SIMSIA: Study of the Contribution of Simulation for Intelligent Autonomous Systems

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ABSTRACT

More and more operational systems embed intelligent functions, based on Artificial Intelligence technology, to ease and improve operators' efficiency to perform military activities. The development and deployment of these functions, which generally rely on several AI techniques, requires an increasing use of simulation during the development life cycle of the systems.

The objective of the French MoD study SIMSIA, contracted to Thales, was to characterize, from a large (149) and diversified panel of use cases:

- *The AI techniques that are the most commonly used mainly for C2 systems and,*
- *The simulation means that might be helpful for the development / qualification of AI technology.*

This study defined typologies characterizing AI and Simulation technics that led to the identification of the most 25 representative pairs {AI; Simulation} in the panel, and to the proposition, for each of these pair, of technical recommendations addressing the evolution of interfaces, models and architecture of simulation and the needs for acceleration and high realism.

As a conclusion, the study ended with the proposition of a roadmap for the M&S improvement, by 2026, dealing with two categories of simulation (virtual and constructive) being most useful to fulfil the requirements to provide operational systems based AI.

INTRODUCTION

The increasing use of Artificial Intelligence (AI) algorithms in our operational systems has created new needs of simulation tools capable of facilitating the development of such algorithms.

As examples, we can mention:

- The development of collaborative combat algorithms before their implementation into next generation land or air vehicles, with, in particular, the realistic simulation of the physical and behavioural models of these vehicles;
- The generation of massive data necessary for the construction of machine learning models used to perform functions such as: decision support, terrain understanding, image recognition, human-machine dialogue, etc.
- The verification, validation and pre-qualification of these AI algorithms in simulation before their integration into operational systems in real conditions.

A first study called "AI & Big Data" was carried out between 2016 and 2018 and established a first panel of intelligent autonomous systems, i.e. operational systems exploiting Artificial Intelligence or massive data processing algorithms.

The objective of the SIMSIA study, whose main results are presented in this paper, was to determine the contribution of simulation for intelligent autonomous systems and, in particular, to define or identify the simulation methods and techniques adapted to the requirements of developing such systems.

This study, contracted the French MoD to Thales, was carried out as an extension of the "AI & Big Data" study and was especially based on the panel of application cases for Artificial Intelligence technologies identified during that study.

The SIMSIA study started in September 2019 and concluded in January 2022 at the end of the three following technical tasks:

- Characterize requirements by identifying and analysing the most likely use cases for simulation to develop AI mechanisms present in operational systems;
- Propose and compare several solution alternatives to produce technical recommendations for the simulation assets identified in Task 1;
- Define in detail the two most representative simulation solutions to build a roadmap proposing the evolution of these simulations by 2026.

2. CHARACTERIZATION OF THE NEED FOR SIMULATION FOR THE DÉVELOPMENT OD AI MECANISMS IN OPERATIONAL SYSTEMS

The first task of the study identified and analysed the most likely uses of simulation mechanisms that may help the development of AI mechanisms present in use cases coming from a panel of intelligent autonomous systems referenced in previous studies on this topic.

2.1 Analysis of the panel of cases studied

The characterization of the need was based on a panel of 149 use cases that constituted the input data for the study. 114 of these 149 cases came from the results of the "AI & Big Data" study, the last 35 cases came from a complementary study carried out by the French Naval “Artificial Intelligence” Task Force.

The detailed analysis of each of the use cases showed that almost all of the intelligent autonomous systems studied use a combination of very diverse AI techniques, often from different domains (combination of symbolic and connectionist techniques, for example).

This analysis also allowed us the identification of:

- The "intelligent" function(s) performed by the combination of AI techniques in each use case (anomaly detection or data recognition, for example) ;
- The simulation capabilities that are used, or might be used, to assist in the development of these AI techniques during the case development cycle.

Concerning this last point, it should be noted that 52 of the 149 use cases studied do not require the use of any simulation means, either because the design of these algorithms must be based on real data that already exist or situations that are difficult to reproduce, or because the validation of these algorithms requires the use of the operational system in real conditions.

2.2 Definition of a typology of Artificial Intelligence techniques

Given the great diversity of Artificial Intelligence techniques referenced in the different use cases, we thought it would be interesting to design, for the rest of the study, a typology of AI techniques based on the distinction between the traditional approach to AI, which is generally referred to as symbolic, and the more recent approach, which is often referred to as connectionist.

The following figure presents the chosen typology which includes 7 categories that are illustrated in this table by a non-exhaustive list of AI techniques associated to each category.

AI category	AI techniques
Formal Techniques	Decision trees, Behavior trees, Markov processes, Bayesian networks, Transferable belief models, Fuzzy logic, Expert systems, Logic programming, Ontologies, Game theory, Multi-agent systems, Graph theory, State machines, Petri nets, etc.
Data-centric Learning	Multilayer perceptrons, convolutional networks, recurrent networks, etc. Auto-encoders, Auto-adaptive maps (Kohonen). Boltzman machines, Regression methods, Random forests. Generative Adversarial Networks (GAN)
Environment-centric Learning	Reinforcement Learning (RL) and Deep RL. Genetic Programming. Classifier systems.
Operational Research	Formal Optimization: Linear & Nonlinear Optimization. Meta-heuristics: Simulated annealing, Genetic algorithms, CMAES. Tree search: A*, Branch & Bound technique, Constraint programming. Multi-criteria decision support: Over-ranking or utility-based methods.
Statistical Data Analysis	Dimension reduction analysis: principal components, correspondence factorial, multiple factorial, etc. Classification analysis: automatic, flat or hierarchical, K-Means. Regression Methods
Motion Planning	Formal Techniques: Utility Function Methods, Multi-Agent Systems. Operational Research: Meta-heuristics, Tree search. Environment-centered learning : Reinforcement Learning
Human-centric Techniques	Monitoring the physical and mental state of a human being. Adaptation of the provision of information. Adaptation of the proposed commands

Figure 1: Typology of AI Techniques

"Formal Techniques" generally refers to traditional AI techniques based on what is called the symbolic approach. We have chosen to distinguish "Operational Research", which also comes from this approach, because it is a well-recognized field in the simulation domain.

Concerning the connectionist approach, we have separated machine learning into two categories ("Data-centric learning" & "Environment-centric learning") because they obviously use different simulation means.

"Statistical data analysis" uses all data processing techniques, whether they are frugal or massive. Finally, the techniques associated with "Motion Planning" and "Human-centric Techniques" categories could have been placed in one of the 5 previous categories, but we preferred to group them together because they fulfil two very specific functions in terms of simulation.

2.3 Definition of a typology of Simulation techniques

We have also chosen to define a typology of simulation techniques (see next figure) to characterize the simulation mechanisms that can be used to develop the AI techniques used by the use cases.

Family of simulations	Simulations or Methods	Technical components
Operational simulation	- Instrumented simulation - Virtual simulation - Constructive simulation	- Image generator - 2D/3D Data Base - Computer Generated Forces (CGF) - Serious video games - Technical data generation
Technical simulation	- Numerical simulation - SIL simulation ("software-in-the-loop") - HIL simulation ("hardware-in-the-loop") - MIL simulation ("man-in-the-loop")	

Figure 2: Typology of Simulation Techniques

This typology corresponds to the characterization generally used in the field of military simulation with a distinction between the family of operational simulations and that of technical simulations, with the distinction of the different categories of simulation used in these two families and with an identification of the main technical components that can be found in these simulations.

2.4 Identification of solution alternatives

The identification of solution alternatives was achieved by crossing the categories of Artificial Intelligence techniques present in the use cases with the categories of simulation techniques that were identified in those cases to be able to help the development of the corresponding AI algorithms.

As stated above, each use case typically implements several different categories of AI to perform its intelligent function(s). This means that each use case can be associated with several {AI category; Simulation category} pairs, especially since the need for development, and therefore simulation means, can be different depending on the development stage of the use case.

{IA; Simulation} Pairs Design, preliminary testing and "AI education" phases	Virtual simulation	Instrumented simulation	Constructive simulation	Numerical simulation	SIL simulation ("software-in-the-loop")	HIL simulation ("hardware-in-the-loop")	MIL simulation ("man-in-the-loop")
Formal Techniques	8	0	24	6	14	0	0
Data centric Learning	21	0	11	7	12	0	1
Environment centric Learning	0	0	8	0	5	0	0
Operational Research	1	0	15	4	8	0	1
Statistical Data Analysis	4	0	9	5	12	0	0
Motion Planning	0	0	3	0	0	0	0
Human centric Techniques	0	0	1	0	3	0	1

{IA; Simulation} Pairs Verification, validation and qualification phases	Virtual simulation	Instrumented simulation	Constructive simulation	Numerical simulation	SIL simulation ("software-in-the-loop")	HIL simulation ("hardware-in-the-loop")	MIL simulation ("man-in-the-loop")
Formal Techniques	1	2	24	4	8	5	1
Data centric Learning	1	1	12	4	11	4	2
Environment centric Learning	0	1	9	0	2	1	1
Operational Research	0	1	17	4	2	3	1
Statistical Data Analysis	1	0	10	3	10	3	0
Motion Planning	0	0	2	0	0	0	0
Human centric Techniques	0	0	3	0	1	0	1

Figure 3: Identification of the 27 solution alternatives

As shown in the figure above, this intersection of the two typologies identified 27 {IA; Simulation} pairs divided into two groups:

- 16 {IA; Simulation} pairs correspond to the simulation means that will allow the development of AI mechanisms in the Upstream phases of use case development (left-hand table), whether during the case design phase, the preliminary testing phase or the phase known as "AI education", which generally refers to the construction of AI models based on data or situations for which the AI algorithm can generate a representation;
- 11 {IA; Simulation} pairs correspond to the simulation means that will allow the verification, the validation and the qualification of the AI mechanisms in what we have called the Downstream phases of use case development (table on the right).

Note: The numbers in these tables represent the number of use cases that each {IA; Simulation} pair represents for the Upstream (left) and Downstream (right) phases, and the boxes coloured in red represent what we considered to be the most representative pairs for each AI category in proportion to their presence in the use cases.

3. COMPARAISON OF THE SOLUTION ALTERNATIVES AND PROPOSITION OF TECHNICAL RECOMMENDATIONS

The objective of the task 2 of the study was to analyse the 27 alternatives of solution, represented by the 16 {AI; Simulation} pairs of the Upstream phases and the 11 pairs of the Downstream phases, to propose a list of concrete technical recommendations for the simulation for each solution analysed.

This construction of technical recommendations for each family of solutions was made possible by a preliminary study that consisted in determining the potential impacts on simulation of its utilization for the development of AI algorithms.

In addition, we selected 12 characteristic use cases from the panel associated with one or more {AI; Simulation} pairs in order to ensure the concreteness of the technical recommendations and to serve as an example for their application. This selection, which will not be described here, was based on a set of easily assessable criteria containing in particular, the diversity of AI mechanisms present in the use case, the maturity of the use case and the amount of information known about each case.

3,1 Identification of the impacts on simulation of its utilization for the development of AI algorithms

The proposed solution for each of the {IA; Simulation} pairs corresponds to a list of recommendations to be applied to the considered simulation category when this simulation is used to develop algorithms belonging to the corresponding AI category in the pair.

To establish these recommendations, we started by listing the different modifications that can be made to the simulation mechanisms to make them fit the need. We categorized these potential impacts into 5 categories:

- The first potential impact concerns the interfaces of the simulation that can facilitate its use by the application containing the AI mechanisms:
  - Open interfaces may allow easier interconnection of the simulation with the use case by providing a very large or easily modifiable API.
  - On the other hand, standardized interfaces (e.g. DIS, HLA, etc.) can formalize this connection to allow a quick replacement of the simulation if needed
- The second potential impact concerns the acceleration capabilities of the simulation:
  - You may need a faster simulation to test a large number of scenarios very quickly, for example. We then speak of a "moderate acceleration" of the order of x10 compared to real time.
  - We can also need a simulation with a much higher acceleration rate (of the order of x1000 compared to real time) to allow its use, for example, by machine learning algorithms.
- Simulation models can also be impacted by their use in the development of AI mechanisms:
  - One may need to parameterize the level of detail of these models to adapt them to the development needs of AI algorithms, either by decreasing this level of detail to speed up data generation, or by increasing it to obtain a higher level of realism.
  - We may also need tools to validate the models used by the simulation (for example to generate data) but also the models built by learning using this simulation.
- Obviously, this use of simulation can have impacts on its software or hardware architecture:
  - It may be necessary to have an infrastructure to parallelize the calculations and thus, accelerate the simulation without having to reduce the quality of its models.

- It is also necessary to have means to ensure the coherence of time and models within the simulation, or with the use case, to avoid temporal inconsistencies or biased data exchanges.
- Finally, it is absolutely necessary to ensure the operational representativeness of the simulation:
  - This concerns the representativeness of the data generated by the simulation, or by the AI algorithms, compared to real operational data,
  - This also concerns the representativeness of the implemented scenarios and of the situations generated from these scenarios.

3.2 Technical recommendations sheets for the 25 selected solution families

The main result of task 2 was the provision of a set of technical recommendation sheets for 25 of the 27 of solution alternatives finally selected. Indeed, we considered that the small number of use cases associated with the two {IA; Simulation} pairs associated with "Human centric AI techniques" did not allow to produce recommendations that were concrete and representative enough to be published.

As an example, the following two figures show the Front and Back sides of the technical recommendations sheet for the pair {Formal Techniques; Virtual Simulation} for the "Upstream" phases of the use case development.

The front part of this form describes:

- In its left part, a presentation of the characteristic use case associated to the pair, which illustrates the use of this sheet (here, the case "IA BD 103 - Automatic Geo-referencing"), by specifying the improvements that can be expected to develop the studied AI mechanism (here, a registration algorithm) using a simulation mechanism (here, an image generator).
- On the right hand side, the list of the other use cases of the panel associated with the {IA; Simulation} pair and the summary of the hard spots to be treated, or the points of vigilance to be monitored, to allow the considered simulation (here, the virtual simulation) to be used for the development of the AI mechanisms (here, the formal techniques) for all the use cases of this pair.

Characteristic Use Case

IA BD 103 : Automatic Geo-referencing

Intelligent Function(s)	Navigation assistance (geo-location)
AI Technique	Registration algorithms (SIFT or SURF)
Technical Component	Image Generator
Phase	Design et preliminary tests

Expected Improvements:

- The use of an easy to use "design & test" environment with the ability to evaluate and visualize the results of the registration calculations.

Schema:

Other use cases of the panel associated with the pair

Use Case	Subject
IA BD 2	Detection of abnormal activity in the context of satellite site monitoring
IA BD 20	3D navigation in unknown environment
IA BD 23	Cognitive radar
IA BD 59	ATR SAR - Synthetic image generation by learning
IA BD 70	NAVALIA - Operation of autonomous sensors (buoys)
IA BD 91	Collaborative SLAM at soldier level
IA BD 95	3D terrain model construction

Hard Spots à deal with :

- None.
- The only issue is the ease with which the user can visualize the results of calculations made by AI algorithms.

Figure 4: Recommendations sheet – Front part

This description of the hard spots corresponds to an analysis of the technical recommendations found on the back of the sheet, which presents each of the five impact categories described above:

- Specific recommendations for the characteristic use case (IA BD 103);
- And more general recommendations concerning all the use cases of the {IA; Simulation} pair. Note that when these general recommendations do not apply to the characteristic use case, the use cases in the panel that justify them are indicated in the last column of the table.

Impacts	General Recommendations	Characteristic Use Case	Other cases
Interfaces	Use open interfaces in the virtual simulation to accommodate various types of data.	-	e.g. : IA BD 23 et 70
	Use a virtual simulation with a native standardized interface corresponding to the type of data to be displayed.	Possible use of geographic data standards for transferring between the use case and the virtual simulation (e.g. SHP, GML, etc.).	
Acceleration	No general recommendations.	-	-
Models	Enable a display in the virtual simulation with a multiple levels of detail.	Possibility to zoom in on the areas to be displayed to check that the results of the recalculations by characteristic points have been carried out.	
Architecture	Ensure the temporal consistency between the calculations performed and the display in the virtual simulation	-	Not in the panel
Representativeness	Use visualization to check the representativeness of the manipulated data in the upstream phase.	Visualize the manipulated images and the geolocation data to be adjusted.	

Figure 5: Example of recommendations sheet – Back part

4. PROPOSED EVOLUTION OF THE SIMULATION TO ASSIST IN THE DEVELOPMENT OF AI MECHANISMS

The objective of Task 3 of the study was to define in more detail one or two solutions identified in Phase 2 by proposing an evolution of the considered simulations in the form of a roadmap.

4.1 Selection of the two solutions to be explored in more detail

The selection of the two solutions, among the 25 alternatives for which technical recommendations were proposed in Task 2, was based on the analysis of the level of criticality of the hard spots that we may encounter when we will use simulation to develop AI mechanisms in our future operational systems.

The idea behind this selection is to consider that the improvements made to one selected simulation category will benefit, not only to the most demanding AI category, but also to the other AI categories with which this simulation has been paired.

We therefore evaluated each of the 25 families of solutions according to the level of criticality of their hard spots. Eight criteria were chosen corresponding to three levels of importance in the impact they could have on the modifications we would have to make to enable the simulations to meet the challenges imposed by the use of AI algorithms.

The main criteria we have identified are the "speed of the simulation" and the "fineness of simulation models" which can be seen as contradictory criteria in current simulations. Indeed, the more fine models of simulation are used, the more CPU time will be needed to make the calculations in the simulation:

- The speed of simulation is probably the most important issue we have encountered in recommendations when it comes to developing AI algorithms. This is especially necessary when generating large amounts of synthetic data in a reasonable amount of time or using simulation to run thousands of tests to find an optimal solution to a problem.
- The fineness of simulation models is also important in many applications. It is indeed a question of being able to build and validate intelligent autonomous systems in simulation environments that are sufficiently representative of the real environments in which they will evolve.

The secondary criteria we have identified are "operational realism" and "interface complexity":

- Operational realism is also an important criterion. It can be obtained thanks to a great fineness of the models when it is a question of synthesizing raw data from sensors for example, but it can also be achieved with expert models that are not necessarily very expensive in terms of calculation, for example to generate a tactical situation. Beyond the quality of the models, it is also a question of verifying that the combination of several models is capable of producing realistic data, situations, behaviours or scenarios from an operational point of view.
- The complexity of the interfaces is also one of the issues to consider. For some application domains, there are already standardized interface standards that allow this criterion to be taken into account, but it is often necessary to implement additional interfaces that allow the transfer of specific data.

Many other criteria can also be used to manage the hard spots. We have selected four of them:

- The integration in the simulation of specific codes or models is sometimes necessary to realize a simulator as close as possible to the real system that we want to model. If this integration is desirable, it still represents difficulties with respect to the normal or accelerated operation of the simulation.
- The use of operational component is an additional step compared to the previous criterion. It implies the presence of components of the real system whose absence could hinder the development and especially the validation of the intelligent autonomous system.
- The system coherence is often a corollary of the two previous criteria insofar as we mix real and virtual environments. This coherence criterion can also be used in systems with several simulations where it is necessary to verify both the coherence between the models and the temporal coherence between the different simulations involved.
- The coverage of the tests is a general criterion that is found especially in the downstream phases where it is delicate to validate a system containing AI algorithms without being able to verify the coverage of the situations covered by these algorithms. This is particularly the case for learning algorithms when the data or situations generated do not cover the extent of the data or situations that may be encountered in reality.

By weighting these three categories of criteria in a strong, medium and weak way, we were able to classify the 25 families of solutions retained. The results of this classification are presented in the following figure.

It can be noted that the 7 most critical families of solutions, from the point of view of the hard spots to deal with in terms of simulation evolution, (coloured in red in the table) all concern solutions proposed for the Upstream phases of case development and that, unsurprisingly, five of these families of solutions concern machine learning.

Considering again the number of use cases associated with each family and the diversity of AI and simulation categories, we have reduced the choice to three families corresponding to the following pairs

{Data centric Learning; Virtual Simulation}, {Environment centric Learning; Constructive Simulation} and {Statistical Data Analysis; Software in the Loop Simulation}. After discussion with the French MoD, it seemed more appropriate to focus on the two main categories of simulation that are used in our forces, namely the virtual simulation and the constructive simulation.

{IA; Simulation} Pairs Design, preliminary testing and "AI education" phases	Virtual simulation	Instrumented simulation	Constructive simulation	Numerical simulation	SIL simulation ("software-in-the-loop")	HIL simulation ("hardware-in-the-loop")	MIL simulation ("man-in-the-loop")
Formal Techniques	8	0	24	6	14	0	0
Data centric Learning	21	0	11	7	12	0	1
Environment centric Learning	0	0	8	0	5	0	0
Operational Research	1	0	15	4	8	0	1
Statistical Data Analysis	4	0	9	5	12	0	0
Motion Planning	0	0	3	0	0	0	0
Human centric Techniques	0	0	1	0	3	0	1

{IA; Simulation} Pairs Verification, validation and qualification phases	Virtual simulation	Instrumented simulation	Constructive simulation	Numerical simulation	SIL simulation ("software-in-the-loop")	HIL simulation ("hardware-in-the-loop")	MIL simulation ("man-in-the-loop")
Formal Techniques	1	2	24	4	8	5	1
Data centric Learning	1	1	12	4	11	4	2
Environment centric Learning	0	1	9	0	2	1	1
Operational Research	0	1	17	4	2	3	1
Statistical Data Analysis	1	0	10	3	10	3	0
Motion Planning	0	0	2	0	0	0	0
Human centric Techniques	0	0	3	0	1	0	1

Figure 6: Classification of the families of solutions according to the degree of criticality of their hard spots and selection of the solutions to explore

The following sections describe the details of the work that has been done to evolve these two categories of simulation and ultimately propose a roadmap for the evolution of each of these two simulations.

To do so, we studied in detail the technical recommendations of these two families of solutions to propose a list of technical tasks to address each to fulfil these recommendations. This work was based on the example of the characteristic use case associated with each of the two solutions in order to verify the feasibility and interest of the future simulation tool.

4.2 "Virtual Simulation" Roadmap

For the virtual simulation issue, it is a question of acquiring a simulation capable of quickly generating a very large number of data (images, videos, etc.) representative of the studied domain by using fine simulation models in order to help with the development of data-centric learning techniques in the upstream phases of the development of the autonomous intelligent system.

For example, this evolution of virtual simulation will allow to generate very quickly, for the characteristic use case "IA BD 103: Automatic Geo-referencing", a large quantity of geo-localized images, and of various qualities, to be used as training data for a neural network based system.

As shown in the roadmap figured below, the goal is to build a multi-resolution virtual simulation containing models with different levels of detail, tools to build these models and interfaces to select them.

This simulation will be integrated into an MSaaS architecture capable of activating the different models of the simulation as services and parameterizing the level of detail of these models. This dual capability will allow this new simulation to implement what is called incremental learning where the first phases of learning can be performed with coarse models and the last with very fine models.

It will also be necessary to integrate, as MSaaS services, in this new simulation architecture, tools for validating simulation models and tools for verifying the representativeness of the data generated by these models. Finally, it is proposed to evolve existing standards for all categories of data that can be generated by simulation and to propose new standards analogues to the ones used for images.

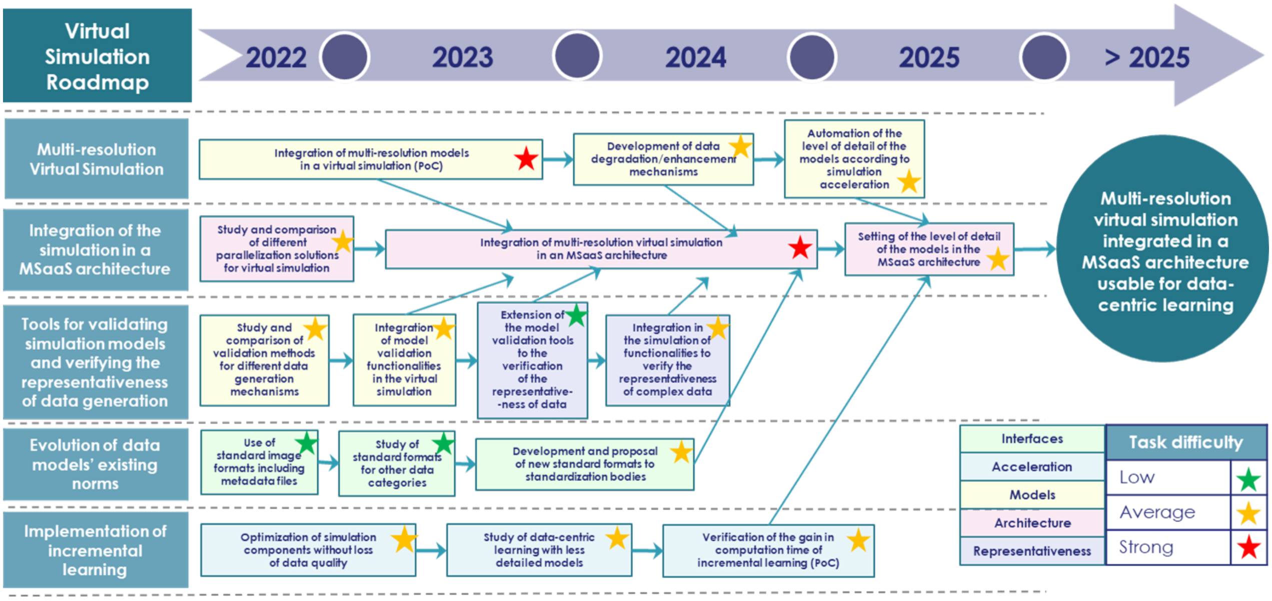

Figure 7: "Virtual Simulation" Roadmap

4.2.1 Roadmap "Simulation Constructive"

For the constructive simulation issue, it is a question of acquiring a simulation capable of combining a very high speed of execution with a strong operational realism of the generated data or situations in order to help in the development of environment-centric learning techniques in the upstream phases of the development of the autonomous intelligent system.

For example, this evolution of the constructive simulation will allow to evaluate very quickly the 4D plans which are built in an iterative way by evolutionary techniques (AFG: Genetically Optimized Fuzzy Logic Decision Trees) for the characteristic use case "IA BD 16: Waze4D multi-actors military avionics".

As shown in the roadmap figured below, the goal is to build a multi-resolution constructive simulation containing models with different levels of detail, tools to build these models and interfaces to select them.

Several parallelization solutions will be studied before integrating the constructive simulation, and then its multi-resolution version, in an MSaaS architecture with the possibility of activating the different models of the simulation as services and to parameterize the level of detail of these models.

This dual capability will allow this new simulation to implement what we have termed gradual learning, where the early phases of learning can be performed with coarser scenarios and models before refining these in the later phases of learning.

It will also involve integrating, as MSaaS services, into this new simulation architecture, tools for validating the simulation models and tools for verifying the representativeness of the data generated by these models.

Finally, this roadmap also plans to propose an extension of interoperability standards to take into account the specific exchanges between simulation and AI mechanisms.

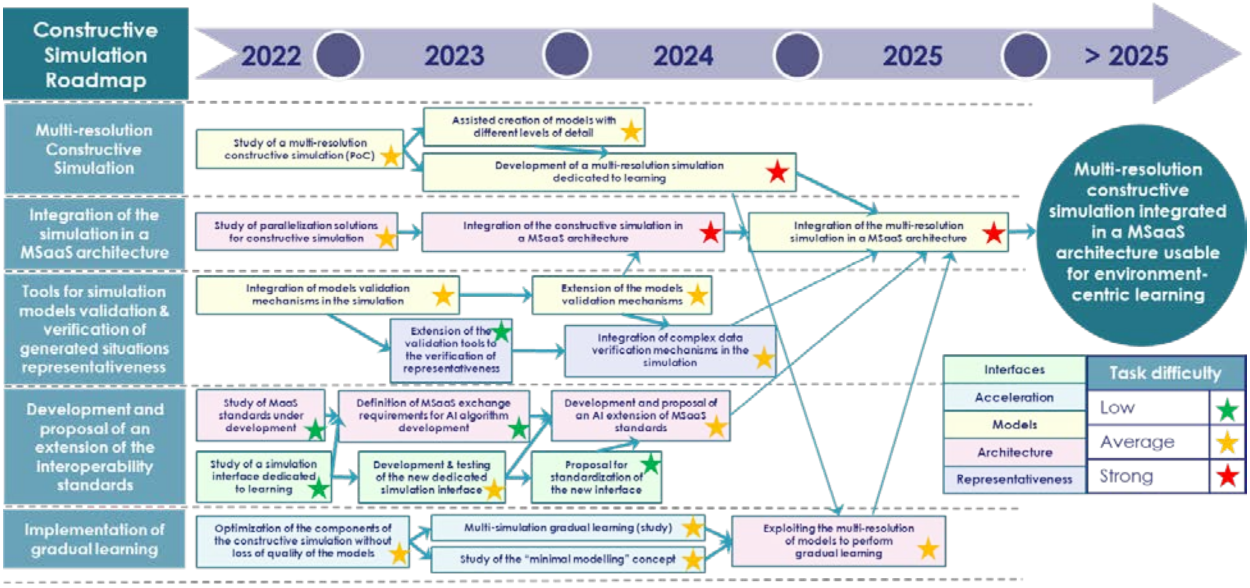

Figure 8: " Constructive Simulation " Roadmap

5. CONCLUSION ET PERSPECTIVES

The work carried out during the SIMSIA study has enabled the implementation of a general method for characterizing operational systems using Artificial Intelligence mechanisms, based on the use of a typology of simulation techniques and a typology of AI techniques specially built for the study.

The result of this categorization allowed us to establish simulation solutions adapted to the development of each AI category in the form of 25 technical recommendations sheets and to identify the impacts on simulation of its utilization in the development of AI mechanisms.

The detailed study of the two solutions finally selected led us to propose to the French MoD a detailed roadmap for the evolution of the virtual and the constructive simulations. The perspectives of the study are contained in these two simulation roadmaps.

Each of the tasks proposed in this roadmap corresponds to a study, a test, a proof of concept or developments that could lead us to the construction of the virtual and constructive simulations that we will need in the future to take into account the issues raised by the use of Artificial Intelligence mechanisms in our operational systems.

The proposed evolutions of the virtual and constructive simulations can be used constructively to meet other Artificial Intelligence needs than those for which they have been proposed and new roadmaps can be established, following the same procedure that has been followed in this study, for the 5 other categories of simulation identified.

Finally, we can see that the two roadmaps are based on relatively similar methods, interfaces and architecture bases and that, therefore, it seems possible to capitalize on the work done in one of the roadmaps to benefit the other. In the same way, all this work could facilitate the evolution of the other categories of simulation or even converge the work towards the realization of a common simulation framework which could, according to the selected services, allow the construction of more general simulations capable of proposing at the same time virtual simulation and constructive simulation services and, later, other categories of simulation.