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.

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

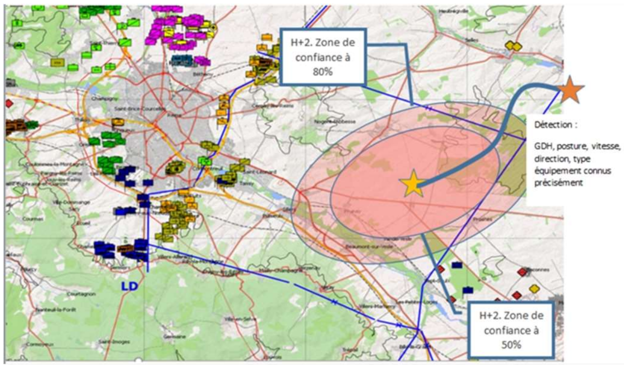

Figure 1 ValoRens initial requirement

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

2 THE VALORENS DEMONSTRATOR

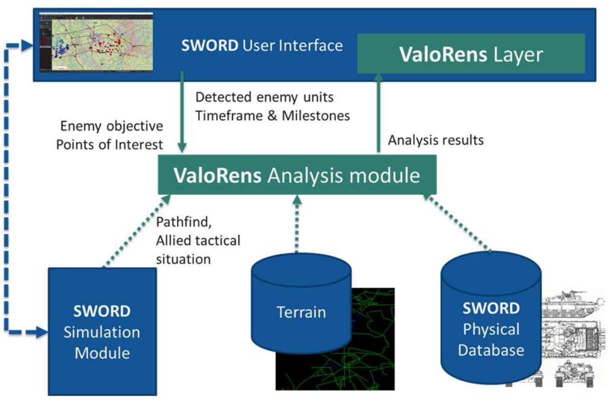

Figure 2 ValoRens demonstrator architecture

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.

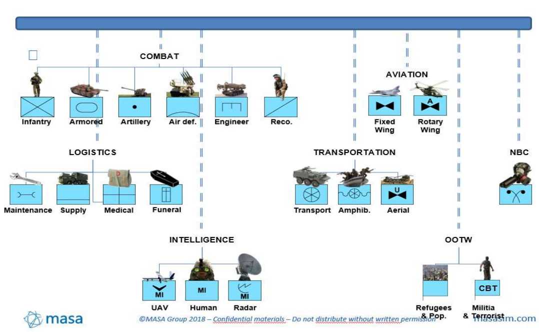

Figure 3 SWORD generic physical and behaviour database

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 have their 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.

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

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

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.

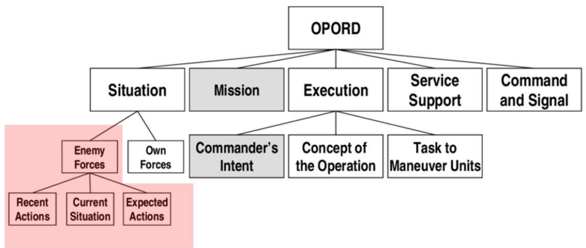

Figure 4 OPORD Content

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.

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.

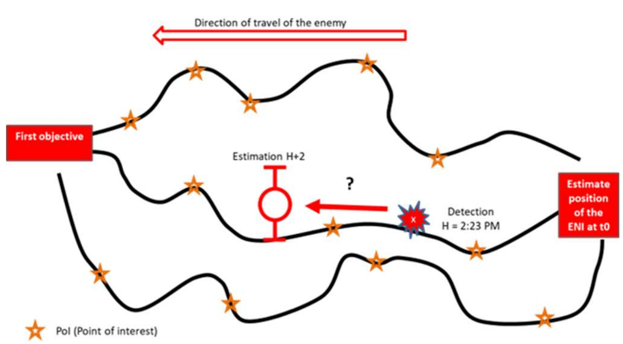

Figure 5 ValoRens Problem Definition

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.

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.

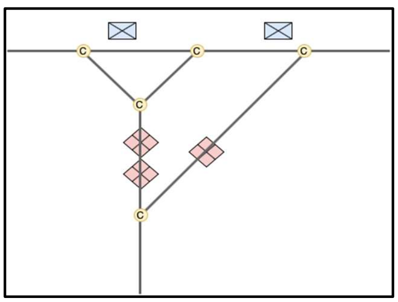

Figure 6 ValoRens algorithm step 1

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)

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 $(p_1, p_2, \ldots, p_n)$ associated with a total travel time, which is the sum of the time taken 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).

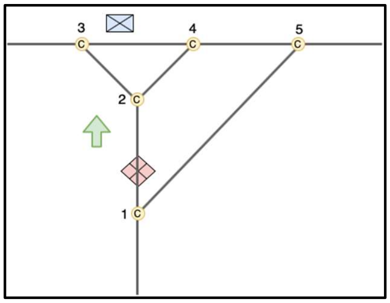

Figure 7 ValoRens algorithm step 2

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.

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%).

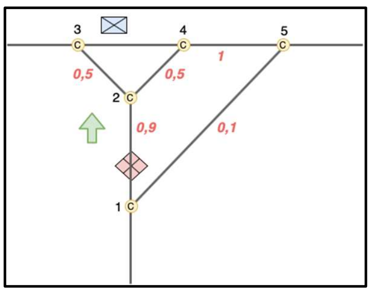

Figure 8 ValoRens algorithm step 3

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 route that leads it momentarily away from its target.

2.4 Demonstration and Results

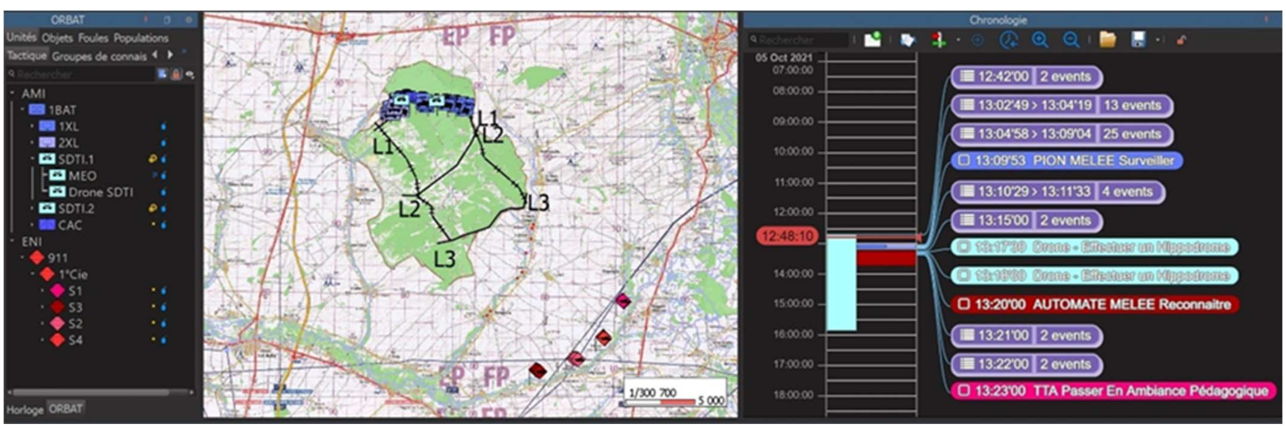

Figure 9 SWORD Scenario

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

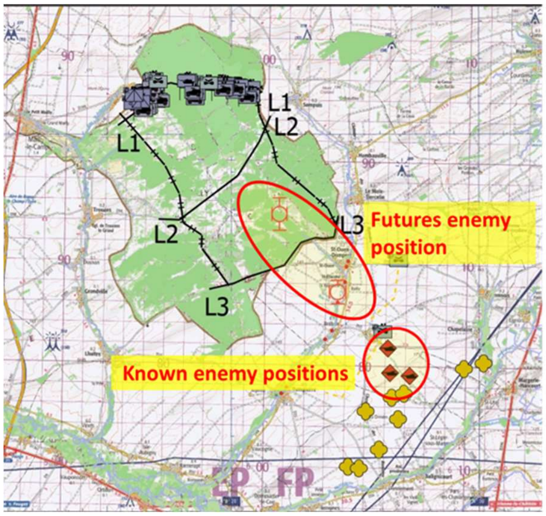

Figure 10 ValoRens Analysis results

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.
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

Figure 12 ValoRens Booth at FID 2022

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.

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.

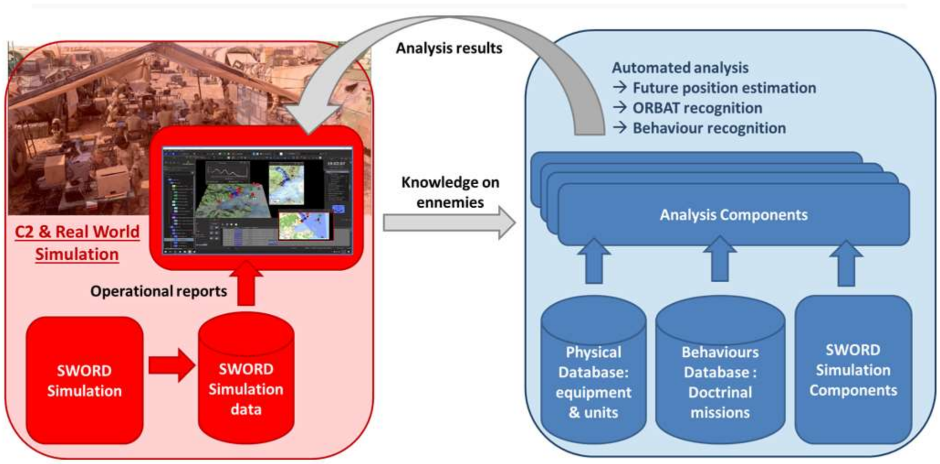

Figure 13 ValoRens Future Directions

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.