Objective 3) Identifying how best to use MUS technologies (Inc. understanding their capabilities and limitations).
>
> DTEX Objective 4) Identifying architectural trade-offs in an environment free from external constrains.

A final value of the workshop in kicking off the human stream development activities was the identification of a shared, multi-community method of communicating with end-uses, subject matter experts and other DTEX stakeholder though the use of Key Performance Indicators (KPIs). The use of the existing DYMS KPIs throughout the DTEX project, provides a common, shared frame of reference spanning from the live DYMS trials with operational systems to each of the DTEX development streams and events.

The learning from this workshop initiated the development of the gameplay development stream. Three iterating wargame stages were matured and implemented, allowing players to review the problem space and configure an improved MUS architecture, before generating data that considered the effects of the architecture and, finally, analysing and exploring the outcomes. Technology stream development activities allowed the creation of an MVP to trial each of the required architectural blocks.

The first of these blocks was implemented in a webbased architecture, allowing players to explore the problem space in their own time, without the presence of a facilitator, and to use interactive, movable cards to select improvements to the existing DYMS MUS architectures. An example of this card-selection capability is provided in Figure 2.

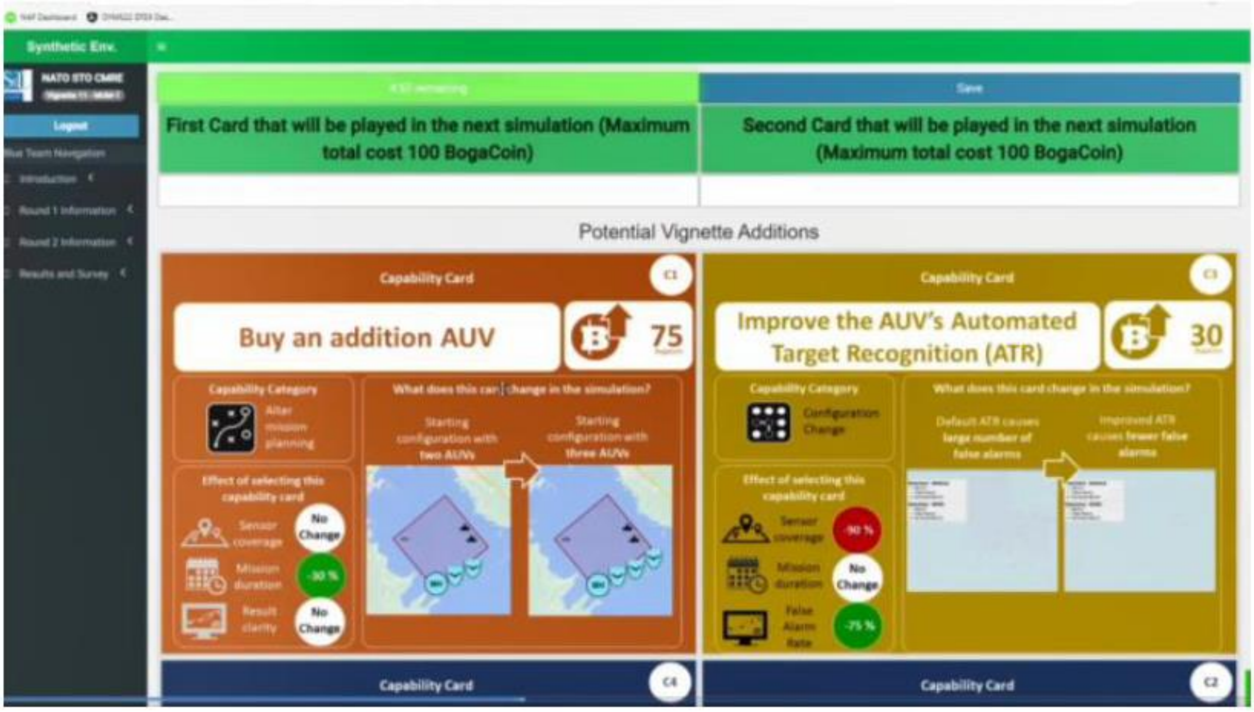

Figure 2: An MVP screenshot of the card-based interactive technology selection toolset

To improve the interaction with a wide range of users, required to address DTEX Objective 2, the user interface was designed in line with guidance contained in NATO's Architectural Framework (NAF) specifications [14]. Within these NAF specifications, varying viewpoints have been developed in order to communicate effectively with stakeholders ranging from high-ranking senior officers, to technical partners and project delivery specialists. Tailored viewpoints are provided to each community group depending upon information obtained from their route into the toolset at login.

Once the players have understood the problem space and selected cards to make their first architectural modifications, a federated simulation capability, based on High Level Architecture (HLA) standard [15],is run to execute the mission with the new configuration and generate a selection-specific data set. A screenshot of the 2D and 3D viewers during the mission execution is shown in Figure 3.

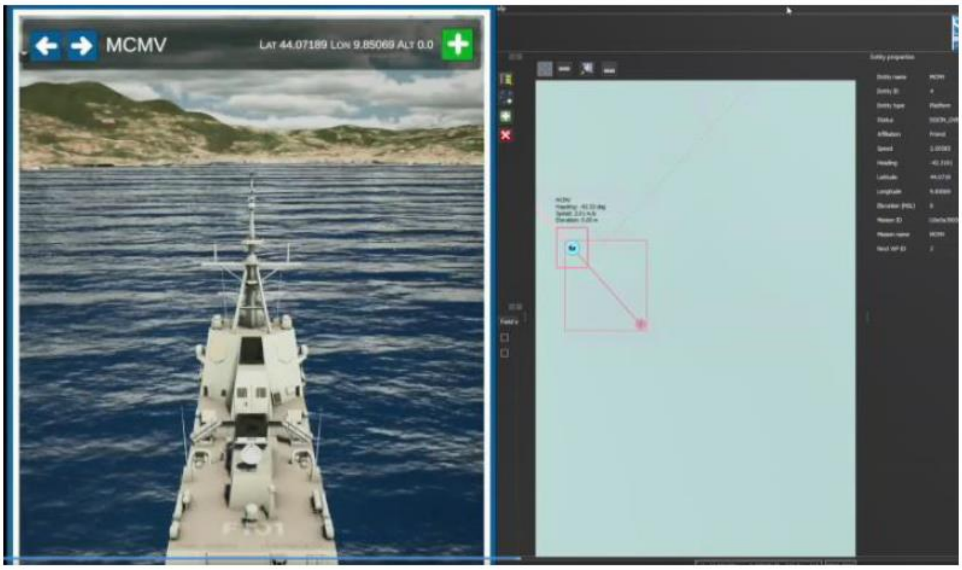

Figure 3: A screenshot showing the tools available to the wargame player during the execution of the mission with their bespoke MUS technology selection.

Due to the fact that the federation is implemented using the highly expandable and configurable HLA standard , previous simulator elements could be efficiently reused to support the DYMS missions and areas of interest required to address DTEX objectives 1, 3 and 4. The data created by the federation of simulators was logged and saved for further processing.

The simulation data generated by the player's execution of the mission with their bespoke MUS technology configuration was processed and presented in the final gameplay development area, a KPI and data visualizer, with a typical view shown in Figure 4.

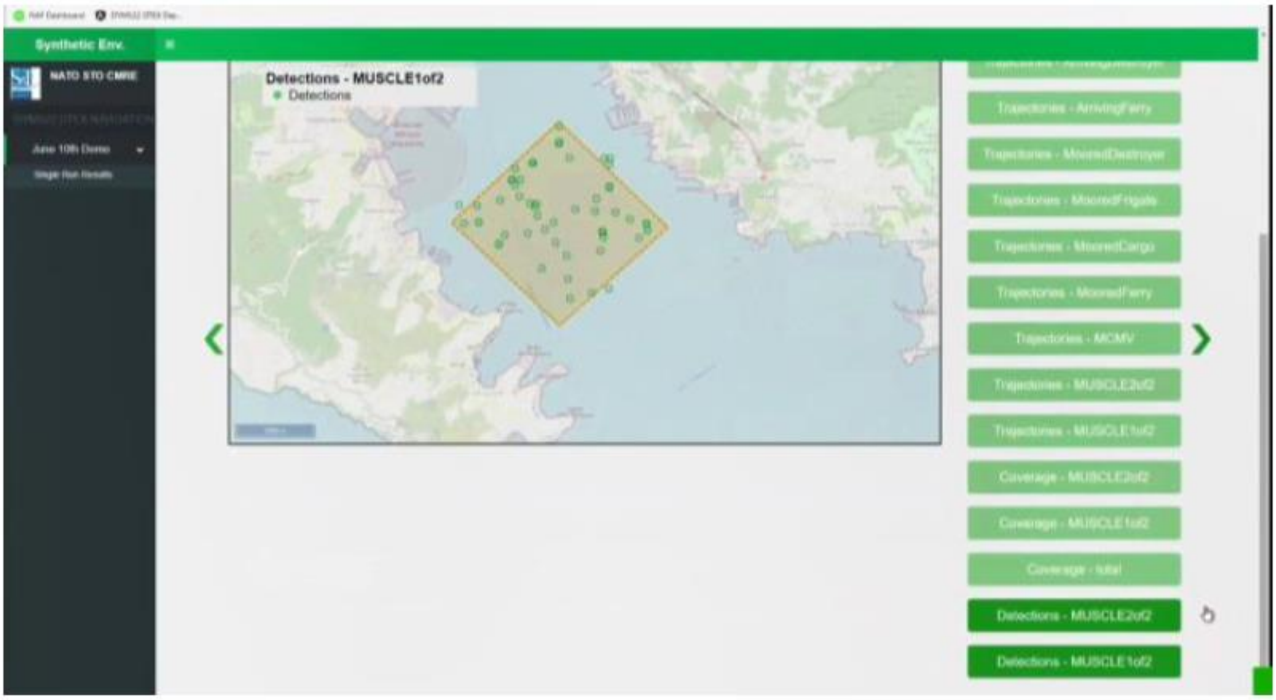

Figure 4: A screenshot showing a map-based analysis of MUS system performance in the data visualizer toolset.

Like the NAF-based configuration tools that allowed the player to explore and configure the mission's MUS technologies, the Data Visualizer toolset is implemented within in a distributed, web-based architecture.

The initial presentation of the data is very closely aligned to the views and methodologies that the end-user communities use to assess the live trial KPIs. This similarity allows the players to immediately understand the context of the data collected and to gain confidence in the simulated technology performances. In addition, the Data Visualizer contains views that allow the simulation generated KPIs to be directly compared to and overlaid onto the results obtained in the DYMS live trials, again allowing an intuitive assessment of their architectural choices to be made. Beyond the high level KPI metrics, the interactive browser-based views allow players to investigate the data in more detail, visualising and investigating layer views in their own time and without the interference of a wargame facilitator or strict time constraints.

Once the player has passed through the technology selection, simulation and data analysis stages, their high level KPI metrics provide them with a 'score' to beat. The player is then encouraged to repeat all three stages multiple times, building up knowledge of the MUS technologies and experimenting with ways to better apply and combine them to improve their score in a gamified setting. Throughout the event, links to on-line feedback forms allow the DTEX project team to develop an understanding of when, how and why the MUS technologies are being selected and combined by the players to address the challenge, providing valuable outputs from the complete DTEX event.

Due to the rapid development of this complete standards-based wargame synthetic environment, it was possible to increase the tempo of the incremental development activities and hold an online and distributed trial event to be held a few weeks after holding the initial human stream development workshop. This short online event provided a series of observations and lessons in all three of the development framework streams that were implemented before the next scheduled test event, again proving the vital importance of agile and incremental development during the development of a synthetic wargame environment.

5 Conclusions and the future of DTEX

This paper presents a development framework that, by focusing on iterative development across the gameplay, human and technology streams, allows simulation capabilities effectively structure and augment wargaming events. To illustrate the effectiveness of the framework in a complex and demanding series of wargame events, this paper presented the application of the framework to develop a first MVP in support of the DTEX project's DYMS 22 activities. Further development activities will progress the development of all three development areas in support of a post-DYMS DTEX event later in 2022.

Beyond DYMS22, future developments within the DTEX project will focus on increasing the distributed nature of the simulation environment, moving to a cloud-based collection of wargaming services to future DTEX project areas.

This activity, by increasing the availability of the synthetic wargaming environment, is expected to result in the ability for M&S methodologies to support an ever wider range of wargame events, allowing more rapid configuration and a wider range of involved players.

This roadmap to a future M&S-based synthetic wargaming environment is expected to further stress, evolve and progress the maturity of the development framework presented in this paper, resulting in a truly versatile, reusable and future-proofed framework that will be available to support the valuable M&S augmentation of future wargame events in NATO.

Innovative Computer Vision Techniques for Person Reidentification

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Abstract

The Decision Support Systems, originally based on a priori knowledge and operational research models, are moving toward the use of data-driven approaches, developed through machine learning techniques. The performance of such systems is thus proportional to the volume of available data and the ability to collect it in real-time to make early decisions. However, a common issue in DSS lies in a restricted vision of the ordinary world complexity: each system specializes in a particular area of interest, processing its own domain of data, and is unlikely to exchange valuable insights with other components. In this paper, a holistic approach to the problem is introduced, where several computer vision models, each having different scopes, are applied on-edge to video streams from both standard fixed cameras and moving devices, to interpret a massive amount of data and give a complete understanding of what is happening in a given environment, on a real-time perspective. To achieve this, computer vision models need to operate in at least three domains: the detection of people and their re-identification through different cameras and contexts (People-Focused); the analysis of objects, infrastructures, and their surroundings (Things-Focused); the identification of specific events or behaviors performed by people (Actions-Focused). A single, high-reliability central system receives, interprets data and makes reasonable decisions. The paper illustrates three examples of models applied to the above areas, proving the importance of a multi-domain approach, and shows an innovative approach for reidentification in a multi-camera environment, with different lighting, points of view, and overall conditions.

1 Introduction

A Decision Support System (DSS) is a software used to support organization's or company's decisions, judgments, and lines of action. A DSS processes and analyses huge amounts of data, producing comprehensive information that can be used to solve problems and make decisions. The corrective actions to be taken can be fully automated or may require human supervision, especially in critical scenarios.

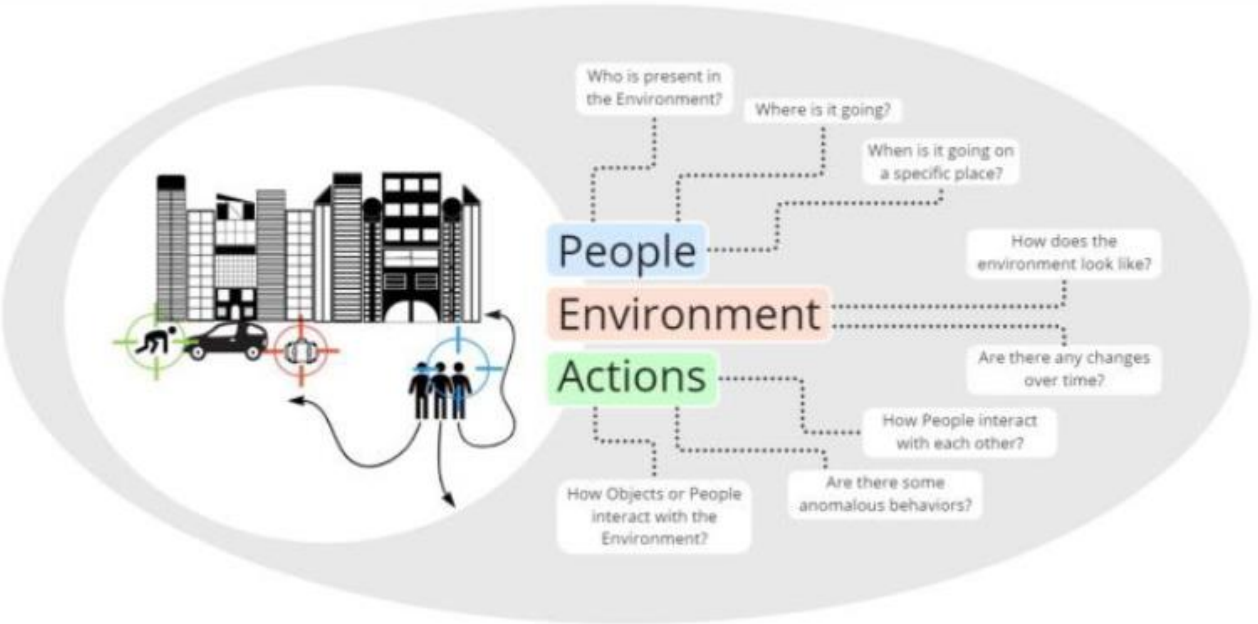

Figure 1: the three domains of operation.

The data collected by a DSS could be of several types and depend on the area of application. For example, a DSS that optimizes road congestion by adjusting traffic light timings will certainly require real-time data from sensors at each crossroads; a DSS that supports marketing decisions will probably need data from social media, or from each customer's purchases. In many cases, this means structured data ready to be processed.

In this paper, the use of Computer Vision and Artificial Intelligence is introduced as a way to extend the data domain to video cameras. This requires artificial intelligence models that perform image understanding and extraction of structured data to be fed to the DSS. In addition, three primary scopes are identified: the monitoring of people and their paths, the monitoring of human behaviors, and the monitoring of the local environment. Each of these areas is developed using different deep learning architectures and helps to achieve a more complete insight into what is happening in a given scenario.

2 Approaches and Methods

The following section provides a discussion of the technologies and methods used to develop three AI models related to the above-mentioned areas. In this article aspects like: the device hardware, the Edge Computing paradigm and the platform data processing algorithms, will be treated, with a special focus on the first use case dealing with people tracing.

2.1 Hardware Specification

Traditionally, an infrastructure that collects data from IoT sensors or receives video streams from a network of cameras consists of a central platform where all this data is gathered and processed to generate statistics, alerts, notifications, etc. With the development of increasingly efficient, small, low-power and high-performance chipsets, this traditional approach is moving towards the paradigm of Edge Computing. Edge computing means that data processing is moved as far as possible to the place where the data itself is produced. This makes it possible to parallelize the workload directly on the sensors' devices. The central platform in this case only takes care of data aggregation and visualization. This paradigm also makes it possible to scale up the number of devices without having to carry out massive changes to the platform configuration and resources [*Fig.2*].

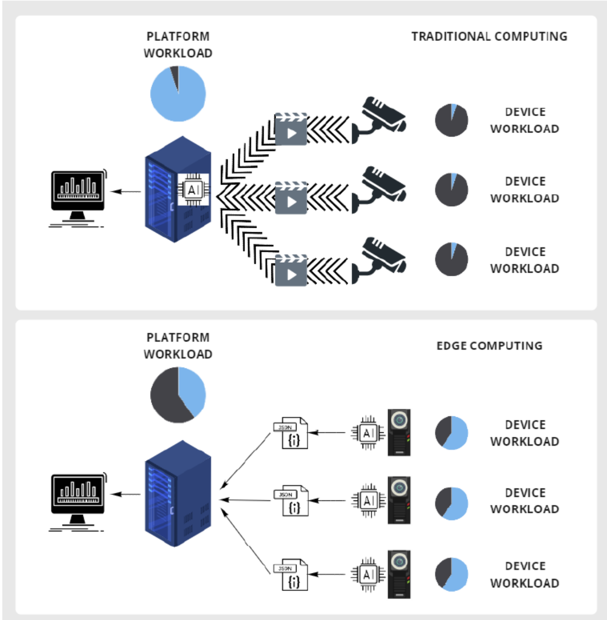

Figure 2: Traditional computing (above) versus Edge computing (below), in terms of devices and platform workloads.

Getting to the matter of video streams, a device that operates in edge computing must have all the requirements to be able to perform Computer Vision models in real-time on the images captured by the camera, and send the results to the platform. For this reason, a specific device that includes all these requirements has been developed and can be used either as a stationary outdoor or indoor camera, as well as a dynamic camera (e.g., car dashcams).

The assembled device consists of several hardware components [*Fig.3*] that perform different tasks. First, there is a main board featuring a Quad core Cortex- A72 (ARM v8) 64-bit SoC @ 1.5GHz, 8GB LPDDR4-3200 SDRAM, 5.0 GHz IEEE 802.11ac wireless, Bluetooth 5.0, BLE Gigabit Ethernet, 2 USB 3.0 ports; 2 USB 2.0 ports, 40 pin GPIO header, 2 × micro-HDMI ports, 2-lane MIPI DSI display port, 2-lane MIPI CSI camera port, Micro-SD card slot for loading operating system and data storage and 5V DC via USB-C connector. The connection to the mobile network is provided by an LTE module including LTE antenna and GPS for localization. An important requirement is the presence of an integrated camera with adjustable lenses, featuring 8 megapixels, V4L2 driver availability, 3.68 x 2.76 mm (4.6 mm diagonal) of sensor image area, 3.04 mm focal length, 62.2 degrees of horizontal FoV and 48.8 degrees of vertical FoV. To complete the unit there is a TPU (tensor processing unit) accelerator designed for rapid execution of AI Tensorflow Lite model inference, an audio buzzer and a notification LED.

It has to be said that the core of the computation is the TPU, which speeds up the execution of models on a frame-by-frame approach by a factor of more than 100 times compared to the CPU. Without the TPU unit, real-time processing would not be possible at all.

Figure 3: Device hardware components.

2.2 Deep Learning Architectures

All Deep Learning models, whether they deal with images or other types of structured or unstructured data, consist of a set of linked layers containing the basic elements of computation, i.e., neurons. The layers process the input and define the output of the model. Depending on the type of task to be performed, there is a wide range of different types of layers: convolutional, recurrent, pooling, signal concatenation, fully connected, and many others. A given model is then built by putting these layers together one by one until the overall architecture of the model is created. For the three use cases the paper deals with, three core architectures are identified upon which the AI models are trained: the object detection architecture (which includes the well-known SSD 1] MobilnetV2 [2] and YOLOv5 [3]), the image classification architecture (specifically MobilenetV2 [2] and ResNet50 [4]) and the person embedding architecture (OSNet [5]).

Each of these models has several variations that may be better or worse in terms of performance and computing speed depending on different scenarios.

When it is necessary to identify and locate objects or people within an image, the principal architecture used is the Object Detection one. A schematic representation is shown in the figure below [Fig.4].

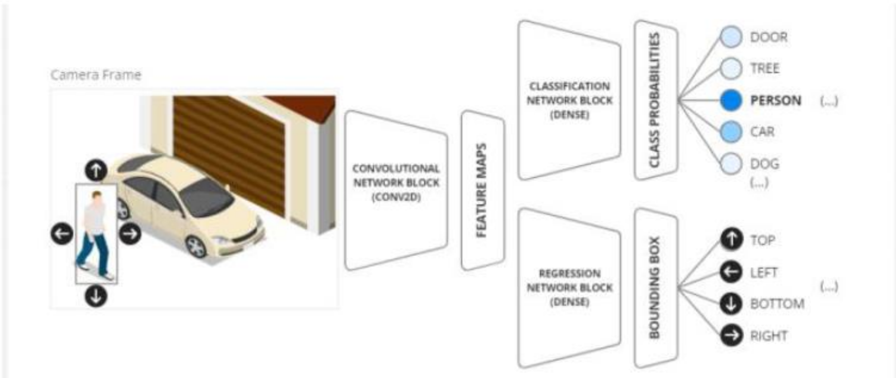

Figure 4: Object Detection Architecture Logics. Multi outputs for classification scores and bounding boxes coordinates.

The model network receives a camera frame as input and outputs the following results: a classification score that denotes the type of each detected item and a list of coordinates that locate each detected object within the frame. The coordinates are in the form of bounding boxes with top-left corner pixel height/width and bottom-right corner pixel height/width.

In the case of action recognition, it is important to not only classify each static frame or person capture, but also to consider the entire sequence of motion. Indeed, an action or behavior takes place during a specific period of time and submitting only one image to the model at a specific time could lead to misleading and erroneous results. For this reason, the model network differs from standard classification (with only convolutional layers) by adding a time-dependent component with the use of recurrent layers such as LSTM (Long-Short term memory units [6]). An example of architecture is shown in the following image [*Fig.5*].

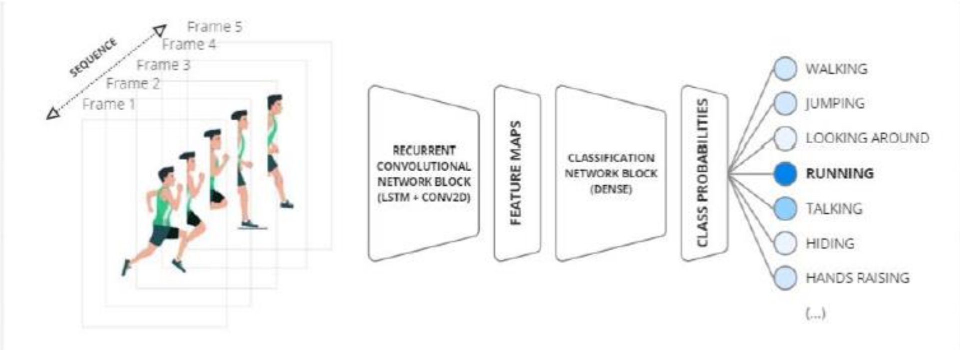

Figure 5: Action Recognition Architecture Logics. Both visual and temporal features affect the output.

The model takes a sequence of frames as input and outputs a classification probability related to the actions or behavior that the model was trained on. Inside the network an LSTM+CONV approach captures all useful time-dependent features to predict the correct class.

Finally, for the purpose of people reidentification, it is necessary to build an architecture that could convert people images into embeddings. An embedding is a compressed, encrypted and low-dimensional representation of a high-dimensional data (such as a person image) that preserves the most important information about the original data. In this case, a person embedding is a vector made of 512 floating points containing information about person appearance, visual features, colors and clothes, except for biometric information that are often not allowed.

Embeddings can be interpreted as points in a 512-dimensional Euclidean space and have the particular property of falling close together when belonging to the same person (even captured in different context and light conditions). Further algorithms make possible to cluster these embeddings and identify each observed identity in order to track people across different cameras and environments. In the following image [*Fig.6*] an example of the embedding model architecture is shown.

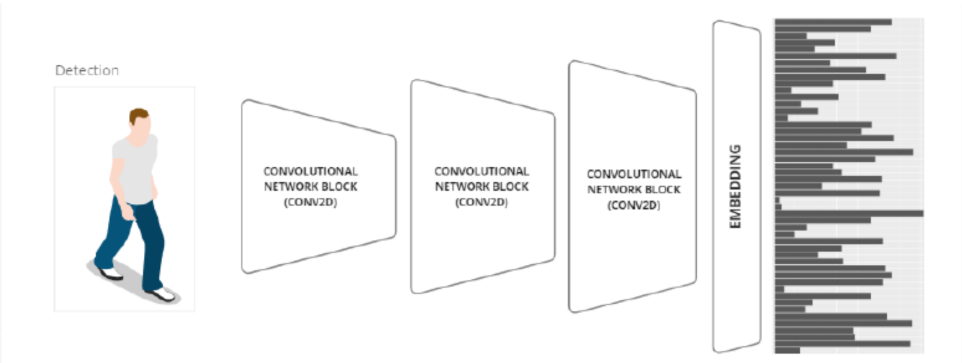

Figure 6: Embedding Architecture Logics. Image is turned into a vector where the most of important visual features are compressed.

The next paragraphs will detail the processing pipelines of the three use cases and the use of the above-mentioned architectures.

2.3 Person Reidentification and Tracking

Current State-of-the-art models in person reidentification tasks have been shown an increasing performance in the last few years. Much of the initial effort has been put on collecting studies and brainstorming on how to develop the reidentification system. Indeed, most of the works focus on pure tracking-based systems or pure appearance-based systems with a particular focus on high performance rather than lightweight and real-time-ready models [7] [8] [9] [10]. One of the main requirements of our edge case is to develop a model that can be deployed on low-energy devices and limited resources. On the other hand, the performance must be high enough to ensure that reidentification takes place.

The pipeline consists of three stages: the people detection frame-by-frame, the person embedding and the clustering algorithm for identities retrieval and path reconstruction.

The AI model that detects people (first stage) within the image consists of a convolutional network of type SSD MobilenetV2 or YoloV5-s. The choice of these architectures is driven mainly by the high ratio between the accuracy of the detection and the complexity of the models, which makes them suitable in real time, where a much more complex model would require prohibitive calculation times for the frame rate of the camera. The following figure [*Fig.7*] shows the first stage of people detection, applied to all frames retrieved by the camera.

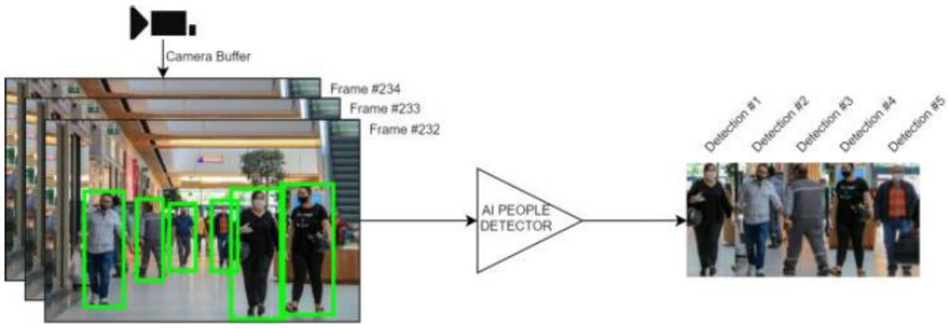

Figure 7: Person Detection Inputs (left) and Outputs (right).

During the inference, the Tensorflow Lite runtime performs all the model layers operations on accelerated support (Coral Edge TPU), turning the input (RGB frame) into output (list of detected items) with the following attributes: index of the detected class (in this case 0: "Person"), confidence (confidence percentage of the detection), top left bottom right (the coordinates of the bounding box expressed in pixels of the image). The following features are then stored for each identified person: frame timestamp, source device, confidence, bounding box coordinates [top, left, bottom, right] and the image of the subject cropped from the original RGB frame. The extracted information is then sent to the embedder, which will analyse the images to extract the embedding vector in asynchronous mode.

The Embedder (second stage) is the most important model of the reidentification system. The AI model that extracts the embedding is a convolutional network based on an architecture called OSNet (Omni-Scale Network) [5]. In the following image [Fig.8] a brief summary of what the person embedding model does.

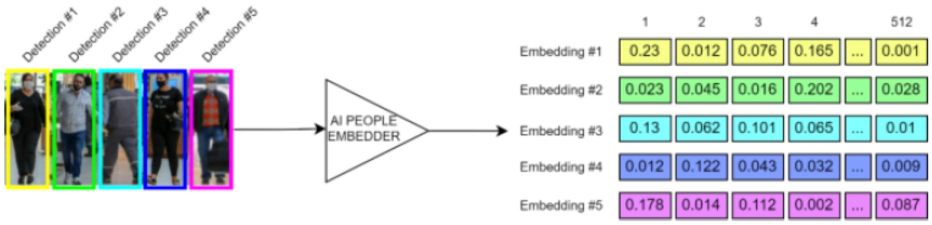

Figure 8: Embedding model inputs (left) and outputs (right).

The model was trained on a pool of datasets of people under a variety of environmental conditions (e.g., indoor cameras, outdoor cameras, different resolutions and lighting conditions) [17] [18] [19]. The peculiarity of this architecture is based on 2 main factors: the first one is the ability to learn and capture the subject's visual features on multiple different scales, i.e., from the particular ones (e.g., logo of a t-shirt) to the global ones (e.g., Silhouette), this is the reason behind the name “Omni-Scale”; the second and equally important factor is the small size of the network that makes it suitable for real time use.

The Identity Matching (third and last stage) algorithm is executed on platform side on all stored data (embeddings and metadata) over a certain period of time. It scans the embeddings and performs the matching of all detections belonging to the same identity. The developed algorithm uses two Machine Learning techniques in the field of unsupervised learning to achieve two specific goals: the first one is to reduce the number of embedding features from 512 to 3, operating a transformation that preserves the distances between different embeddings; the second one is to assign different IDs to groups of embeddings that are close to each other.

In technical words, a dimensionality reduction is performed by using the UMAP [11] algorithm and a density-based clustering using DBSCAN [12]. Therefore, processing the data coming from all the devices, we obtain tags that we are going to call "person_id" which, for each detection, provide the unique identifier of the detected person.

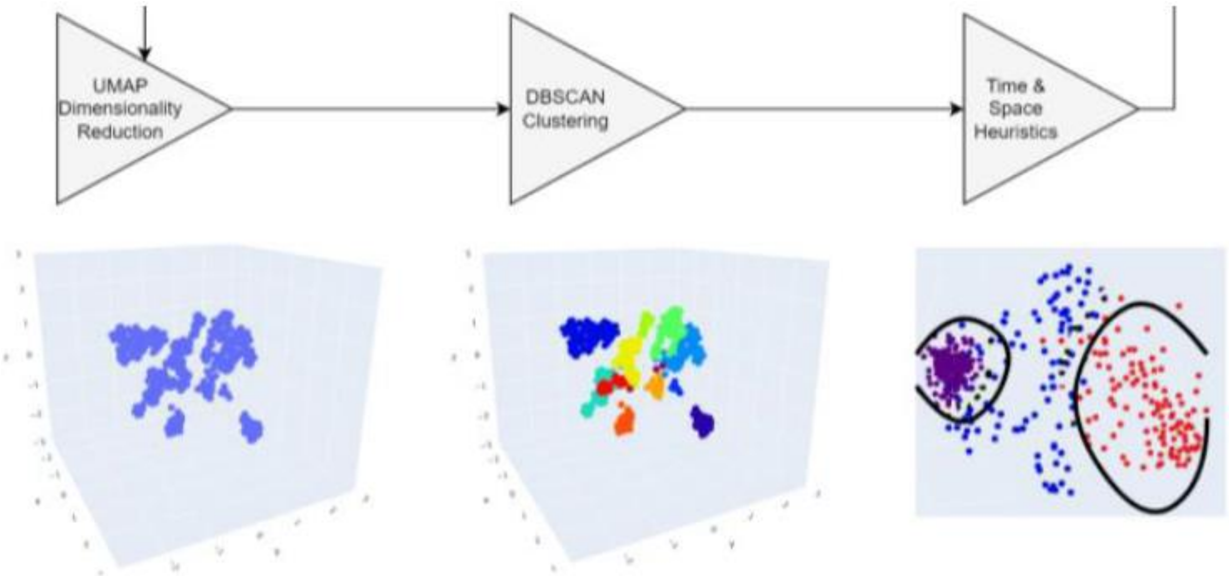

Figure 9: The process of matching algorithm. From left to right: dimensionality reduction of the embeddings, clustering and heuristics application for error reduction.

Further techniques are then applied downstream to enhance the clustering process by considering heuristics related to time and space [Fig.9].

At the end of the pipeline, all detections and identities are projected back to the original frames, providing a walking path for each person across all the different cameras. In this way, one could determine the places visited by each person in the scene [*Fig.10*] and make powerful analytics or trigger alarms in case of unusual patterns.

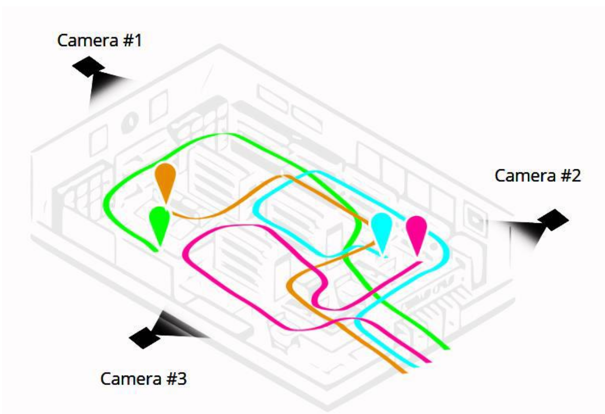

Figure 10: Paths reconstruction from embeddings metadata and Person IDs.

2.4 Actions and Behaviours Detection

The second use case is related to Human Behaviors monitoring. The proposed AI model aims to detect unsafe and improper behaviors by distracted drivers. The device must be placed inside the car on the right-hand side pillar of the windshield (on the opposite side facing the driver). The orientation must be adjusted to perfectly frame the driving subject: adherence and inclination are possible thanks to a specific support, equipped with vacuum cups and joints.

The proposed AI model aims to identify ten classes of action: talking to the phone - left/right ear, texting - left/right hand, talking to the passenger, operating the radio, hair fixing and makeup, reaching behind, drinking, and safe driving. It consists of a recurrent convolutional network with a MobileNetV2 [2] backbone architecture. The network takes multiple frames as input [*Fig.11*] and outputs a class probability for each action.

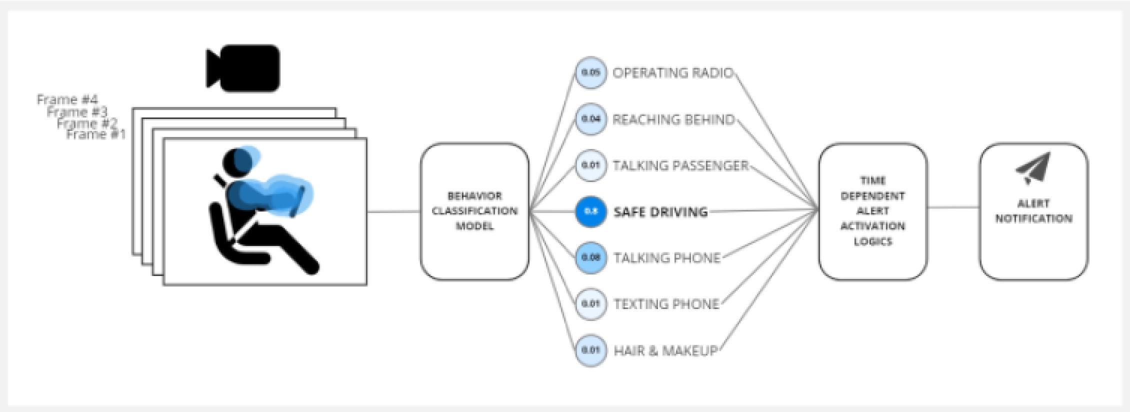

Figure 11: Distracted Drivers Detection Pipeline.

After the inference phase, the result is a frame-by-frame history of the probabilities of each class of action. Basically, the model provides a prediction for each specific instant of time T: it is necessary to turn this data into what are known as Alert Events. An Alert Event has a beginning timestamp and an end timestamp and covers the time slot in which the probability of a particular class dominates over the neutral class (safe driving). For example, an Alert may begin when the driver answers a mobile phone call, and it finishes when the driver ends the call.

In order to catch all these events, a specific processing module applies moving average to output data (this makes the signal more stable), user defines a threshold value for alert activation and the module generates all the events with related metadata, sending them to the platform. The metadata includes: device ID, startTime, endTime, time length, detected class, probability associated to detected class and GPS coordinates. In the following figure [Fig.12] the Alert generation process is shown.

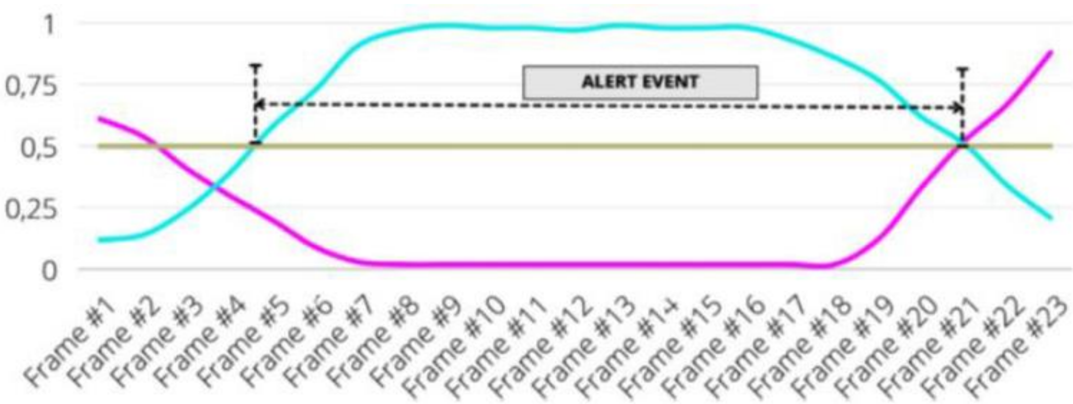

Figure 12: Alert Event Generation process.

2.5 Environment Awareness and Anomaly Detection

The third use case is related to Environment monitoring and the proposed AI model aims to estimate the maintenance status of the road surface, detecting all possible types of damages. This is just an example of environmental models which can range from monitoring infrastructure to detecting anomalies such as unattended or unusual objects in the monitored environment. Here the device is placed inside the car on the rear-view mirror, with the camera pointing outwards. During the journey, it acquires images from the camera and extracts information regarding potholes, cracks and lines, enabling their geographical localization [*Fig.13*] and estimating their severity.

The AI model that detects potholes, cracks and lines within the image consists of a convolutional network of the same type for person reidentification task: SSD MobilenetV2 [2] or YoloV5s [3]. The difference lies in the network training, based on pothole and pavement defects pictures.

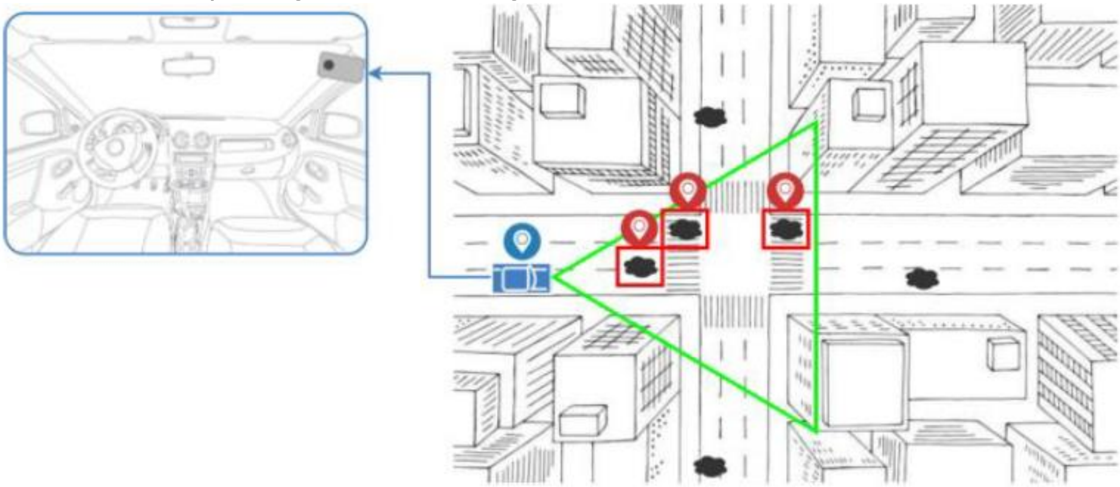

Figure 13: Potholes Detection System: Edge AI model detects potholes and tags them with GPS info.

During the inference, the Tensorflow Lite runtime performs all the model layers operations on accelerated support (Coral Edge TPU), turning the input (RGB frame) into output (list of detected items) with the following attributes: index of the detected class (in this case 0/1/2: which means "Pothole", "Crack" or "Lines"), confidence (confidence percentage of the detection), top left bottom right (the coordinates of the bounding box expressed in pixels of the image) [*Fig.14*].

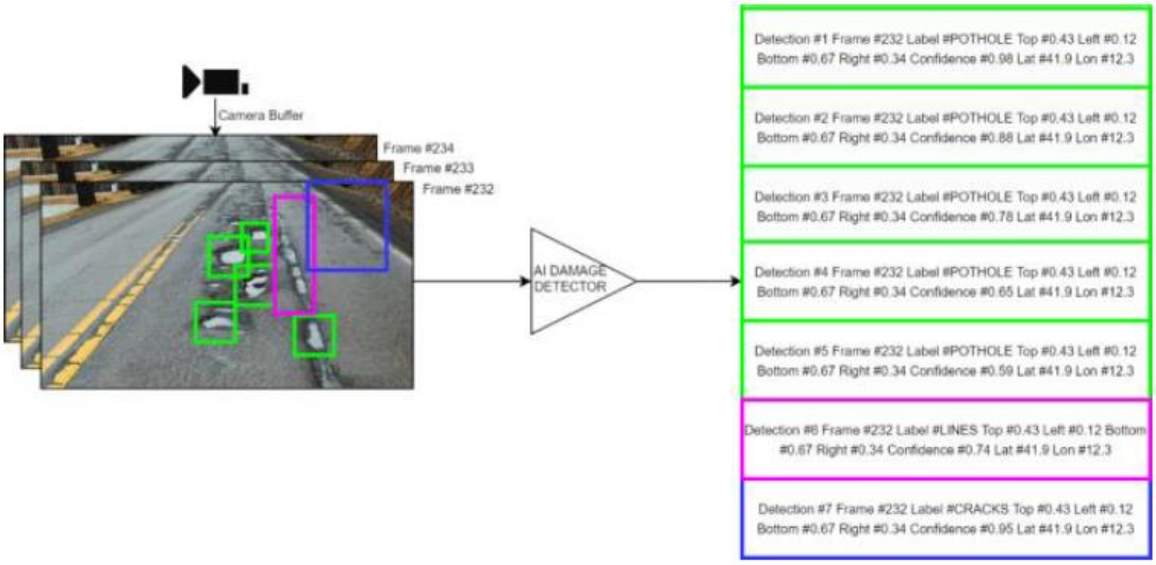

Figure 14: Asphalt defeats detections and their metadata.

During the detection, a numerical algorithm estimates the severity and magnitude of the damage. This algorithm takes into account the size of the bounding box, the elevation of the camera from the road surface, the optical parameters of the lens, the orientation angles of the device [*Fig.15*], in order to determine the distance between camera and target and the actual area in meters covered by the damage.

Finally, an additional tracker [13] assigns a unique ID to each detected defect over the frames in order to avoid multiple alerts for the same target [*Fig.16*]. Estimated data on location and severity of damage are aggregated by tracking ID, suppressing any measurement errors and making more robust results.

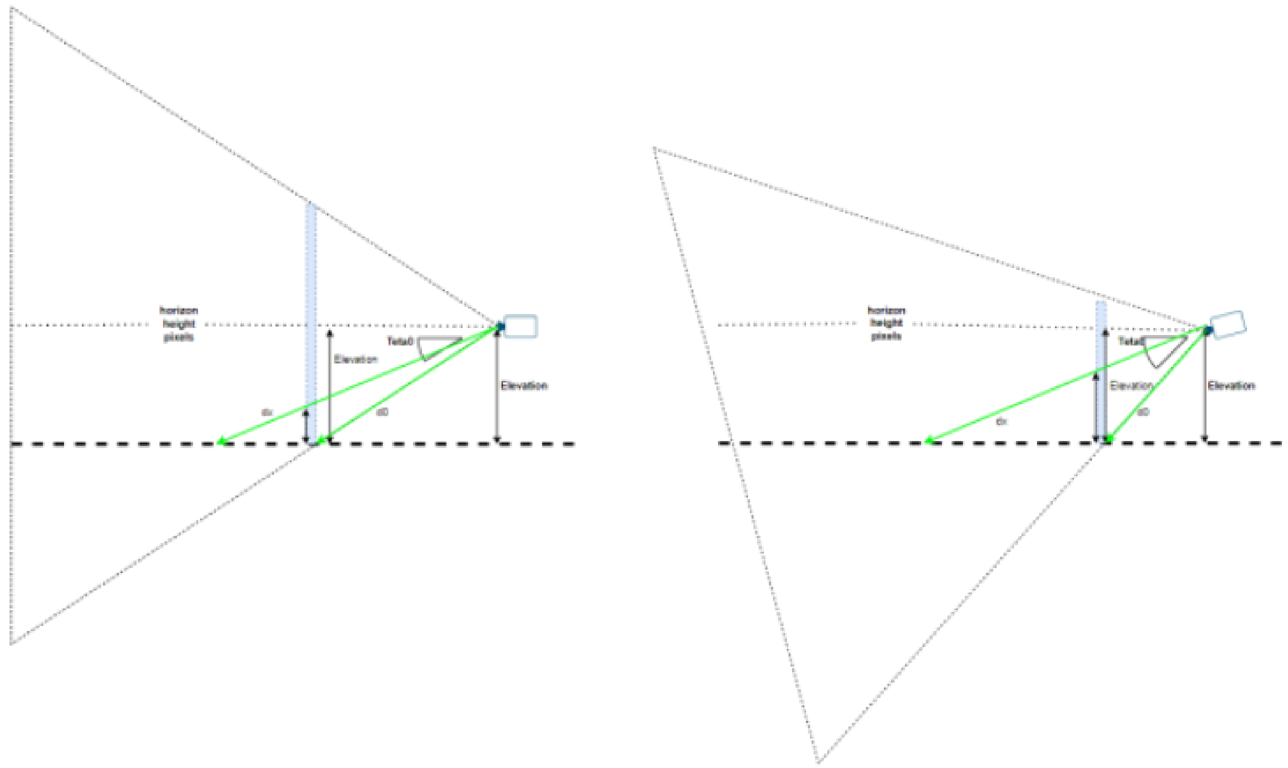

Figure 15: Target size estimation scheme based on camera intrinsic parameters and relative attitude with respect to the asphalt.

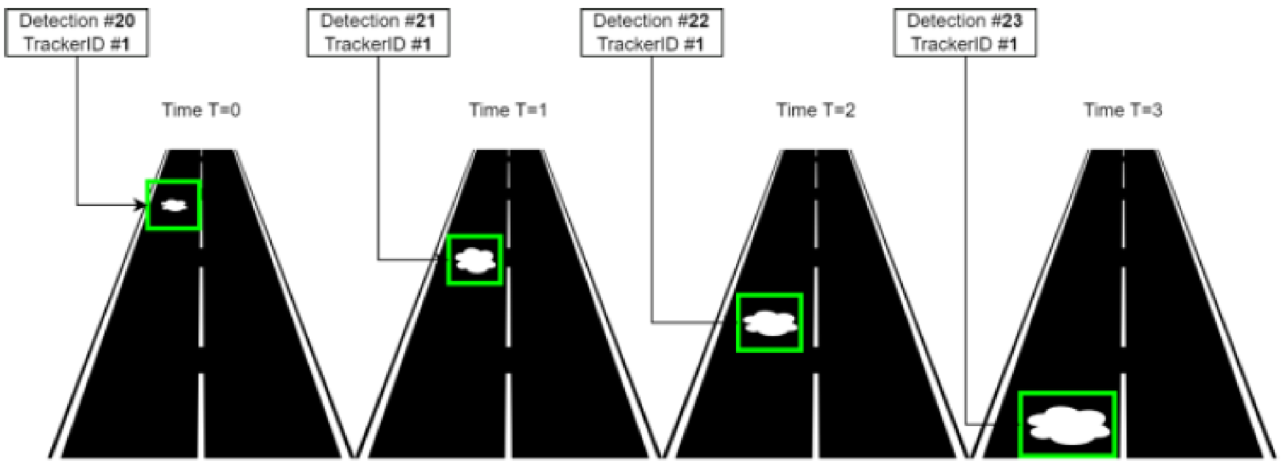

Figure 16: Tracking system logics to avoid multiple detections of the same instance.

3 Experiments and Results

3.1 Person Reidentification and Tracking

The evaluation of the person reidentification performance of the first use case was performed through the acquisition of four videos. Four cameras were placed inside and outside a service area for a total duration of 15 minutes of footage. The videos capture a significant number of people passing and standing in front of each camera. The same people are framed in two or more cameras at different times. The aim is to test the accuracy of both the people detection model and the embedding model and consequently the identity matching algorithm across different cameras and contexts.

Extensive manual labelling was applied to the four videos. This activity consists of creating bounding boxes – frame by frame - containing persons and assigning to each box a unique ID related to the individual identity. These two annotations are needed to obtain a reference (ground truth) for both detection and re-identification tasks.

The next procedure is to separately submit the videos to the AI person detection model and obtain the predicted bounding boxes: through the calculation of specific metrics (mAP-0.5-0.9, Precision, Recall [14]) which consider ground truth and predictions, it is possible to determine how accurate the model is in detecting persons within the frames. The results of detection are briefly shown in [*Tab.1*], with multicamera and single camera analysis.

	COCO mAP@0.5-0.9
Camera 1 (indoor)	0.407
Camera 2 (indoor)	0.392
Camera 3 (outdoor)	0.122
Camera 4 (indoor)	0.446
Multicamera	0.358

Table 1: Person Detection Performance.

The overall performance is very good, also considering the inference speed of 30 fps for each camera. The camera that suffers the most is the outdoor one where the people result to be much smaller causing the loss of some detections. A general inspection, however, confirms that all identities have been detected at least once.

After testing the detector, the next step is the validation of person matching. For this purpose, the cropped images are submitted to the embedding model to generate the embeddings. At the end of the procedure, the images are deleted and the embeddings as well as the metadata are processed by the person matching algorithm, which aims to identify the number of unique identities detected by the cameras and assign a unique ID to each detection belonging to the same person.

In order to measure how accurate the algorithm is in recognizing identities and correctly assigning IDs, the Adjusted Rand Index (ARI) [15] metric is used: ARI is a metric that can range from 0 to 1 and establishes the percentage of overlap between the groups of IDs associated in the labelling phase (ground truth) and the groups of IDs generated by the algorithm. If the overlap is complete, the ARI will be 1, if the IDs are assigned in a completely random manner, the ARI will be 0. The ARI can be seen as the percentage of detections that are correctly associated with the same person. The results depend essentially on the quality of embeddings (see the paper about OSNet [5] for benchmarks) and the ability to efficiently group embeddings of the same person.

In the following table [*Tab.2*] the results of single camera and multicamera re-identification are shown.

	Adjusted Rand Score [ARI]
Camera 1 ARI	0.9339
Camera 2 ARI	0.8106
Camera 3 ARI	0.8322
Camera 4 ARI	0.9838
Multicamera ARI	0.9111

Table 2: Person Reid Performance with ARI index.

It can be clearly seen that the Identity Matcher algorithm performs very well on the four videos with an overall multicamera ARI of 0.91. This value means that almost the total real identities have been matched properly by the system on all cameras. This result reflects the reliability of the algorithm and its robustness to brightness changes, detection sizes and background conditions.

In the following figure [*Fig.17*], some examples of re-identification across different cameras are shown, with relative images.

Figure 17: Samples of clustered detections across different cameras based on embeddings. Each cluster correctly reflects people identities.

3.2 Distracted Drivers Behaviours

The distracted driver detection system is a system based on a classification AI model applied to all frame coming from the device's camera. Since it is a classification task, the metrics to measure performance are accuracy, precision and recall. Accuracy is the ratio of correctly classified images against the total images submitted to the model during testing. Precision indicates the ratio of true positives to the sum of true positives and false positives. Recall indicates the ratio of true positives to the sum of true positives and false negatives.

The validation process is made possible by the manual labelling of all the frames extracted by several short videos involving different people in different model cars. Each person performs all the ten classes of action including safe driving. The model outputs the classes probabilities for each frame. This distribution of probability is then compared to the ground truth, obtaining all the three previous metrics. The following table [*Tab.3*] shows the results.

	Results
Accuracy	92 %
Precision	94 %
Recall	87 %

Table 3: Distracted Drivers Detection Performance.

The following figure [*Fig.18*] shows a sample of test images with relative predictions, relative confidence and the heatmap of Gradient Convolution Activation Maps (GradCam) [16] highlighting the most important regions that activate each class.

3.3 Road Damages Detection

The Pothole Detection and Estimation system is made up of two main components: the detector and the estimator. The performance of the system is measured by using a potholes dataset consisting in a set of images with known bounding boxes. Therefore, it makes possible to compare ground truth boxes with predicted boxes and to get an overall performance index.

Dealing with detection task, the metrics used are the same as for the person detection module in Person Reidentification System: mAP (I.e., Mean

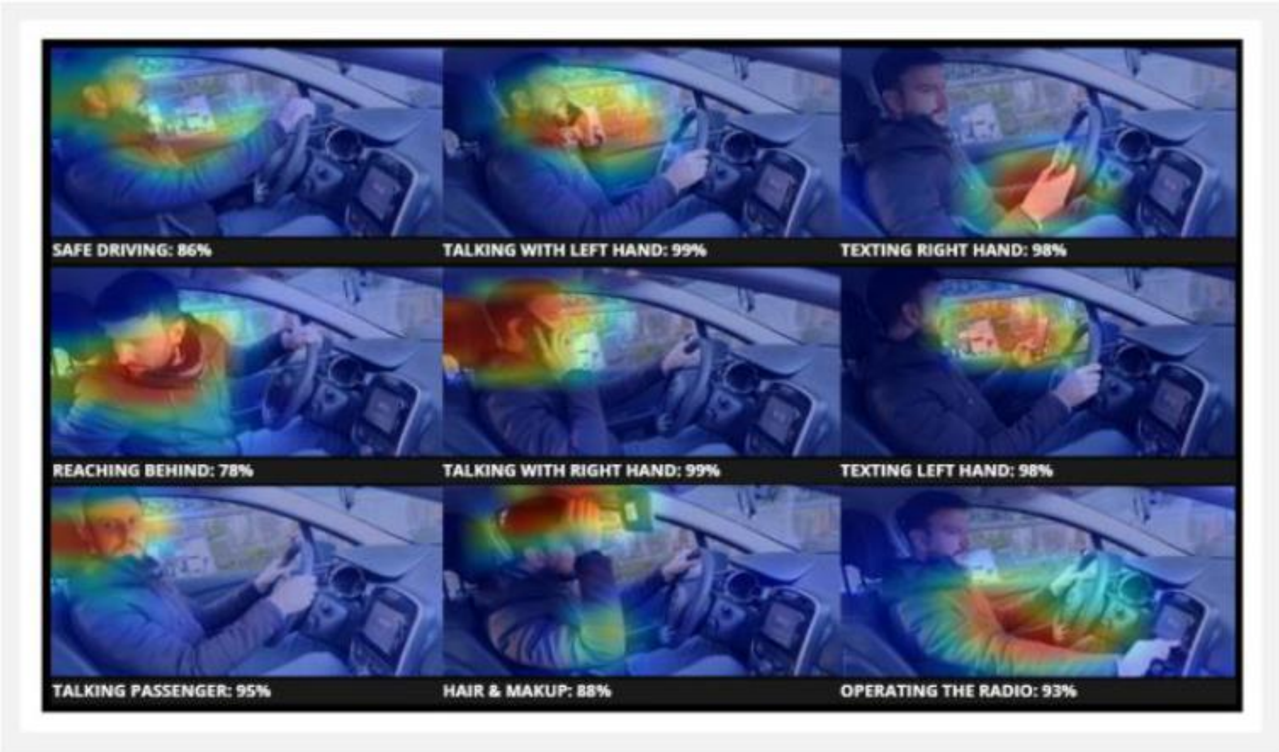

Figure 18: Applied GradCAM technique to predictions in order to obtain activation regions.

Average Precision) [14]. After feeding the system with all dataset images, the following table [*Tab.4*] summarizes the obtained results.

	Results
PASCAL VOC mAP@0.5	0.536
COCO mAP@0.5-0.95	0.414
mAP@IoU-0.5	0.563
mAP@IoU-0.55	0.538
mAP@IoU-0.6	0.506
mAP@IoU-0.65	0.480
mAP@IoU-0.7	0.454
mAP@IoU-0.75	0.433
mAP@IoU-0.8	0.402
mAP@IoU-0.85	0.365
mAP@IoU-0.9	0.286
mAP@IoU-0.95	0.110

The detection performance is high and reaches up to 73% of matched detection percentage with a mAP of about 0.56 at 0.5 IoU threshold. The number of detected potholes is larger than the ground truth so it means that the system is very sensitive but still could be improved by adding filtering algorithm in post-processing. The following figure [*Fig.19*] shows a sample of the test images with ground truth bounding boxes (yellow rectangles) vs. Predicted by the system (blue rectangles).

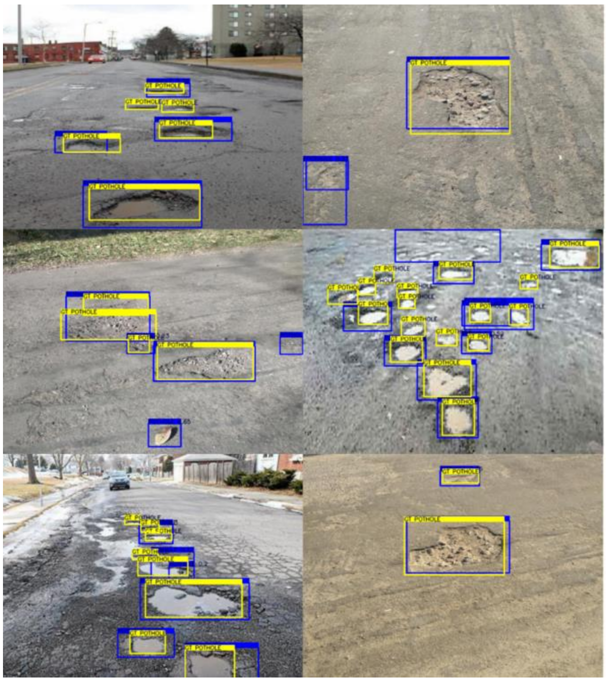

Figure 19: Sample of Detection results (blue boxes) versus Ground Truth (yellow boxes).

4 Discussion and Conclusion

In this paper, three applications of the three approaches people-focused, action-focused and things-focused were illustrated.

The person reidentification system shows high performance in terms of accuracy, scalability and robustness. All the data about subjects and their movements can be joined with data coming from infrastructure or object monitoring systems. An important aspect of this use case is that the implemented reidentification system does not involve any violation of privacy nor the persistence of sensitive data such as images. The embedding and metadata are the only features stored in the DSS platform and also the only information useful to perform the task successfully.

The road surface damage identification system achieves a high performance and demonstrates how it is possible to identify any type of object or degradation state of a specific infrastructure, locating it geographically and over time. Like any other type of data, this information can be processed in conjunction with person and action tracking data, to enhance further and more complex analysis.

The third use case on action and behavior recognition, with its excellent performance, shows how it is possible to train a model to recognize any type of activity performed by a given subject.

There are many future challenges to be faced and solved. Many of them concern:

- *Different environmental conditioning* such as lights, night vision with infrared captioning and POV;
- *Error management*: fine tuning of confidence thresholds, the handling strategy for False positives and False negatives for each use case.
- *Biases in person recognition*: the embedding model has been trained with hundreds of thousands of images but most of the available datasets don't explain the variability of human features.
- *Model update*: remote updating of capabilities and device configuration.
- *Hardware capabilities*: the proposed device has many features that make it suitable for AI task (such as inference speed and specialized hardware for video stream operations). However, the development of use cases involving multiple AI models processing multiple video streams simultaneously could be problematic. Low energy int8 GPUs or multi-TPU parallelization may be one of the best implementable solutions.

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Negotiation and Artificial Intelligence: concrete application and future developments

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Abstract

In the first part, the work in question analyzes the use of Artificial Intelligence in the Negotiation Process by identifying the moments and phases in which it would be helpful to negotiators. By reducing cognitive effort and strategy preparation time, artificial intelligence could be an indispensable tool for the negotiations of the future. In the second part it analyzes a concrete example of the application offering an overview also of the potential developments of the use of virtual reality in the preparatory phase of the negotiations.

Introduction

Negotiation is a process in which two or more parties recognize the difference in interests but who want or are forced to find an agreement. This is not a static process but a dynamic and flexible one. The evolution of this process does not begin in 1981 with the creation of the Harvard Negotiation Process but the negotiation has always been able to evolve over the centuries. This is the secret to always being an effective tool for resolving conflicts between human beings. Neglecting the historical evolution of negotiation limits the future development of new negotiation strategies that are fundamental for managing conflicts around the world. As in the second half of the 1980s, the science of negotiation has moved from the rationalist phase to the postmodern phase. Similarly, today, negotiation experts cannot overlook the influence that new technologies will have on the negotiation process.

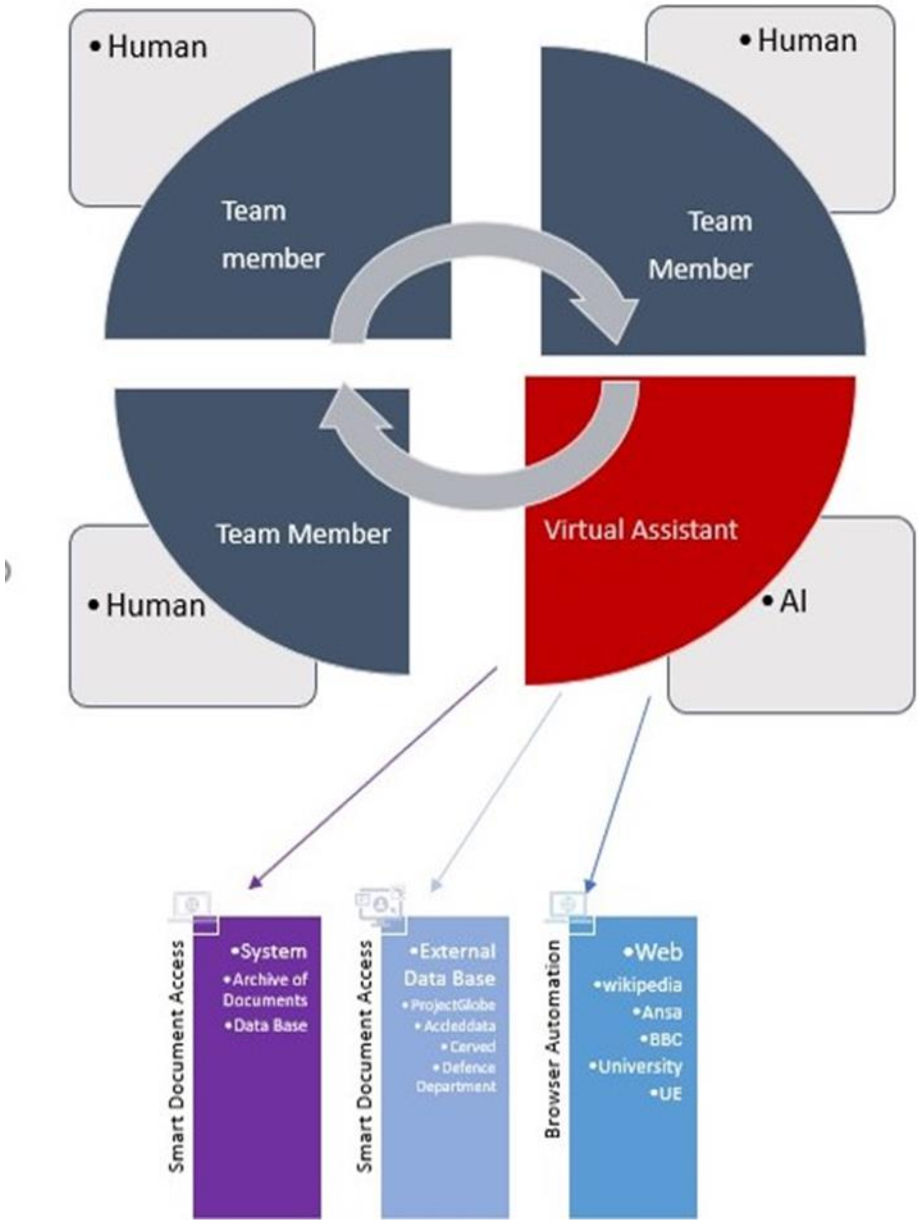
For this reason, it is nowadays crucial to pay attention to the potential scenarios that could arise from the relationship between Artificial Intelligence and negotiation. These tools seem distant and incompatible but with their integration, a new and powerful development could arise in terms of strategies, techniques, and conflict resolution. Its transversal application, therefore, also requires a reflection on the potential points of contact with negotiation, an increasingly topical tool in the contemporary world, where negotiated solutions to problems and conflicts are increasingly required. In this first work, we will refer to the possible interaction between negotiation and weak AI technology, specialized in certain areas, with specific skills and able to support humans thanks to a well-built knowledge base that allows them to face and store a large amount of data, providing the necessary answers for the continuation of the negotiation activity. In this way, the use of data controlled and dictated by trained intelligence, especially in negotiations in crisis contexts, could become an essential element in the management of the negotiations of the future. After all, Artificial Intelligence, through automatic learning, can collect signals and questions, classify, learn, reason, and predict possible scenarios; as well as interacting with people and objects.

1 Artificial intelligence and the Strategic Phase

Most of the negotiation doctrine recognizes four fundamental phases, beyond the specific negotiating context: the strategic phase, the operational phase, the agreement phase and lastly the evaluation of the agreement. The phase in which integration with Artificial Intelligence appears most natural is the strategic or preparation phase. Negotiation literature highlights how the most experienced negotiators prepare the negotiation by paying particular attention to the following activities: **the** exploration of alternatives, searching for common ground with the negotiating partner, and analysis of the long-term implications of the latter. This is followed by the construction of the strategy and the choice of techniques that are always subordinate to it. But the brief description of these activities is not representative of the complexity of the strategic phase and the importance of dedicating a substantial amount of time to its preparation. In fact, what is required of the negotiators, or the negotiation team is a real intelligence activity that is not generalized and superficial but controlled and directed towards all those aspects, even of a psychological nature, which makes the negotiating context unique, and can contribute to creating a psychological, cultural, and social profile of the negotiating partners. A collection of information becomes more demanding based on the complexity of the negotiation itself, starting from the essential assumption that at the negotiating table one of the most powerful forms of power is precise information. The recognition of the negotiation form, the structure of interests, the quantification of our power and our interlocutor's, and the analysis of intangible elements, such as emotions, cognitive distortions, and belief systems, must each time be tailored to the specific negotiation context that we are about to face since the choice of strategy and, consequently, of the techniques we use will derive from this. Completing the required preparation in a timely and accurate manner is crucial to reaching an advantageous agreement, but it is a serious problem in practice, precisely because very often time is not an element available to negotiators. The most extreme example can be found in crisis negotiations: hostage-taking, urban barricades, and cases of international piracy, where the temporal element significantly affects the conduct of the negotiations and consequently the results. In these cases, the collection of information will take place concurrently with the negotiation itself, producing a sort of overlap of the strategic phase with the operational one, with all the risks that this entails. But the same difficulties are observed in international negotiations, be they pure multilateral or multi-party bilateral. In these cases, the strategic phase will have to be set on several levels and the usual elements on which the strategy is built will have to be decided considering the different nationalities and consequently the related cultural syndromes that can greatly affect the outcome of a negotiation. To simplify cognitive effort, the fate of Artificial Intelligence is placed in the interaction between machine and negotiation, so much so that, thanks to the specifically created knowledge base, it becomes the container of all the knowledge that negotiators normally use for a deep understanding of beliefs, the scale of possible emotions, needs, potential cognitive dissonances and thus decreases the time needed for adequate preparation for the negotiation.

The construction of a profile, through the careful analysis of behaviour and the choice of elements of the cultural background and of the linguistic and historical practice of social and psychological behaviour, increases the potential for the success of the negotiation. The speed and punctuality with which the profile is analysed by AI support could represent a turning point in the conduct of negotiations and in the conduct of negotiators. The combination of Machine Learning Techniques and Algorithms of Natural Language Processing and Understanding, combined with the ability to gather information and analyze documents (Smart Document Access), would significantly contribute to the creation of a detailed profile of our partners, as evidenced by the research and the systems that have already been studied.

Building the knowledge base is one of the critical elements of the relationship between negotiation and AI. In general, a knowledge base is a centralized repository of information: a public library, a database of related information on a particular topic. About information technology (IT), a knowledge base is a machine-readable resource for disseminating information, generally online or with the ability to be put online. A knowledge base is used to optimize the collection, arrangement and retrieval of information for an organization, a company or institution. This aims to represent the knowledge that we humans use to perform certain tasks, so that they can be used by a computer to reproduce our behaviour. In our case, the construction of a refined, multidisciplinary, and selected knowledge base will be decisive. In fact, alongside the basic notions of negotiation processes, it will be crucial to take from other scientific sectors the skills and ideas that the science of negotiation will use to optimize strategies and approaches.



2 Applications in development

2.1 The case of CNF (Crisis Negotiation Future srl.)

CNF is an innovative start-up that aims to develop an artificial intelligence avatar that will help negotiators to collect useful information for the preparation of their strategy. By connecting to databases that are used by negotiation professionals, the collection of static information will be accelerated, making it easier to build the negotiation strategy. This development project is built on the combination of Machine Learning / Deep Learning techniques, Natural Language Processing and Understanding Algorithms, combined with the capabilities of document analysis and information collection (Smart Document Access).

This combination would significantly contribute to the creation of a precise profile of our partners, as evidenced by the research and systems that have already been studied. Furthermore, the avatar, named Crisis, acting in the analysis phase, would help in the search for information that could identify the characteristics and figures of the previous cases. The analysis of previous events would be useful for the preparatory investigation, offering the negotiator and his team the possibility to identify the key elements of the negotiation up to the predictive analysis that would help to determine the potential outcomes of the negotiation based on changes and events that will be perceived based on the strategy used. This will affect the identification of scenarios, abandoning, once and for all, useless mental superstructures related to negotiation schools and styles, which often limit and constrain the behaviour of negotiators.

2.2 Perspectives and Challenges.

Currently, research and practice seek to consider all potential digitization technologies to optimize negotiation management. This includes virtual reality (VR), augmented reality (AR), and mixed reality (MR). Within the next three decades, the use of VR, AR and MR will become more common in many types of business applications. Research results have shown that training, human resource development, and skills development are areas of business using virtual reality. Virtual reality systems have long been effective tools for modifying human behaviour, for example influencing medical skills training, children's education, military procedures, and flying, but also the treatment of phobias through exposure to virtual reality therapy. A key feature of these systems is that they are effective in inducing cognitive and behavioural changes through a focused and well-defined approach. These systems seem to be effective in dealing with anxiety by exposing the subject to contexts. One example is triage in emergencies. More recently, training in this manner has been used to increase cultural understanding, persuasion, and negotiation. One possible development is the consideration that the venue is part of the tangible elements of a negotiation. In this sense, professors and scholars of diplomacy have long recognized that the choice of venue is an important part of strategy building. Diplomats, for example, consider factors such as expediency, tradition, and prestige in determining the appropriate venue for delicate international negotiations, and these decisions themselves are often the subject of lengthy "preliminary talks." The reason for this concern stems from the fact that individuals engaged in a negotiation almost always assume that where they negotiate will have consequences for the subsequent process and, ultimately, its outcome. For this reason, many diplomats argue that the choice of negotiating venue, physical location, and surroundings, is not entirely free and does not represent an arbitrary choice, believing the power structure within the international system may influence them. Linking Bandura's studies on the mechanism of self-efficacy to this first consideration, it comes automatically to think of combining the use of virtual reality with the negotiating avatar. Albert Bandura was a well-known social-cognitive psychologist born in 1925 in Alberta, Canada, known for his work in social-cognitive psychology, the branch of psychology that deals with people learning by observing others and interacting with them. One of Bandura's most famous theories is his theory of self-efficacy. Self-efficacy means a person's belief that one's actions are effective or make a difference. The idea behind self-efficacy is that when individuals feel that their actions can influence the outcome of a given situation, several things happen. Firstly, they feel much better about themselves. Secondly, they feel they have a sense of power and control over what happens in the world. And finally, they do not float hopelessly from one activity to another. In short, they act, think, and feel differently from people who do not have self-efficacious beliefs. Self-efficacy, then, is defined as "a person's judgment of their ability to organize and execute certain behaviours necessary to achieve certain types of performance. Moreover, self-efficacy "is not about the skills you possess, but about judgments about what you can do with whatever skills you have. Individuals who approach an activity with high levels of self-efficacy are more likely to show high motivation to successfully complete the activity. In contrast, people who have serious doubts about their abilities tend to reduce their efforts when difficulties arise. Bandura identified four main sources of self-efficacy information and the main pathways through which they operate The sources of self-efficacy information are: performance outcomes (including participant modeling, performance desensitization, performance exposure, and self-directed performance), vicarious experience (including live and symbolic models), emotional arousal (including attribution, relaxation, biofeedback, symbolic desensitization, and symbolic exposure), and verbal persuasion (including prompting, exhortation, self-instruction, and interpretive treatments). These four methods of information acquisition can be used to improve an individual's perceived self-efficacy concerning one or more specific tasks. In addition, increased self-efficacy can influence other tasks in which performance was previously hampered by thoughts of inadequacy or incompetence.

In light of the above, a potential development could be the combination of artificial intelligence and virtual reality. With AI it will be possible to gather information faster, and with VR it will be possible to reconstruct the physical location of the negotiation and through the negotiator's immersion offers the possibility of preparing space management using proxemics, the study of space and distances as a communicative fact, that is, on the psychological level, the study of the possible meanings of the material distances that humans tend to interpose between themselves and others.

3 Conclusion

Knowledge of its historical evolution shows us that negotiation is a conflict resolution tool capable of adapting to economic, cultural, and scientific contexts and which draws its innovative strength from the ability to improve its effectiveness by borrowing strategies and techniques from other disciplines. As has already happened with developments coming from intercultural communication, neuroscience, and cognitive psychology, negotiation methodology is now facing a new challenge: understanding the potential and limits of the enormous developments that have been made in terms of Artificial Intelligence in the technological field. This work has tried to analyse the relationship between Negotiation and Artificial Intelligence within a specific international scenario. In this sense, the literature is unanimous in believing that the success of negotiation does not depend exclusively on the natural skills of the negotiator but above all on the accuracy of his/her preparation. Practical analysis shows that what is required of the negotiators, or the negotiation team is a real intelligence activity that is not generalized and superficial but controlled and directed towards all those aspects, even of a psychological nature, that make the negotiating context unique, and which can help create a psychological, cultural, and social profile of negotiating partners. The oriented information allows negotiators to predict, as far as possible, the development of the negotiation by analysing the opportunities, strengths, and weaknesses of the negotiating partners and their characteristics. In short, information reduces the uncertainty inherent in the negotiation dynamics while partial knowledge can cause obstructive positional behaviour which in turn produces costly delays and failure of negotiations. In a messy world characterized by hyper-information, it is possible to acquire data from a variety of sources: Internet, e-mail, Facebook, Google, Microsoft, electronic libraries, protocol reports, accounts, and interviews. But a large amount of data and time constraints make information analysis difficult for negotiators. Furthermore, the high level of interdisciplinarity makes the strategic phase even more challenging. In this sense, an Avatar that can make the decoding of negotiation scenarios and profiles faster and more efficient thanks to an oriented knowledge base can represent a valid tool both for negotiation teams and for individual negotiators. The introduction of the virtual assistant would speed up the preparatory phase of the negotiation and decrease the margin of error in the collection of information, significantly reducing the areas related to emotion and prejudice, typical of human beings. It could allow you to "act in an informed manner" in the face of the need to negotiate and "react in an informed manner" in the face of variants that may arise during the negotiation. Artificial Intelligence, thanks to the specially created knowledge base, becomes the container of all the knowledge that negotiators normally use for a deep understanding of the fundamental elements of the negotiation. Without ever forgetting that the more complex the negotiation, the more important the preparation process will be. On the other hand, as Benjamin Franklin, an American statesman, diplomat and writer said: "If you fail to prepare, you are preparing to fail."

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