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ADP014149

TITLE: Simulation of Aircraft Deployment Support

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Simulation of Aircraft Deployment Support

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Abstract

Dassault Aviation uses different software tools as decision-support system for several goals in the logistics support simulation area. A great number of such tools are based on complex mathematical methods that nevertheless required simplification assumptions for the simulated model. They are often irrelevant for logistics network with very erratic behaviors (small fleets for example) where the "steady state" approach is not usable. During the last years software providers have disseminated cheap tools based on Monte Carlo approach which allow to perform, in a very short time, a great number of types of simulation related to Operations Research. "Simulation of Aircraft Deployment Support" (SADS) was developed by the Military Customer Support Division of Dassault Aviation to perform simulations for logistics deployment and support analysis of aircraft sustainment. The SADS tool includes animated visualizations, and is based on the common used ARENA© software (Systems Modeling Corporation) dedicated to modelling and simulation.

1. A new approach for Simulation of Aircraft fleets support

1.1 The background

The "full support" approach which is more and more common in the sustainment of military aircraft area, requires a very accurate attention about the commitments to level of services (like availability of fleets or mission success rate).

Regarding these constraints, different types of simulation (like cost or support and warehouse networks) are very useful for the following tasks, to make cost effective and relevant proposals for future contracts :

- Integrated Logistics Support approach for design of the aircraft and support concept (warehouses network and relevant logistics facilities associated with reliability and maintainability studies).
- Dissemination of the Initial Provisioning Lists for the calculation of the initial logistics resources.
- Supply and support Chain Management for the management of the logistics resources (replenishment of consumables and repair of parts, inventory management) facing a moving context (like new operational needs or raise of the maintenance costs of geriatric aircraft).

1.2 Features of some existing support modelling tools for behaviour simulation

A great number of "in house" software tools dedicated to these needs were disseminated this last decade. They use analytical algorithms based essentially on classical mathematics tools like the "Poisson law" methods for the calculation of level of stocks (theory of replenishment with constant failure rate) and the "Markov Chain" methods when some parameters, as the lead times or times to repair for example, aren't constant.

Based on average values and on simplification assumptions, their main advantage is their capacity to solve the equations describing the model and so to find automatically optimized solutions for several given criteria (like ownership cost or commitment to a given level of service).

For instance, the Initial Provisioning List process for large fleets can often take advantage of thorough but rapid calculations done by such tools. They are based on simplifications and average values of parameters without prohibitive impact regarding the required accuracy of the results.

Paper presented at the RTO AVT Symposium on "Reduction of Military Vehicle Acquisition Time and Cost through Advanced Modelling and Virtual Simulation", held in Paris, France, 22-25 April 2002, and published in RTO-MP-089.

1.3 The limits of analytical tools as help decision systems

But after Initial Provisioning, for the Supply and Support Chain Management (SCM) during the life of the fleets, the strategic forecasts and fleets average parameters are, most often, extremely poor predictors of operational tempo and of the repair/replenishment demand, particularly at the aircraft level (organizational or intermediate level). Additionally, the users and the manufacturers highlight the lack of systematic feedback about the existing fleets support. Often, very few historical data are available about operational readiness, cost of ownership, efficiency of the repair chain, adequacy of quantities of spares parts or health monitoring of reparable items.

So, the classic analytical methods, based on average values and standard deviations of common probabilistic functions, aren't always relevant for this kind of need. And the current modelling tools based on resolution of probabilistic equations aren't efficient for unsteady scenario and process. Indeed, these mathematical models impose prohibitive simplifications in order to be solvable. And there are numerous examples where these assumptions have severe impacts on the level of confidence of the results, like small fleets (less than 10 aircraft), logistics footprint for deployment, erratic operational mission schedules and sudden change of the required availability. Consequently it is very hard, with the existing tools mentioned above, to perform short-term evaluations of the responsiveness of the support system in a very erratic context.

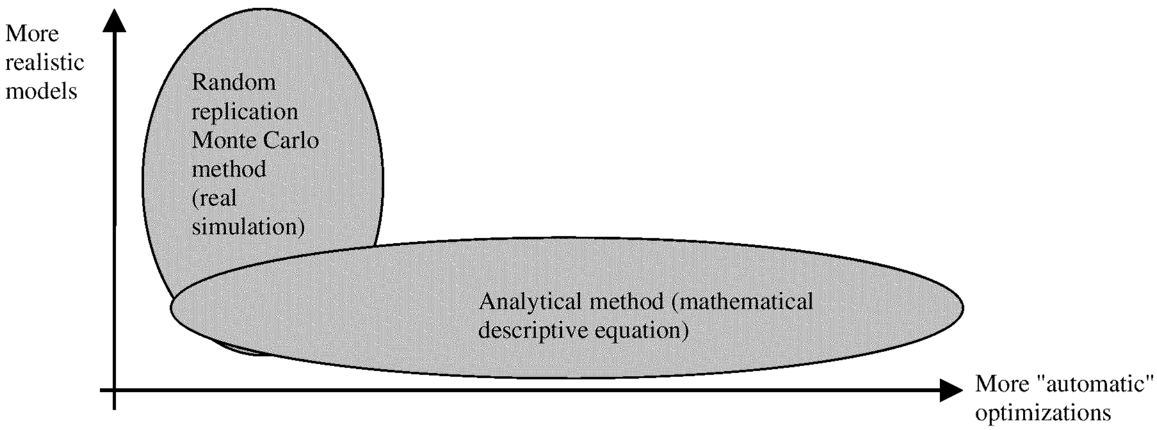
Regarding the maintenance cost of these tools, an other fact must be underlined : when the user needs to implement some changes in the input characteristics of the logistics network, the complexity of these algorithms requires too often unaffordable evolutions. Indeed, they can be performed virtually only by the rare specialists who own the knowledge about this proprietary tools.

1.4 A new generation of simulation tools based on random replications

Nowadays, a new generation of standard software for simulations and animated visualizations are proposed for process with deterministic or random behaviours.

These software are based on Monte Carlo replication method. They offer ergonomic and graphical interfaces which allow to model rapidly, in a realistic way, very complex systems with reusable templates. Consequently, they are easy to use by non-dedicated persons reluctant to complex algorithms implementations. These efforts are very gratifying because you can run immediately animated simulations which show, in an interactive way, the behaviour of the described system whatever the level of its complexity (logistics network facilities, number of random input parameters). In spite of their inability to perform automatic optimizations ("What if ?" approach), they can be considered nevertheless as the "best of breed" to demonstrate the capabilities of complex and random workflow organizations.

These software are often used by manufacturers to model human resources in production facilities or materials needs in workshop.



Dassault Aviation uses such software tools, based on random simulation, by different ways in response to its specific requirements for logistics and support activities. As mentioned above, the aim is to fulfil numerous needs where the “steady state” approach is not necessarily relevant. One of these tools, named "Simulation of Aircraft Deployment Support", is specifically dedicated to model aircraft deployment support.

2. What is SADS ?

2.1 Main features

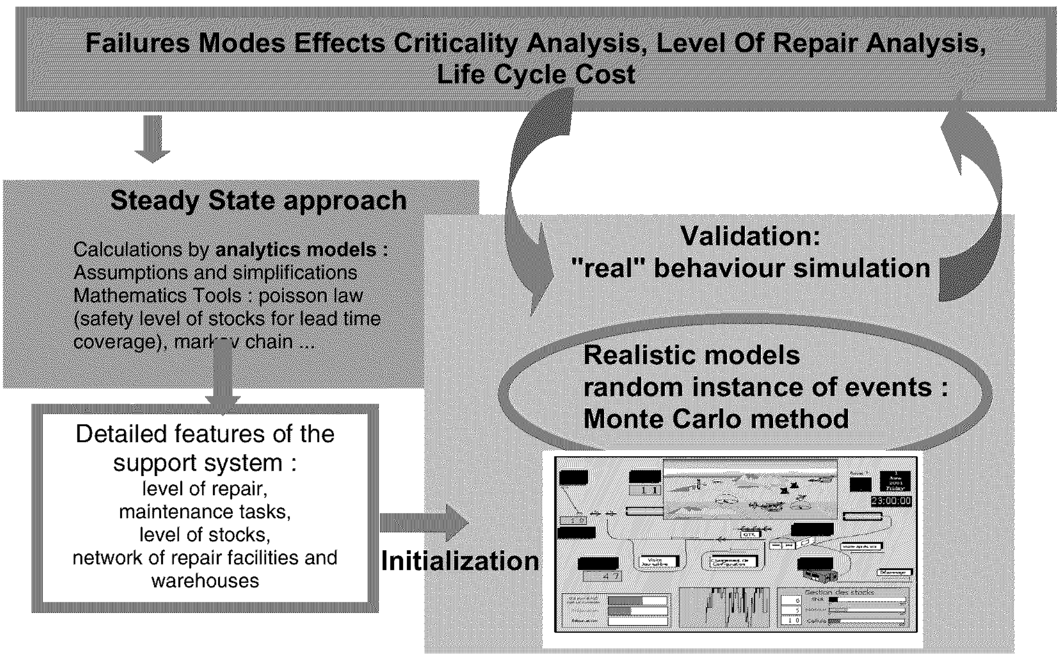
SADS (Simulation of Aircraft Deployment Support) is a software developed "in house" by the Military Customer Support Division of Dassault Aviation. It is based on ARENA© software tool for animated simulations (based on Monte Carlo method and visualizations of deterministic or random process). It is operated on a common PC.

2.2 Goals

SADS is dedicated to operational help-decision for deployment of aircraft (fleet size, logistics footprint, supply chain network) with model of the random behaviour of aircraft subsystems and of logistics networks and maintenance organizations (with their human resources).
SADS is particularly relevant to complex logistics and maintenance models where hazard is very present and where erratic behaviours are relatively unpredictable. It is particularly relevant to studies for full "contractor assisted support" proposals. So, SADS can be used for a large number of matters like the following : level of repair analysis (to influence aircraft system design), calculations for support system design (initial provisioning), business model evaluation (life cycle cost), determination of the best ways for risk mitigation (lead time coverage, safety level for a given no stock-out probability), comparisons of the supportability of different types of aircraft, evaluation of the availability of aircraft depending on deployed logistics footprint during isolated deployments, measurement of the performances of different supply and repair chain organizations regarding expected service level (missions success rate).

2.3 Limitations and best uses

The simulation with SADS isn't relevant to optimize automatically a support system (the best solutions must be found manually), or to calculate directly optimum solutions (example : to calculate the more cost effective level of repair and support network in accordance to a given operational requirement). But SADS is relevant to size accurately a given logistics support network which was initially roughly calculated by analytic methods, and to make comprehensive and very realistic validations. This approach is detailed in the following figure.



3. Detailed presentation

3.1 Main parameters

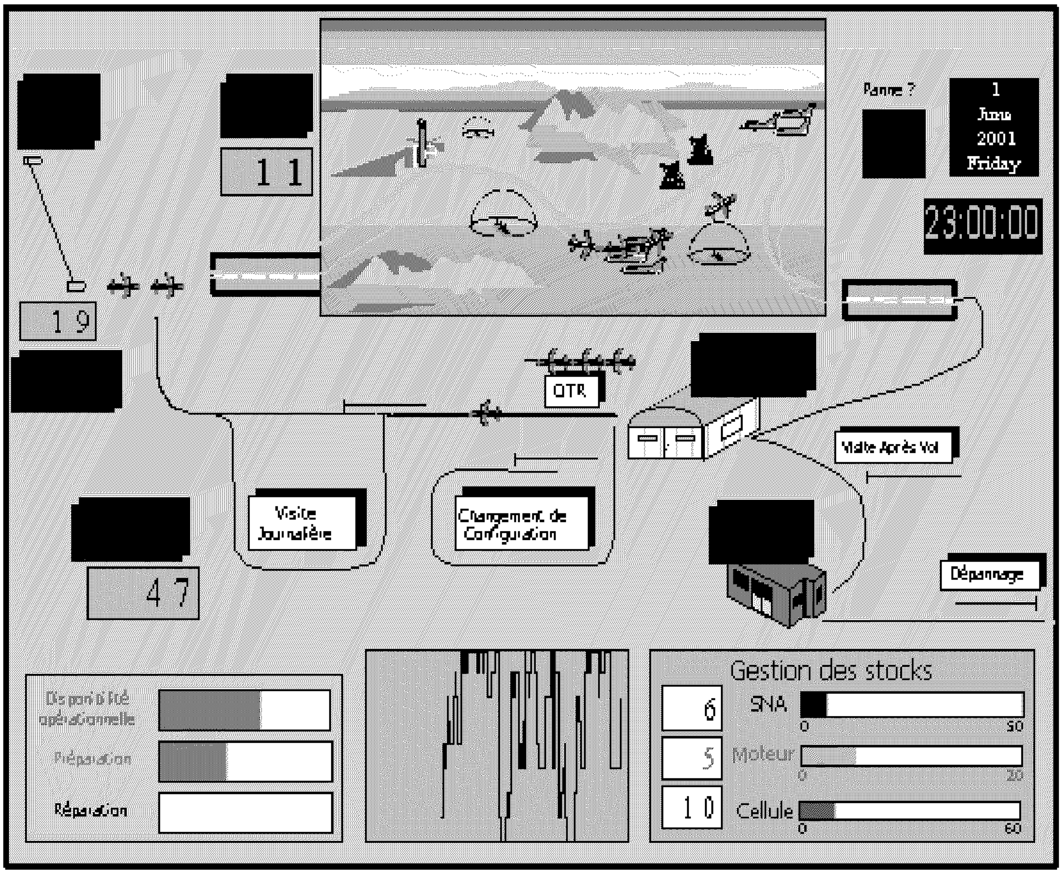
The main input parameters of the model are the following :

- Size of the fleet (the number of initial available aircraft can be defined).
- Description of the operational context : mission schedule, patrol size, duration of flights.
- Type of aircraft (different types of aircraft can be defined) : breakdown of the aircraft (description of aircraft elements or subsystems by LRUs (Line Replaceable Unit) characterized by MTBF, parameters for flight servicing and visits (human resources and time required).
- Maintenance tasks to replace failed LRUs (time to restore).
- Maintenance capacities (human resources) : preparation, flight servicing, visit and maintenance of aircraft (visit before flight, visit after flight, daily visit, change of configuration, OTR (operational turn around) air-air or air-ground at the organizational level), repair of LRUs at intermediate level by exchange of Shop Replaceable Assemblies.
- Logistics network and available resources (intermediate level warehouse, maintenance depot level activities) : repairability of LRUs, consummations of SRAs (Shop Replaceable Assemblies), replenishment of spare parts (flow and throughput times of spares replenishment from the depot level to the aircraft).

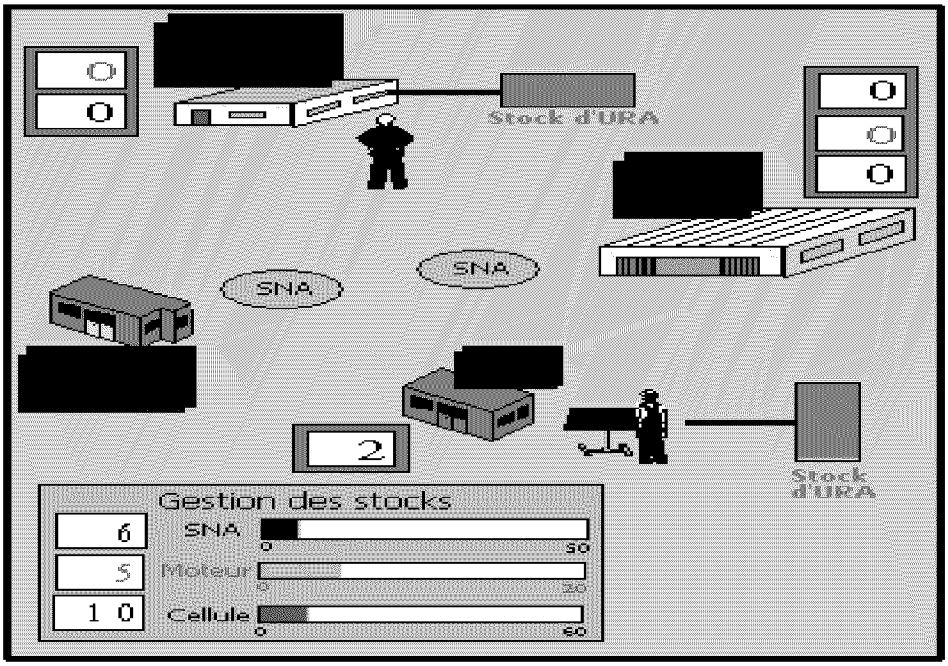
3.2 Global view of the model

A graphical view of the model is provided in the following figures.

ORGANIZATIONAL LEVEL :



INTERMEDIATE AND DEPOT LEVEL :



3.3 Used scenario and detailed parameters

Note that every value of the following parameters can be easily changed, depending on the needs of the users.

- Aircraft description :

For the aircraft, three subsystems (considered as LRUs) are defined for this simplified use of SADS aimed at showing the different operational behaviours (engine, WDNS[1], aircraft systems).

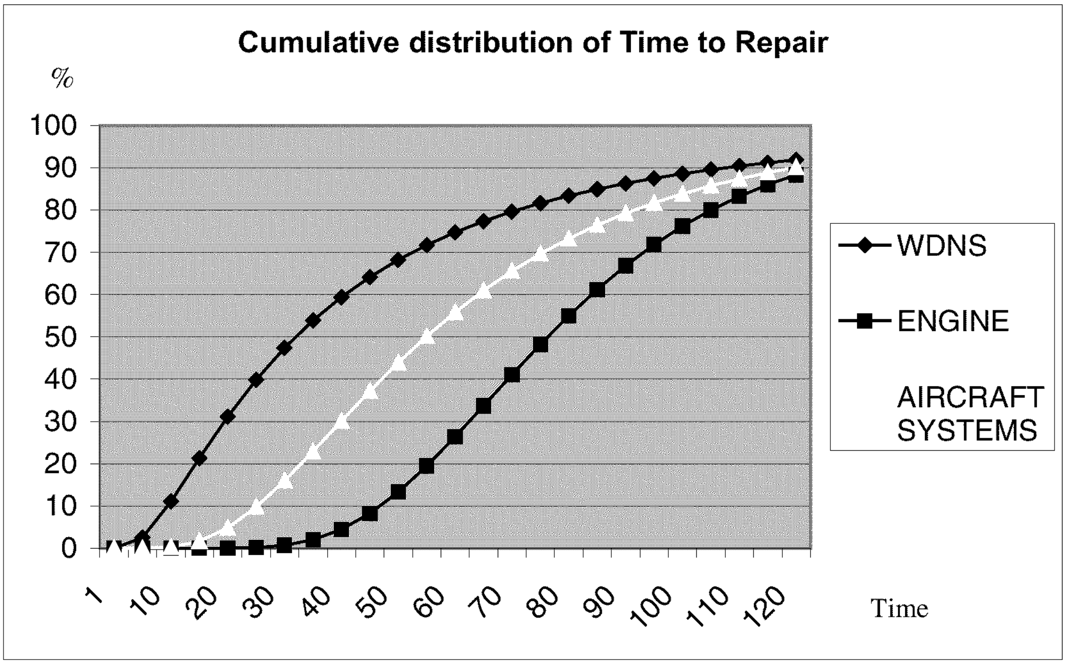
- For each LRU the following elements are described :

Maintainability : Time to restore (lognormal distribution law with shape parameters "Mu" and "Sigma" based on extractions of Logistics Support Analysis Record), with a complementary parameter "exchange time" for the engine only.
Number of required mechanists for the maintenance tasks.
Reliability (Time between failures : exponential distribution with shape parameter "lambda" as the constant rate of failure).

[1] weapons delivery and navigation systems.

- Example of input Data for each aircraft :

Cumulative distribution of "Time to Restore" (time in minutes) :



MTBF (flight hours) :

WDNS	9
Engine	50
Aircraft Systems	11

Human resources :

	Duration (minutes)	Number
Visit before flight	15	2
Daily visit	45	2
Visit after flight	15	1
Air-air Turnaround	23	6
Air-ground Turnaround	45	6
Change of configuration	45	3
Engine exchange time	45	4
LRU exchange		3

- Operational needs :

Every day, missions are generated responding to a defined schedule (15 missions per day, one mission every 1.5 hours). Each mission is characterized by the required number of aircraft (random distribution between 2 and 4) and its duration (2 hours).
If the number of available aircraft is insufficient, the mission is canceled ; the number of canceled missions is recorded.

- At the organizational level :

The preparation tasks of aircraft are characterized by the type of visit and flight servicing on aircraft (visit before flight, visit after flight, daily visit, change of configuration, operational turnaround); the need of OTR

and change of configuration is determined randomly (with a fixed average rate) for every aircraft after every flight.
For maintenance works, the failures of LRUs during flight are randomly generated depending on the probabilistic law of failure of each type of LRU. Note that for the flight hours count, in case of failure of one LRU, the time duration of flight is the time preceeding the failure. For the required human resources (mechanists), time and human resources are required depending, for each task, on the type of LRU as mentioned for the aircraft parameters. Note that, for the engine, if the time to change the engine is smaller than the time to restore randomly determined, the time to repair the aircraft is the time to change the engine. The number of mechanists who are available for all this tasks, can be defined as an input parameter.

- At the intermediate level

The activity of aircraft generates needs for "ready for issue" LRUs, so the intermediate level activities are modelled with several representative parameters. The number of spare parts available in warehouse for aircraft is tracked, the warehouse is replenished by the repair workshop. For the maintenance tasks dedicated to the repair of parts and the replenishment of warehouses, a repairability rate is defined for each LRU; so a certain quantity of LRUs isn't repaired at the intermediate level and is directly sent to the depot level. The time to repair at the intermediate level is determined randomly with the probabilistic laws depending on each type of LRU. Two workshops with limited human resources and waiting queue are defined, "Automatic Test Equipment" for WDNS, and Repair workshop for engine or aircraft systems. Elimination rate is not yet incorporated in the model.

Workshop	**LRU**	**repairability rate**	**Time to repair** (random triangular law, shape parameters in hours)	**human resources required for repair of one URL**
ATE	WDNS	80%	18, 24, 30	2 mechanists during 4,8 hours
Repair	Engine	20%	18, 24, 30	4 mechanists during 20 hours
Repair	Aircraft systems	20%	18, 24, 30	4 mechanists during 8 hours

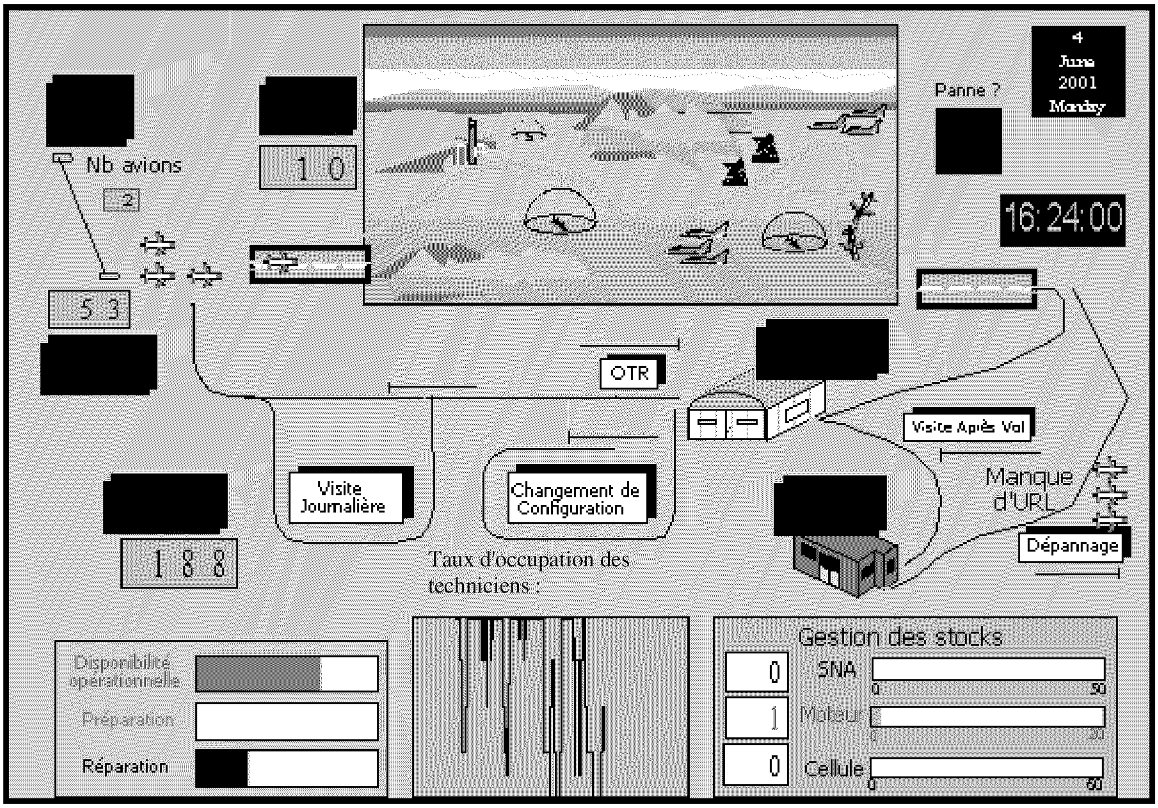
- At the depot level :

The activities of depot are described by transportation times, repair times and replenishment of intermediate level warehouses. The global Turn Around Time is determined by a random triangular law with the following shape parameters : 144, 168, 192 (in hours).

3.4 Demonstration : output parameters and metrics of the behaviour of the system

The metrics used to evaluate the behaviour of the system (efficiency, proportion of busy technicians, level of service, operational efficiency…) can be freely implemented in an large number of different ways. Indeed, every entity of the model can be measured, and the relevant data can be captured and recorded during each simulation. All sorts of charts and figures can be produced easily, with standard interfaces, to calculate and show all sorts of synthetic parameters.
But the first way to verify the behaviour or the efficiency of the system is to look directly at the simulation ; this is particularly relevant for very erratic contexts.

As an example see the impact on availability of insufficient number of spares in stocks :



Depending on the chosen output parameters, several instances of use can be performed as the evaluation of a given sustainment network (obtained level of service), the evaluation of the required size of a fleet for a determined mission schedule regarding logistics means or to tighten the space of multi dimensional feasible region (size of fleet, human resources, stocks) for a given rate of missions success. An other way of using SADS is to compare different types of aircraft, regarding the availability of their LRUs and their Time to Repair for a given logistics capability.

To illustrate the features mentioned above, the following scenario is provided about the optimization of logistics resources for a given operational need. The objective is to minimize level of stocks without impact on the rate of non aborted mission. To meet this requirement several simulations are run (the assumptions for each parameters are those which were mentioned above)

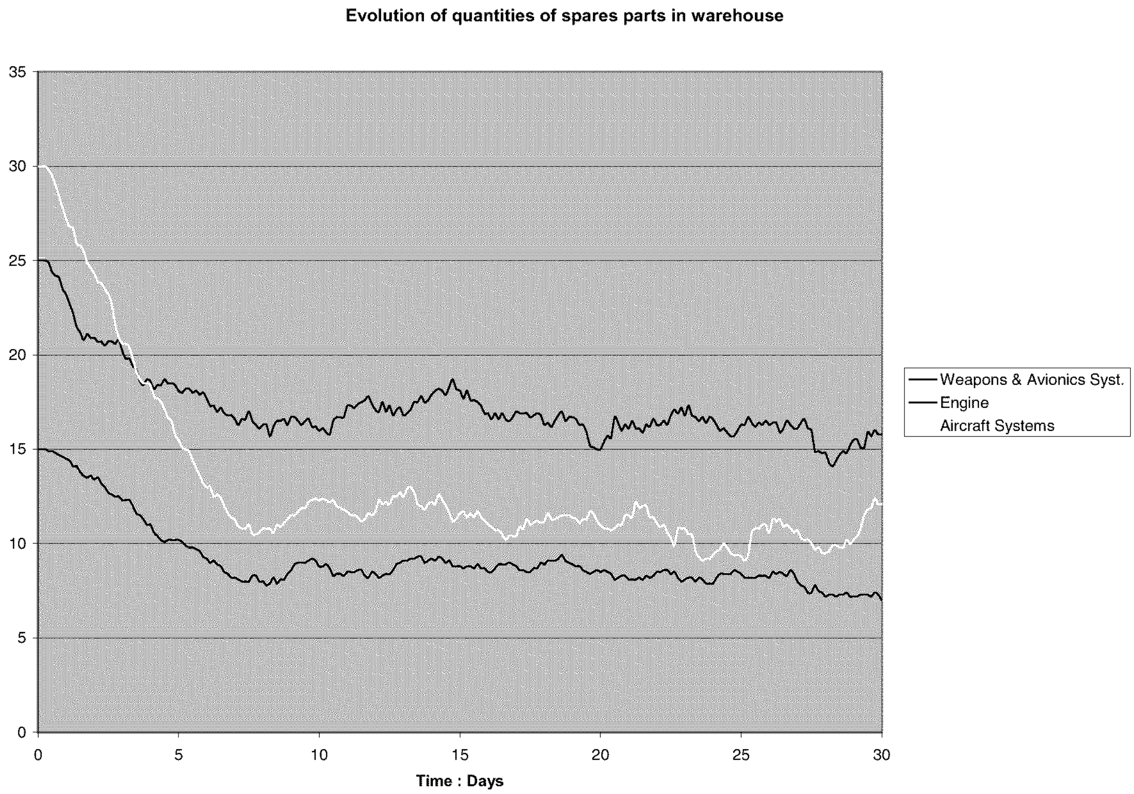
- First Simulation :

	Initial number of LRU
WDNS	25
Engine	15
Aircraft Systems	30

The results are :

	Number of used LRU
WDNS	107
Engine	34
Aircraft Systems	96

Rate of non aborted mission : 81,76 %
Cumulative total of hours of flight :1862,30
Average number of available aircraft :6,50 sur 10



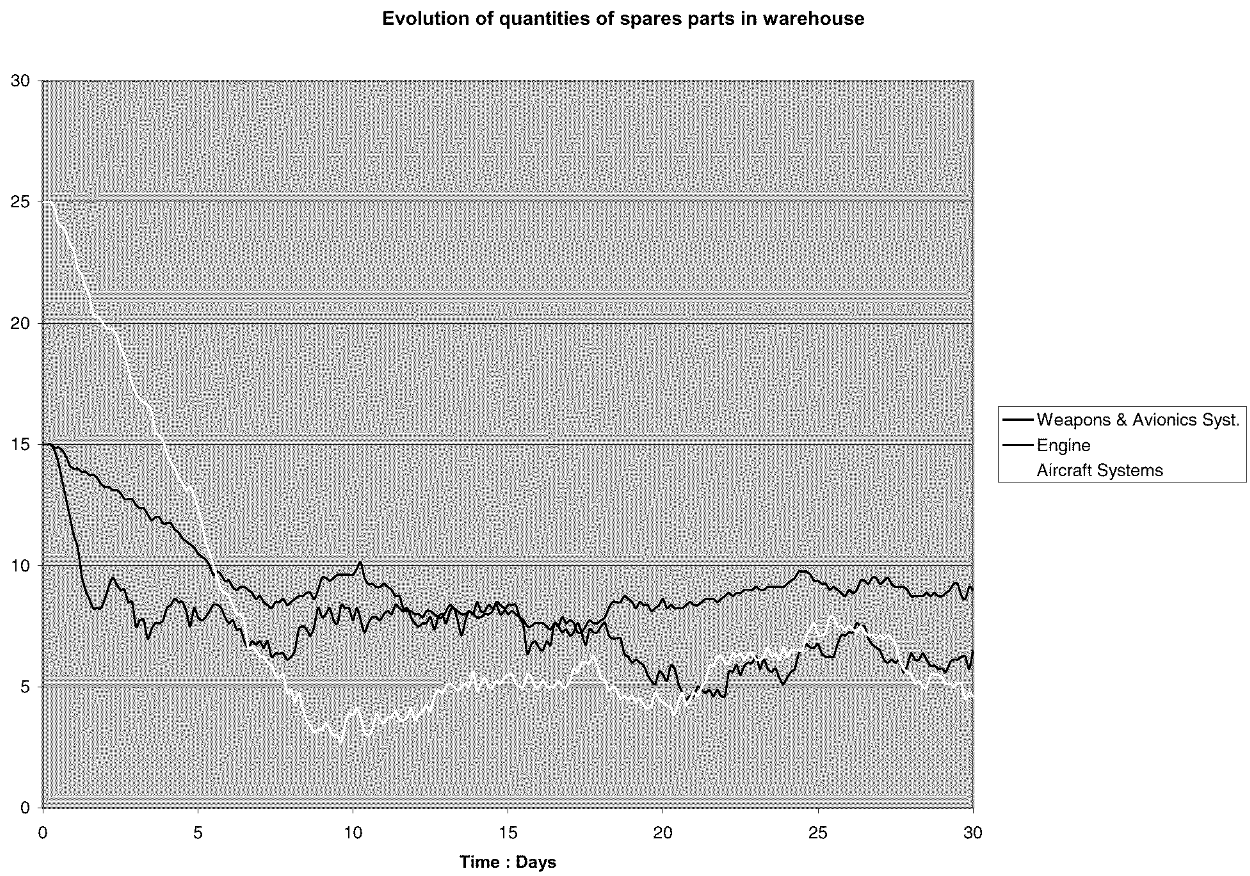
- Second simulation :

	Initial number of LRU
WDNS	15
Engine	15
Aircraft Systems	25

The results are :

	Number of used LRU
WDNS	106
Engine	33
Aircraft Systems	101

Rate of non aborted mission : 80,69 %
Cumulative total of hours of flight : 1822,00
Average number of available aircraft : 6,50 sur 10



So we have demonstrated that a significant reduction of initial quantities of spares parts has no real impact on the availability of aircraft and missions success rate.

3.5 Convergence criteria and validation of the models

The first step in order to validate the model is to determine convergence criteria. Indeed, the results obtained by Monte Carlo simulations must be associated with the required confidence level. The confidence interval must be measured with representative metrics (one or several discriminating output parameters). The confidence interval of the results for an output parameter is linked with the number of random input parameters, the probabilistic distribution of each input parameter and the number of replications which were run for the simulation. The required confidence interval must be compliant with the number of replications which can be performed in accordance with the available hardware capacities (time of computation). For example, with 6 Random input parameters for this model (3 probabilistic laws "Times To Repair" and 3 probabilistic laws "Time Between Failures") we have chosen the number of non aborted missions (15 missions are generated every days) and the number of failures per WDNS URL as output parameters ; simulated duration for each replication is 3 days. So, the following confidence intervals[2] (half width at 95 %) were obtained :

10 replications :	**Half width**	Average	Maximum	Minimum
Number of canceled missions	**1.25**	2.80	7.00	1.00
Number of WDNS failures	**2.15**	10.20	15.00	7.00

50 replications	**Half width**	Average	Maximum	Minimum
Number of canceled missions	**0.49**	3.32	8.00	0.00
Number of WDNS failures	**0.99**	11.2400	22.0000	5.0000

100 replications	**Half width**	Average	Maximum	Minimum
Number of canceled missions	**0.28**	3.34	8.00	0.00
Number of WDNS failures	**0.63**	11.45	22.00	5.00

With these examples we verify how the confidence interval narrows when the number of replications increases.

Then, the validation of the model can be ended by the following methods :
- compare the reactivity of the SADS simulation system responding to the change of the values of discriminating input parameters,
- compare the results with other tools (like analytical algorithms).

3.6 Main advantages in comparison with other types of legacy systems

As mentioned above, the main advantages of such common-used information technology (ARENA© and Monte Carlo Simulation Method) are the possibility to build by an interactive and graphical way complex models of logistics and maintenance networks. So you can show the realistic behaviour (with all required details) of the system through animations (function of the time) with the ability to perform accurate real life age tracking of the described system (the convergence criteria are easy to determine).
Additionally, in spite of this ease of use, you have the free choice of probabilistic distribution functions (for instance whatever their complexity and their features) relevant to the real behaviour of the operational systems without simplification constraints.
Note that the ownership costs (license for ARENA©) are compensated by the "light" maintenance (open source, no proprietary contract) of the model.

4. Conclusion

As said above the model is always scalable, so the following enhancements are scheduled to propose a more comprehensive model : detailed age track parameters of aircraft activities (number of landing,…) for scheduled maintenance on LRUs, different or random features of missions regarding the tracking of aging parameters, multiple LRUs, simulation of forecasting tools and adaptation of the reactivity of the supply or repair chain (show the added value of pro active support chain).

It is important to note that each user, with a minimum knowledge of the ARENA© tool, is able to complement the model so as to make it relevant to his particular needs. Generally, the goal is to enhance the realism of input parameters (more realistic probabilistic distribution law, deterministic parameters change by random data) regarding the modeled context, to complete the core model (functional workflow and logistics network), and, finally, to add output metrics. But currently, SADS is well suited to accurate comparisons between different types of aircraft programs, particularly for isolated deployments.

[2] This value is interpreted by saying "in 95% of repeated trials, the sample mean would be reported as within the interval sample mean ± half width".

Additionally, the Military Customer Support Division may extend the use of SADS. The objective is to demonstrate and calculate the added value of an adaptable logistics loop (priority, Turn Around Time) which should be able to adapt his reactivity and his responsiveness in front of, for example, sudden changes of the customers operational needs or increase of unscheduled maintenance tasks. The aim is to give help decision data to build a collaborative logistics approach between Dassault Aviation and his customers so as to bridge the void between planning and execution.

As a final conclusion we could underline that, in comparison with the classical approach based on analytical algorithms which are useful for a large number of needs (see PRICE HL© or CESAR© [3] for initial conception's stages or long-term ownership's cost optimisation), the approach based on Monte Carlo random trials is relevant to short term "dynamic behavior" only but it does it very well. So, software as SADS, could be used in a very efficient way for the Air Forces or Naval Air Forces as help decision tool.

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[3] Software tool of the "Direction Générale de l'Armement" (French Ministery of Defense) used at Dassault Aviation.