

The STRATEGIC project : Innovative automated analysis tools for After Action Review (AAR) using AI and modeling & simulation

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ABSTRACT

During a training session using simulations, all information is recorded for replay, visualization and detailed analysis purposes. Classical After Action Review (AAR) tools offer many functionalities to zoom in on a specific moment or to give general feedback on the choices of the trainees. The materials trainers generally use are scores, videos and screenshots, which they have to enrich manually.

The STRATEGIC research project proposes innovative automated analysis tools, based on artificial intelligence and modelling & simulation. Our work focuses on three strategic pillars:

- A narrative reconstruction of the causality of the events using a graph model. This helps in understanding the consequences of the trainee's choices and highlights the key events of the session, thus facilitating communication during the debriefing session.
- An automatic generation of enriched operational diagrams offering smart synthesis of the tactical situation and its history: local force ratio, tactical lines, main effects of missions, contextual units capacities, and others.
- Interactive pictures for alternative solutions exploration.

Early results are so promising that the french land Army ordered many smart diagrams; not only for 3A and supervision of training sessions, but also for intelligence valuation. In the future, it could be also used as a decision support & alert system at HQ.

ABOUT THE AUTHORS

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François Legras helps design innovative UI for startups and defense industry stakeholders. His research interests include UAV swarms command & control, interactive dataviz with a strong bias towards maps and graphs, and more recently narratives.

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1.0 THE STRATEGIC PROJECT

1.1 Objectives of the STRATEGIC project

Broadly speaking, a training session starts with a preparation phase, where the realistic operational environment is created, followed by an exercise phase where all the trainees take part in the simulation and, finally, a debriefing phase, also called After Action Review(AAR) where the stakeholders have an interactive discussion in order to understand what happened during the exercise and why, as well as how to improve or sustain performance in similar situations in the future. Duration and timing of the discussion are very important: too many details lead to a lack of concentration among the participants and inadequate timing tends to make the participants forget the real reasons that made them choose a specific course of action.

Just as there is no one correct way to conduct an AAR, there is also no one correct way to automate an AAR. There are common requirements to be met in all types of training and AAR. Interviews with army observers/controllers at various combat training centers (Dyer, 2005) (Salter, 2007) clearly indicate that automation that improves training recall and diagnosis is desirable. Dyer et al (Dyer, 2005) noted that “AAR aids should assist the trainer, and should be used when they are “value added”. The statement indicates that automated AAR should be geared toward assisting the trainer and not as a replacement for the trainer. According to (C.L Johnson, 2008), one of the biggest flaws of automated AAR tools is inability to determine cause and effect relationships and connections between events. Available AAR automations easily list events, but do not assist the trainer in linking these events to the mission plan.

As explained earlier, during a training session using simulations, all information is recorded for replay, visualization and detailed analysis purposes. Classical After Action Review (AAR) tools offer many functionalities to zoom in on a specific moment or to understand and give general feedback on the choices made by trainees. The material usually available to communicate with trainees are numerical indicators, videos and screenshots, all of which have to be manually enriched (see Figure 1.)

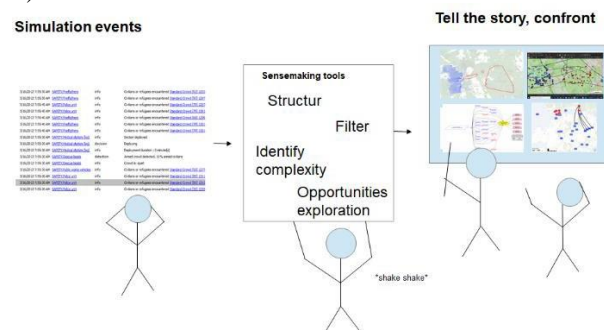


Figure 1. After Action Review supported by the STRATEGIC project

The STRATEGIC research project proposed innovative automated analysis tools, based on artificial intelligence and modelling & simulation :

- a narrative reconstruction of the event's causality in the form of a graph of events. This facilitates the understanding of the consequences of the trainee's choices and highlights the key events of the session and thus supports the communication during the debriefing session.

- an automatic generation of enriched operational pictures offering a smart synthesis of the tactical situation and its history: local force ratio, tactical lines, main effects of missions, contextual units capacities, ...
- interactive diagrams supporting the exploration of alternative solutions

1.2 SWORD, a Constructive Simulation for Military Training

The training software we used, SWORD, relies on a constructive simulation which allows brigade and division command staff to become immersed in large-scale conflict scenarios such as stabilization operations, terrorist threats or natural disasters. It simulates a diverse range of situations in realistic environments and lets trainees lead thousands of autonomous subordinate units (at platoon and company levels) on the virtual field. Agents can receive operation orders and execute them without additional input from the players, while adapting their behavior accordingly as the situation evolves.

Models capturing such behaviors comprise two components: algorithms that make agents perceive, move, communicate and shoot, and the description of the capabilities of the underlying equipment. The simulation session database contains three different types of information:

- Data regarding the physical element: components of units are described here. Because the simulation is a constructive simulation most of the features of the equipment or units are described by their effects or their capacities. This facilitates their description in terms of action and change.
- Initialization data for the scenario contains the following information: terrain, order of battle, weather, data provided by the simulation such as events, knowledge obtained by the agents, etc.
- Data generated by the simulation describes the evolution of the situation: information describing the evolution of the game containing all events, knowledge about the environment, and all mission reports.

All this information is presented to the participants as a set of messages exchanged among the agents during the simulation that contains all the information described above. An extract of the simulation is shown below:

[07:29:47] - Report - ENG.Counter mobility platoon: Disembarkment started

.....

[07:30:17] - Report - INF.Mortar troop: Unit detected at ...

.....

[07:30:17] - Report - INF.Rifle platoon: Unit detected at ...

1.3 Functional Architecture

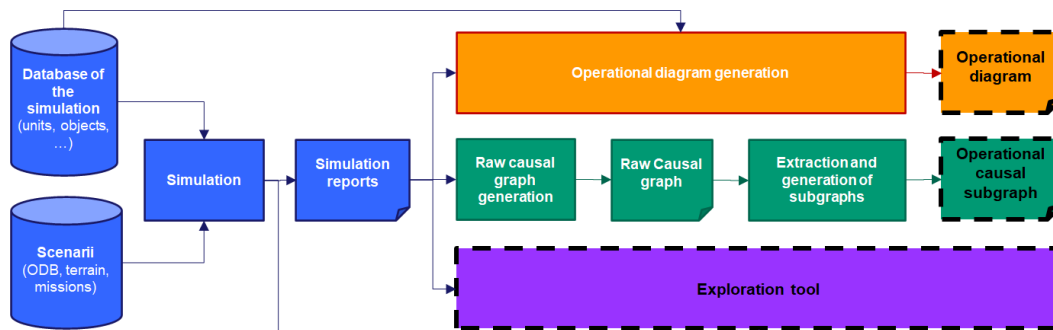


Figure 2. Functional architecture

Our work focuses on three main areas:

- an innovative and alternative conception of the representation of the tactical situation according to an operational focal point, exploiting the ontology of the simulation (effects of missions, role of units, ...) in a novel manner, and its models (ex: capacities of units, balance of power, ...), in order to allow the production of operational pictures illustrating the tactical situation at any moment in time.
- an analysis, interpretation and structuring of the reports of events resulting from the simulation in a form that allows for the employment of causal relationships: this work includes the reflection around the causality model to be adopted, as it had to be compatible with the information in the reports, and expressive enough to support an interactive construction of the explanation.
- careful consideration of the human-computer interface required to generate relevant narrative subgraphs and intuitive and intelligible operational diagrams easy to understand

The use of many different scenarios allowed us to validate the genericity of our technical and algorithmic solutions: different terrain, different order of battle and units, different missions, different durations.

2.0 NARRATIVE RECONSTRUCTION OF THE CAUSALITY OF EVENTS

The construction of the narrative support tool involves two steps: first, a raw causal graph is constructed by translating the simulation's reports into events linked by causal relationships, then subgraphs are extracted and automatically reworked in order to be readable.

2.1 Construction of the Raw Causal Graph: a Linear-Logic Based Approach to Story Construction and Analysis

The formalization of narratives is a problem that has often been approached in Artificial Intelligence from the perspective of representation and Reasoning about Action and Change (RAC), starting from the atomic modeling of a narrative action, and describing its impact on the environment. (Anne-Gwenn Bosser, 2010) & (Anne-Gwenn Bosser P. C., 2011) use Linear Logic (Girard, 1987) in modeling which has led to formal approaches to story analysis and property verification. Among other advantages, this approach allows for the modeling, in a declarative way, of each event, by describing its impact on the environment in terms of consumption and the production of resources. This has led to systems where stories generated from a linear-logic based declarative specification could be described by reconstructing causal relationships between events and displayed in the form of causal diagrams (Chris Martens, 2013), (Chris Martens J. F.-G., 2014).

We have produced a formal description of the translation of the traces of SWORD events into atomic actions, thereby building blocks of the raw graph. These actions represent exactly what, in the simulation, was changed by the triggering of the corresponding events. This component provides both a method for the translation of SWORD traces into actions in the raw graph, and the construction of a graph of contributing causes. The algorithm is based on the sequential processing of the state of the simulation over time, which in the future will allow it to build the above on-the-fly as the simulation progresses (through integration in SWORD rather than as a separate component). This state maintains at each moment of the simulation the entire operational status of the simulation unit, as well as the knowledge units have about each other (visibility). The current implementation uses Go, and the process takes about 500ms on a mid-range computer for our most complex scenario. The graph produced is described in dot and json formats which facilitates their processing by standard tools (visualization, processing libraries).

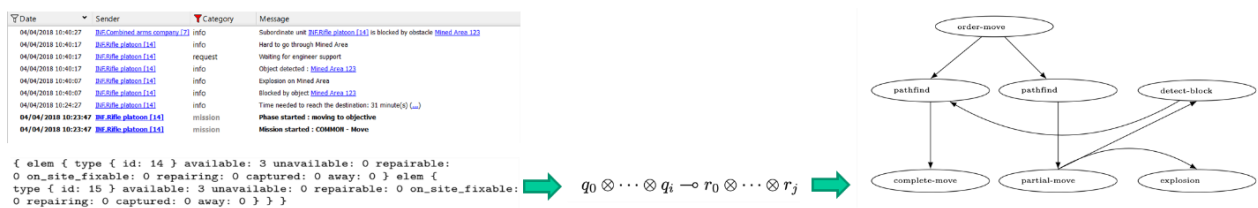


Figure 3. From the simulation events to the raw causal graph

The different kinds of events and reports produced by the simulation (position & state of the units, firefights, detection and move events, ...) have been translated into linear logic formulas. The diagrams obtained retrace the contributing causes of the events. The diagram above (see Figure 3) shows an example of a graph computed using a simple scenario as a basis: a unit moves and encounters a mined area.

For example, a move can be caused by a mission, or damages can be caused by an explosion or firefights:

```

order-move: location(Y)  $\rightarrow$  mission(id, move(Y));
pathfind: mission(id, move(Y))  $\otimes$  pos(id, X)  $\otimes$  Context(id, C)  $\rightarrow$  mission(id, move(Y))  $\otimes$  pos(id, X)  $\otimes$  Context(id, C)  $\otimes$  path(X, Y);
partial-movement: mission(id, move(Y))  $\otimes$  path(X, Y)  $\otimes$  pos(id, Z)  $\otimes$  Y  $\neq$  Z  $\rightarrow$  Y  $\neq$  Z  $\otimes$  mission(id, move(Y))  $\otimes$  path(Y)  $\otimes$  pos(id, Y);
detect-block: path(X, Y)  $\otimes$  pos(id, Z)  $\otimes$  mine(Z)  $\rightarrow$  knowledge(id, block(mine(Z)));
explosion: pos(id, Z)  $\otimes$  mine(Z)  $\otimes$  context(id, C)  $\rightarrow$  pos(id, Z)  $\otimes$  damages(context(id, C));
pathfind: mission(id, move(Y))  $\otimes$  pos(id, X)  $\otimes$  context(id, C)  $\rightarrow$  mission(id, move(Y))  $\otimes$  context(id, C)  $\otimes$  pos(id, X)  $\otimes$  path(X, Y);
complete-movement: mission(id, move(Y))  $\otimes$  path(X, Y)  $\otimes$  pos(id, X)  $\rightarrow$  pos(id, Y)

```

Figure 4. Example of linear logic formulas

2.2 Construction of the Narrative Graph

The raw causal graph produced after the process described above is not directly usable as they are too big, even for small scenarios. One aim of the project was to provide a set of tools, based on generic or ad-hoc heuristics, to render it tractable for human understanding. Here are examples of heuristics we used for aggregating nodes of the raw graph into higher level narrative events or suggest entry-points for the analysis:

- The relationship between the number of causal relationships on a set of events and the importance of perceiving an event in a story has been discussed in (Mazlack, 2004). This was used as an heuristic to highlight events of interest.
- Spatio-temporal zones where events involve attrition were likely to correspond to exchange of fires, with many interactions between units and events. We used this as a heuristic to simplify and summarize a number of nodes into high-level ones.

The component thus offers a solution for the representation of the simulation's events in the form of a more streamlined causal graph in order to support the narration. It first applies ad-hoc simplification heuristics and clusterization algorithms on the raw causal graph. This allows us to obtain a higher level graph, called the “narrative graph” with a greatly reduced size that makes it computationally manageable in interactive time.

Table 1. Numbers of links and nodes generated on different scenarios.

Test Scenario	Raw Causal Graph		Narrative Graph	
	# nodes	# links	# nodes	# links
Egypt	1902	4021	326	503
Sweden	5760	12620	973	1429

Smart filters are then applied, and offer partial views of the narrative graph. For example, one can ask for the history of a specific unit or the inventory of events that results in getting a specific event of the simulation (see Figure 5). The result details the missions of the units, their moves, the enemies detected, firefight events and damages. Views can also be enriched with their temporal and spatial extensions.

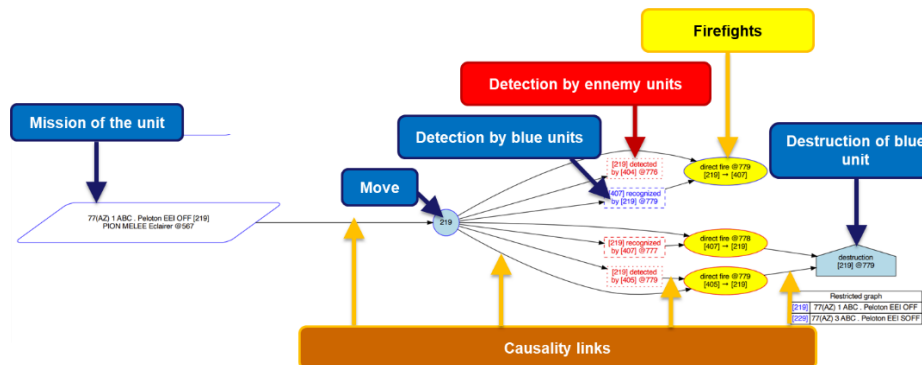


Figure 5. Narrative graph representation example : a focus on the history of a unit

We considered some heuristics promising, such as the use of force ratio shifts, ultimately proved to be ineffective and redundant in spotting and factoring landmark events regarding the analysis of the causal centrality of certain nodes. On the other hand, simple mechanisms based on their spatio-temporal proximity for bringing together complex actions have proved to be very effective. They also naturally offer the highlighting of the salience of certain events from an operational point of view. From a performance point of view, the generation of the complete narrative graph may take a few minutes on the larger scenario, but once generated, the requests receive rapid responses.

3.0 AUTOMATIC GENERATION OF ENRICHED OPERATIONAL DIAGRAMS

In order to better understand the tactical context at a specific moment in time, to support the discussion and to offer a shared comprehension, we decided to propose smart diagrams based on the doctrinal decision parameters or directly inspired by operational synthesis generated at HQ for debriefing purposes.

3.1 Occupying The Terrain

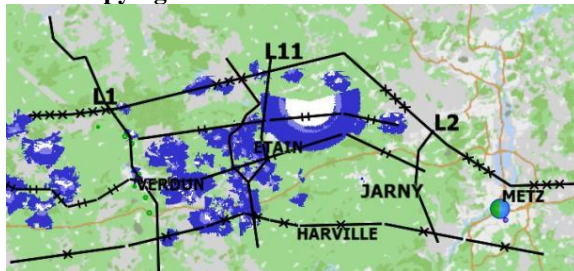


Figure 6. Contextual perception capacities

The system calculates the total area occupied by all units, the entire perception zone based on available equipment, the current missions of units, and the potential area covered by fire (see Figure 6). These calculations can be performed on the basis of the hierarchical level of units, their equipment capacities, current missions, and positions. We directly used the capacities module of the SWORD simulation in charge of the calculation of the potential effects of the equipment of the units. Moreover, to provide an indication of the global force deployed at a glance, calculations of the density of forces could be added.

3.2 Local Force Ratio

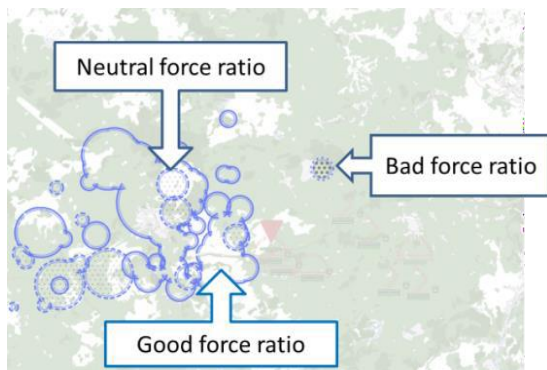


Figure 7. Local Force Ratio

The simulation calculates the force ratio of each agent based on its knowledge of the tactical situation. This is used as a decision-making parameter by autonomous units to help them determine whether they are likely to be able to accomplish their mission, or whether the situation is considered to be too dangerous (as written in the use of the force doctrine). It is therefore possible to offer a dedicated view of the local force ratios (see Figure 7), which provides an insight into which forces, or area, may have required reinforcements.

3.3 Common Offensive and Defensive Control Measures

Commanders use common offensive and defensive control measures to synchronize the effects of combat power. Understanding and using commonly understood control measures enables commanders and staff to develop and publish clear and concise mission orders, as well as direct tactical actions quickly, with minimal communication during execution.

Based on current missions, knowledge of enemies, and combat capacities of units, we are able to generate on the fly a global maneuver summary, which includes a calculation of tactical lines (see Figure 8) :

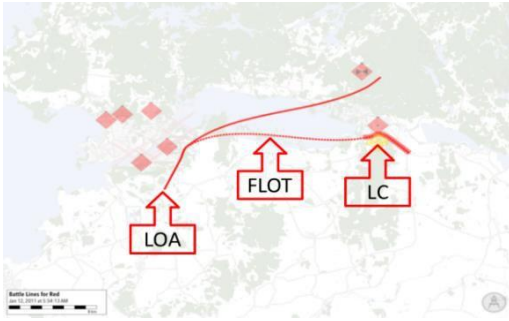


Figure 8. Tactical lines

- Forward Line of Own Troops (FLOT) that indicates the most forward position of the forces. The FLOT normally identifies the forward location of covering or screening forces.
- Limit Of Advance (LOA) is a phase line used to control the forward progress of the attack.
- Line of Contact (LC) is a general trace delineating the location where friendly and enemy forces are engaged.
- The forward edge of the battle area (FEBA) is the foremost limit of a series of areas in which ground combat units are deployed to coordinate fire support, the positioning of forces, or the maneuver of units, excluding areas in which covering or screening forces are operating (JP 3-09.3).

3.4 Current Effect Applied Layer

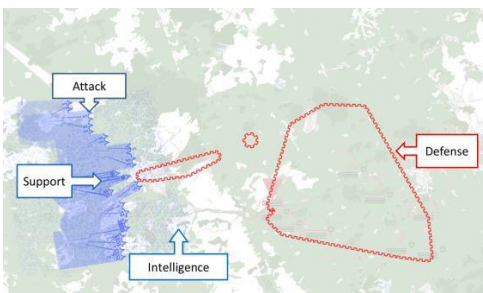


Figure 9. Effect applied

According to the past and current missions of the units, it is possible to provide a view of the main effects exerted by units on the field. For this purpose, the missions have been classified according to their main goal effect on the field and on enemies. In this first version (see Figure9) we focused on four main effects: the intelligence, the offensive effect (attack), the defense effect (including engineering defense works) and the support. The result is an interactive layer that offers a way to choose the effect and the side. Naturally, the line of the front with an indication of the available support, the defense positions, and the scouted zones, all appear.

To take this analysis further, we could provide a maneuver view that relies on the major expected effects regarding the enemy and terrain. For example one could produce a layer that differentiates between zones that must be recognized, conquered, controlled, etc., or enemies that must be eliminated or stopped. This could be achieved through the interpretation of the advancement of current missions, and the nature of planned missions.

4.0 ALTERNATIVE SOLUTION EXPLORATION TOOL

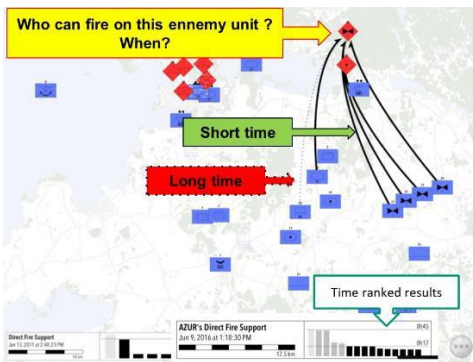


Figure 10. Delay to support calculation

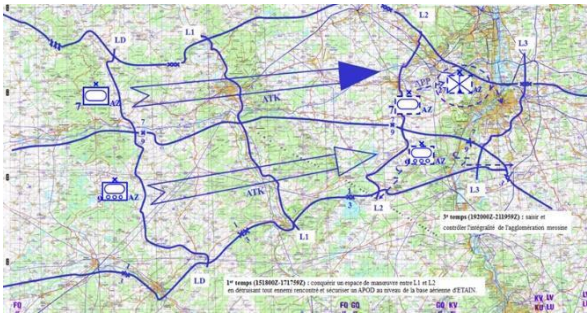
The idea here is to offer an easy way to explore possible alternatives when managing the tactical situation and in this way propose the foundation for counterfactual analysis. For each unit on the battlefield, we provide a calculation of the time taken to reach a position to support a unit facing an enemy (see Figure10). To achieve this, the simulation calculates the best route for each unit. This calculation takes into account all equipment capable of direct or indirect fire, known enemy positions, the terrain, friendly and enemy engineering works, tactical limits, etc.

Thanks to the simulation, it is possible to easily identify who could support a unit or fire at an enemy and within which timeframe, considering the terrain and the capabilities of the units.

5.0 EXPLOITATION OF THE RESULTS

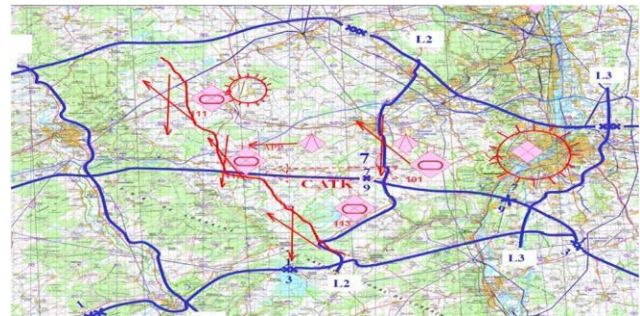
5.1 Example of an operational use case

Simulation scenario



Blue objectives:

- Conquer the zone between lines L1 and L2 by overpowering each encountered enemy.
- Conquer the L2 line before June 17th.



Enemy objectives :

- Install two battalions on the defense line.
- Create large connected mined obstacle zones between the river and the defense line.
- Render the west of Metz a no-go zone, and retain control of the Etain airport.

The blue operation is a success, despite heavy losses. It appears that the bulk of the blue losses are made up of platoons from a reconnaissance battalion. It would therefore appear beneficial to identify the causes of these losses, and determine whether they could have been avoided.

Understanding the cause of heavy losses

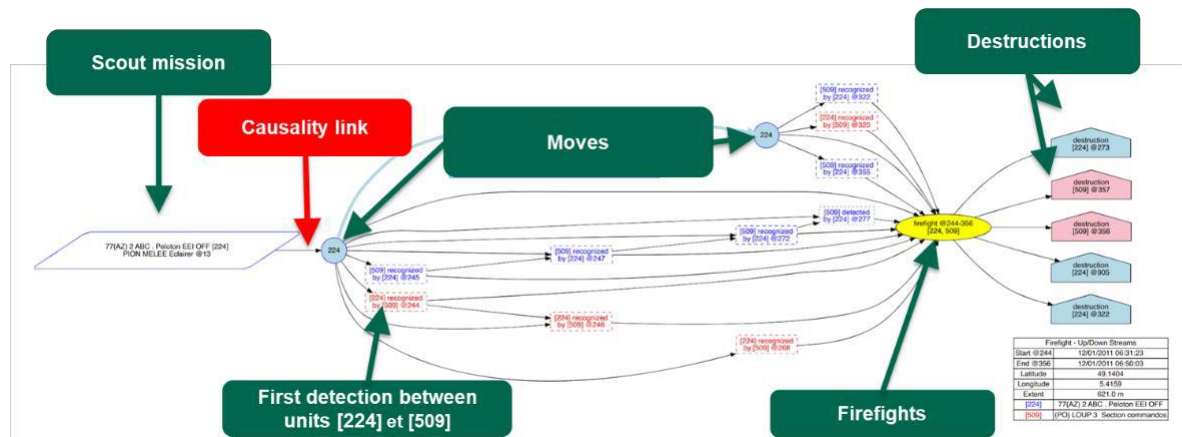


Figure 11. Narrative graph focused on unit 224

To this end, we generated a narrative graph focused on one of the destroyed scout platoons, the [224] unit (see Figure11).

This option makes it easy to understand and recount the unit's story: it received a scout mission at 11h35 (tick 224), at which point it moved, and two minutes later encountered the enemy unit [509]. The two units detected each other, exchanged fire, and inflicted damage on each other between 11h43 (tick 273) and 12h21 (tick 500). Having a view of the tactical situation at this moment consequently appears highly beneficial (see Figure 12).

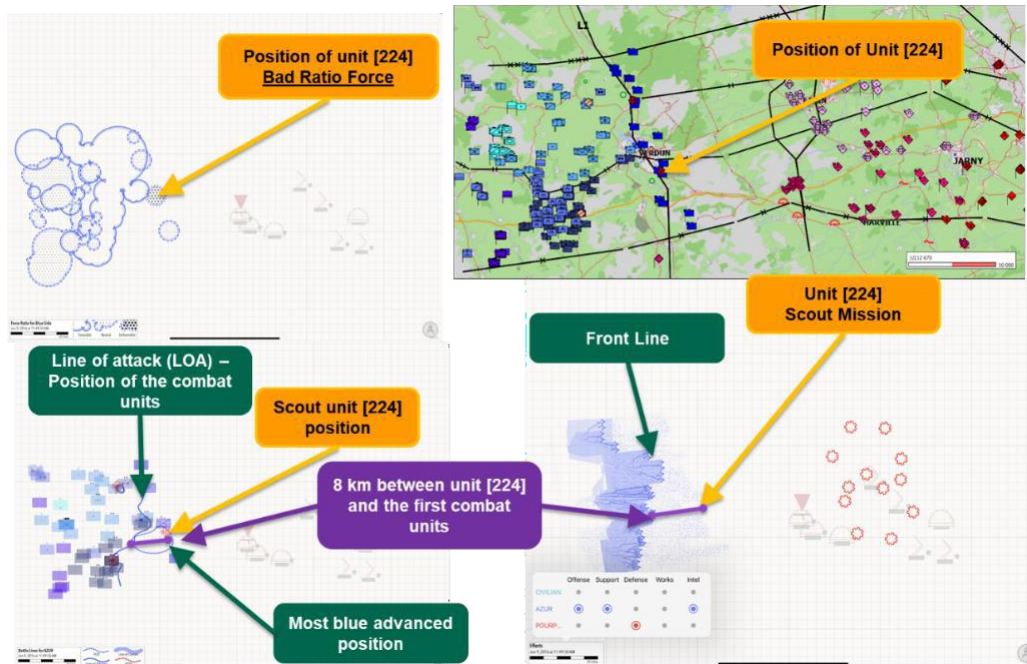


Figure 12. Tactical context of unit 224 during the firefight

These operational diagrams offer a view of the tactical context when the scout unit [224] is being shelled. The force ratio diagram indicates that it was isolated: the two other diagrams show that it was on a front more than 8 kilometers from the first combat units.

5.2 Immediate and further exploitation perspectives

Following multiple demonstrations and presentations of the project to operational and MOD staff, a variety of profiles were highly interested in the project. On one hand, the teams in charge of the SOULT training program have therefore ordered “smart diagrams” from MASA for mobile exercise supervision and AAR. On the other hand, the section of the Digital Office of the Land HQ(EMAT), in charge of analysis and operational research, also ordered smart diagrams related to the enhancement of intelligence. This section's mission is to analyze digital data, both organic and operational, to present objective and consolidated views. Two capabilities have been ordered: the display of the contextual detection capabilities of a camp and the interpolation of the future enemy positions.

To create his/her own version of the course of the simulation and give a point of view, rather than just building a narrative graph, the user could also receive automatically simplified portions, and combine them with the other views of the AAR tool: a map, smart pictures, indicators... Then, the exploration of counterfactual “*what if*” scenarios would also be possible from the simulation interface, thanks to the replay function that allows you to start the simulation again from a given timestamp. The trainee and trainers could then modify the course of action and evaluate the benefits of these changes. This counterfactual exploration offers the possibility to go beyond a simple understanding by identifying the contributing cause and events which “if they had happened in a different manner would have changed the outcome of the simulation”: it is this type of simulative reasoning that underlies the human causal interpretation.

To conclude, the use of this set of tools for sensemaking purposes in the context of decision support is an avenue that needs to be explored. Not only are these tools naturally adapted to the needs of a command post, but it is also possible to think further ahead and dynamically process information from the battlefield to prioritize, alert, contextualize and calculate their consequences. Indeed, by creating a digital twin of the battlefield, and integrating these innovative tools, it would be possible to:

- Contextualize the information from the terrain: prioritization of information and automatic sending of alerts through intelligent information processing. Indeed, depending on its tactical context, the same information will

not have the same meaning. For example, the report « *Enemy unit detected at XXX position* » may have totally different meanings according to the position and the context of this detection (see Figure 13)

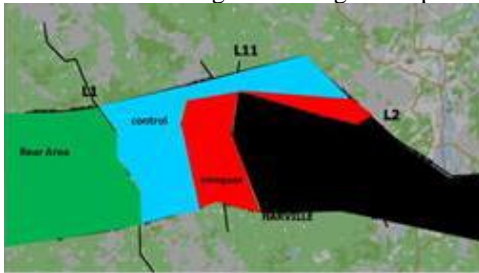


Figure 13. Context of the information

- In the black zone, to reconnoiter, means that the scout missions are going well.
- In the red zone, to conquer, an increase in the number of enemy units could mean the arrival of reinforcements and therefore a force ratio switchover.
- In the blue zone, to be secured, new enemies should not remain in this area, it means that remaining enemy forces were not all evaluated.
- In the green zone, that is secured, enemies in this area should result in a serious alert being sent.

- Calculate and alert on the consequences of events: automatic alert if a current (or planned) mission is compromised by the evolution of the tactical situation. For example, the destruction of a bridge can compromise medical support or require the preparation of a new logistical route.
- Calculate smart indicators for mission monitoring: as explained earlier, it would be possible to compare the current situation to the expected one or automatically compute the reports from the field to evaluate efficiency, the evolution of events, or the risks from a specific mission.
- Identify chain of events: a study has explored the use of classification techniques to format the raw graph on a data set test using machine learning methods. These methods would then not be used for the construction of the raw graph, but we propose to explore this avenue to perform manipulable "summaries" of the graph. The contribution of machine learning methods to facilitate the understanding of this graph could be deepened and in particular be used to:
 - Determine the probability of the occurrence of a sequence of actions
 - Detect unlikely sequences (threshold value)
 - Predict the rest of a sequence

Many AI applications requiring trust start to turn to these methods, especially when the core of the technology remains based on symbolic methods and machine learning methods are applied to the processing of the raw graph.

All innovative solutions proposed here for decision support require two principal prerequisites:

- 1) a database containing all friendly equipment, plus presumed enemy equipment. Descriptions of all types of equipment must be accompanied by effect descriptions, to enable the simulation of the battlefield.
- 2) the integration of the command and control systems within the tools described above, with a view to importing all data into the simulation: unit positions, logistic states, enemy knowledge, engineering work, NRBC zones, available missions, etc. We then have to design a data representation that provides an easy-to-understand, intuitive display of processed information.

6.0 CONCLUSION

To conclude, narrative graphs used for simulation based training can be simple, or extremely complex. They let us :

- Explain the story of a unit
- Understand the role of all the units involved in a phase or firefight and its context
- Visualize the role of the units in the maneuver and assess their importance (a mission may or may not have multiple consequences)

So far we have focused on combat units and more specifically on the following events: mission, fire, movement, detection, damage. We need to add other types of units, missions and events: logistics, engineering, ... and offer an interactive graph path to obtain a global and detailed view. A learning algorithm could then propose automatic simplifications of the graph.

In addition, in order to understand the overall tactical context at an identified moment, we offer innovative and alternative views of the tactical situation, offering:

- A calculation of the capacities of the units on the ground according to the tactical context (current mission & speed of unit, weather, experience of the unit...)
- A calculation of the main effects applied on the terrain according to the missions assigned to the units
- A calculation of the force ratio (or units' local strengths) based on their knowledge of the enemy
- A calculation of the main tactical lines (FLOT, LC, LOA)

Some work has already been commissioned by the Army in a framework that goes far beyond the scope of the AAR.

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