ADVANCED MONITORING SYSTEM BASED ON UNMANNED AERIAL VEHICLES; FLEET AND INTEGRATED LOGISTIC SYSTEM SIZING BY MONTE-CARLO SIMULATION

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Abstract

SMAT-F1 is a research project funded by the Regione Piemonte (Italy) and promoted through the Comitato Promotore Distretto Aerospaziale Piemonte (Piedmont's Aerospace District Promoter Board).

It is also co-funded by European Regional Development Fund (E.R.D.F.) within the Regional Operative Program 2007/2013.

The main objective of SMAT-F1 research project is monitoring the Piedmont environment, both to accomplish with planned tasks and to deal with emergencies or other kinds of anomalies; the system concept was driven with the idea of 3 different classes of Unmanned Aerial Systems (UAS), each one with several Unmanned Aerial Vehicles ((UAV)and its own Ground Control Station (GCS). The three GCS have to be interfaced with a single Station of Supervision and Control (SSC), to coordinate and control the operations of the whole system.

The intrinsic complexity of the proposed system leads to the need of a thorough study about integration between the different assets playing working in this scenario, in terms of system availability and–effectiveness; reaching the goal of a well-balanced system necessarily goes through the sizing of a proper logistic support system, in terms of operating and maintenance basis spread throughout the monitored territory, relative logistic resources amount, as well as the more convenient Reliability and Maintainability levels for various UAS and the best maintenance strategy for the 3 fleets.

For this reason, considering the high number of choices available, it has been considered a simulation, through the implementation of a Monte-Carlo method, in order to verify the proposed model and define a complete operational environment for the described system.

1 General Introduction

SMAT project has been funded by Regione Piemonte, by now for the first phase (named SMAT-F1), currently under development under the direction of ALENIA AERONAUTICA SPA and with the participation of other large companies (such as SELEX GALILEO), Research Institutes and several SMEs.

In particular, this work shows a contribution by a Research team of Politecnico di Torino and one of the SMEs involved in the Project, S.P.A.I.C. srl, a "Spin-off" of Politecnico di Torino.

A conceptual overview of SMAT system is shown in in which it can be seen how the 3 Unmanned Aerial Systems (UASs, that is the join of an UAV and its own GCS) are respectively:

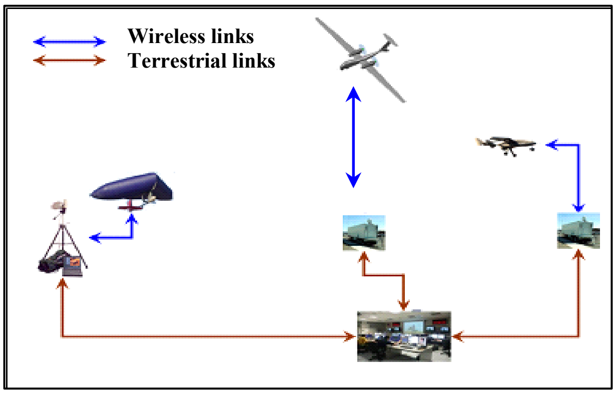

Fig 1. The link scheme between Assets/GCS/SSC

a) A Medium (High) Altitude – Medium Endurance (MALE) UAS;
b) A Medium Altitude – Medium Endurance (MAME) UAS;
c) A Low Altitude – Short/Medium Endurance (LASME) UAS;

The system appears to be highly complex, in particular considering the associated Logistic Support System (for the 3 UASs and for SSC), needed to guarantee an efficient operational activity; this last issue would imply, by means of System Requirements:

1. a certain number of UAVs, for each class;
2. certain values of technical features such as Reliability and Maintainability of UAS (and of SSC);
3. a sizing for logistic support system of UAS and SSC ;

The optimization of the set shown in Fig 2 is difficult, particularly considering the complexity, but really more extended yet, considering the different classes of UAS and the complexity brought by SSC and by the telecommunication network.

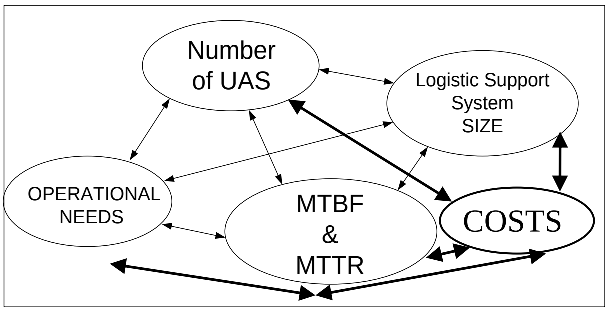

Fig 2. Correlation between operating variables

This problem was faced by a Research Team from Politecnico di Torino and S.P.A.I.C. srl; the chosen way was the development of an efficiency simulation of the whole system based on Monte-Carlo method, topic on which the Research Group has achieved great experiences in the past [1], [2], [3].

The paper will describe with more detail the configuration and the features of such a simulation model, showing how it would result extremely useful in the phase of requirements definition, in particular providing feasible values for the following issues:

a) number of UAV for each class of UAS;
b) requirements about Reliability and Maintainability (for both UAS and SSC);
c) Features and sizing of maintenance resources, such as number of maintenance teams for each UAS and for each operation basis, number of daily and weekly shifts, strategies for maintenance.

2 S.M.A.T. program context

As described in section 1, the S.M.A.T. program is based on the simultaneous and synergic use of three different Unmanned Air Systems (UAS) in order to gain a full monitoring of the Piedmont territory. This can be achieved through the cooperation of the three described assets.

As shown in Fig 3, each of the UAS plays a different role in the scenario: the MALE UAV operates as a general supervisor of the controlled area, circling alone at 45000 ft over the territory and monitoring the entire Piedmont region; in case of need, it's possible to activate the other two systems (MAME and LASME) in order to perform a more accurate investigation on the phenomena that have required special attention (e.g. anomalies or danger situations, like fires and floods): the lower flying altitude of the other two UASs, combined with a smaller speed, allows the payload carried by this two assets (mainly high definitions cameras and IR sensors) to achieve a better situational awareness of the monitored event. In Fig 3 it can be seen that while the MALE UAV plays its role, generally, alone, for the reasons previously described there are more than one MAME or LASME UAV circling over the monitored area, depending on what the MALE found interesting to further monitor.

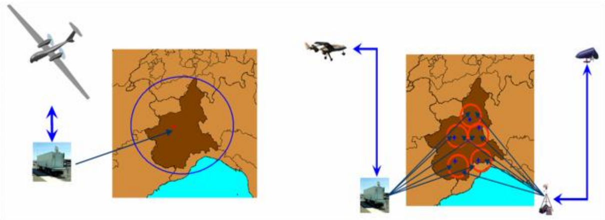

Fig 3. Mission scheme for each asset

For this reason, it is particularly interesting to investigate what would be the right size of the three different fleets, and their related logistic support (in terms of operating basis, scheduled maintenance, working crews), in order to achieve the desired efficacy of the system, contemporarily reducing the operating costs.

Each of the three assets has been deeply studied, in order to achieve as much information as possible, in terms of logistic needs, maintenance tasks and performances, in order to have a correct model to run the simulation with.

The three assets used in the S.M.A.T. program are those depicted below:

- A possible MALE asset, shown in Fig 4, which will circle at 45000 ft over Piedmont region area. An overview of its main performances is given in Tab 1, even it is to be considered that size of craft could be change in the future;

Fig 4. The MALE asset

Dimensions	
Length	11.47 m
Wing Span	25 m
Weights	
Empty Weight	2213 kg
Maximum Take-off	3763 kg
Performances	
Endurance	30 hrs
Cruise speed	200 KTAS
Operational altitude	45000 ft

Tab 1. MALE main features

- The MAME asset, which is more likely to be identified with the Falco UAS (as shown in Fig 5), produced by Selex Galileo. The company gives, for this kind of asset, the data reported in Tab 2; as mentioned before (see Fig 3 for reference) this asset could not be employed alone, but in mutual cooperation with other similar UAVs and/or with the further assistance of a third type of UAS; certainly the MAME will fly from more than one base, spread on the territory

Fig 5. The MAME asset

Dimensions	
Length	5.25 m
Wing Span	7.2 m
Weights	
Empty Weight	300 kg (approx)
Maximum Take-off	420 kg
Performances	
Endurance	14 hrs
Cruise speed	60 m/s
Operational altitude	15000 ft

Tab 2. MAME main features

- The LASME asset, whose mission will be to deeply monitor the areas that the MALE marked as "hot" at low speed and low altitude. The type of UAV used for this mission is the one depicted in Fig 6 (a small UAV made by Nimbus company), which combines static and dynamic lift in order to achieve a lower flying speed, useful to slowly pass over the "hot areas" to monitor them. Again, an overview of the main performances is given in Tab 3.

Fig 6. The LASME asset

Dimensions	
Length	4.3 m
Wing Span	6.5 m
Weights	
Empty Weight	35 kg (approx)
Maximum Take-off	40 kg
Performances	
Endurance	2 hrs
Cruise speed	30 km/h
Operational altitude	1000 ft

Tab 3. LASME main features

3 Fleet analysis

For the purposes described in section 1, it is currently under development a tool (in MATLAB/Simulink suite) able to simulate the operational environment mentioned above and, as a result, forecast the right size for the three asset's fleet and for their related logistic support (always in terms of operating basis and maintenance needs).

To provide an example of application, the tool can be used to verify the fulfilment of a given requirement, with the relative confidence level about time spent with at least one aircraft operating with respect to the overall length of simulation, by means of a given set of input parameters, such as:

- Mission Parameters (e.g. the length of a single mission);
- Reliability and Maintainability features (above all, MTBF, statistical distribution of times required for different kinds of maintenance actions);
- Number of vehicles;
- Number of maintenance teams;
- Length of shifts for maintenance teams;
- Maintenance and fleet management strategies.

The software can provide information about the system effective capability to fulfil the requirements and eventually provide information about the optimal size of fleet and logistic support service; for example, if there is a confidence about the fact that a number of vehicles, would not be utilized in a significant timeframe, the conclusion would be that they are redundant. The same can be applied for the maintenance hours cumulated by each maintenance teams; other possible extensions are currently under assessment; a possible improvement could be the usage of numeric multi-variable optimization algorithms, such as genetic algorithms or simulated annealing.

Actually, the tool has been applied in a complete environment only to the first asset (MALE), but deep studies are being made to apply the same scheme for the other two remaining fleets.

3.1 The MALE fleet

As mentioned, the first analysis has been carried out on the MALE fleet. This kind of application has been very useful to trim the behaviour of the simulation tool , due to the lower number of variables that have to be taken into account.

The study has been organized into a series of steps that has to be processed in the right way, in order to ensure the correctness of the entire process: the first part was to model all the flowcharts that would describe the behaviour of all the actors present in the scenario (mostly the flying asset and the maintenance teams) related to the mission scenario described above and depicted in Fig 7.

Once defined the sets of variables and what would they mean (for example, the different operating statuses for the UAV as simulation time passed), the research team draw a complete set of flowcharts, mutually connected depending of the operational situation, which would lead the way to the proper definition of the simulation software. In Fig 8 it has been shown the main chart, able to describe the general situation of the system: for each of the different statuses (the cyan boxes) it has been developed an autonomous flowchart (an example is depicted in Fig 9 for the in-flight backup) capable of dealing with a particular need of the complete system.

The main variables which had to be taken into account were, mainly, the number of UAVs composing the fleet (more than one, even considering that the MALE would operate as the only asset in the scenario able to fulfil its mission, because of necessary maintenance downtime), the number of operating basis, the necessary maintenance teams (and, eventually, their work shifts) and the maintenance basis.

Fig 7. MALE mission scenario

These variables are deeply influenced by the R.A.M.S. (Reliability, Availability, Maintainability, Safety) characteristics of the UAS (mainly represented by the planes' MTBF *mean time between failures* and MTTR, *mean time to repair*), so a correct set of maintainability data for the UAV is of great importance.

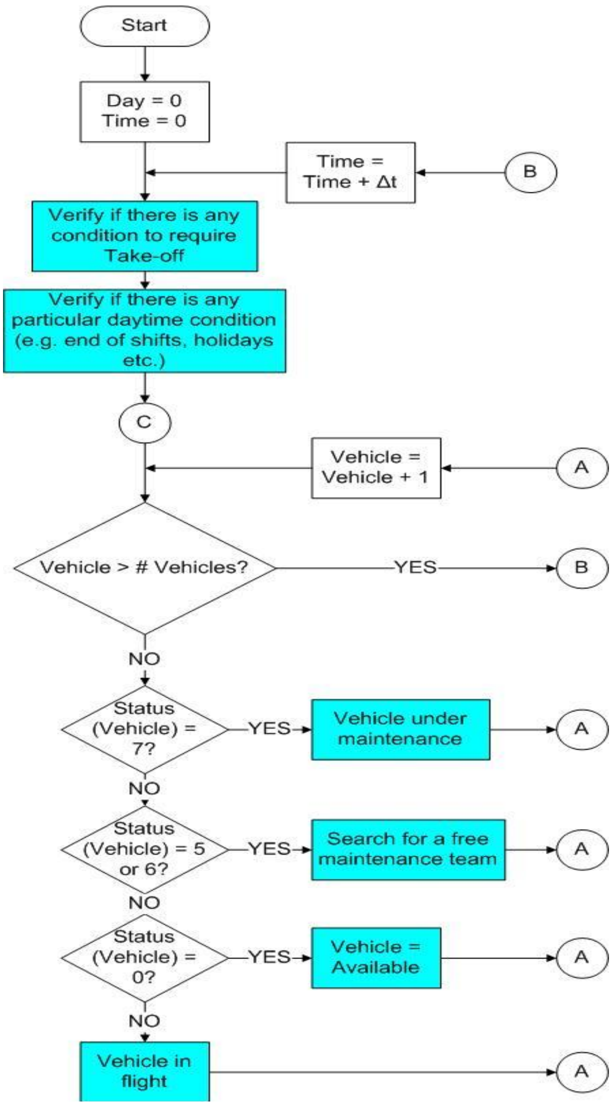

Fig 8. Main loop flowchart

Another factor of great importance is the design of the logistic support net for the considered asset: in order to optimize the whole system it is necessary to consider the best maintenance and logistic strategy, for example if the operative base for the UAV is also a maintenance base, considering also the fact that there are several maintenance levels and only a few of them can be performed on a remote location, so it has to be planned even the number of maintenance basis, each one with its own working crew.

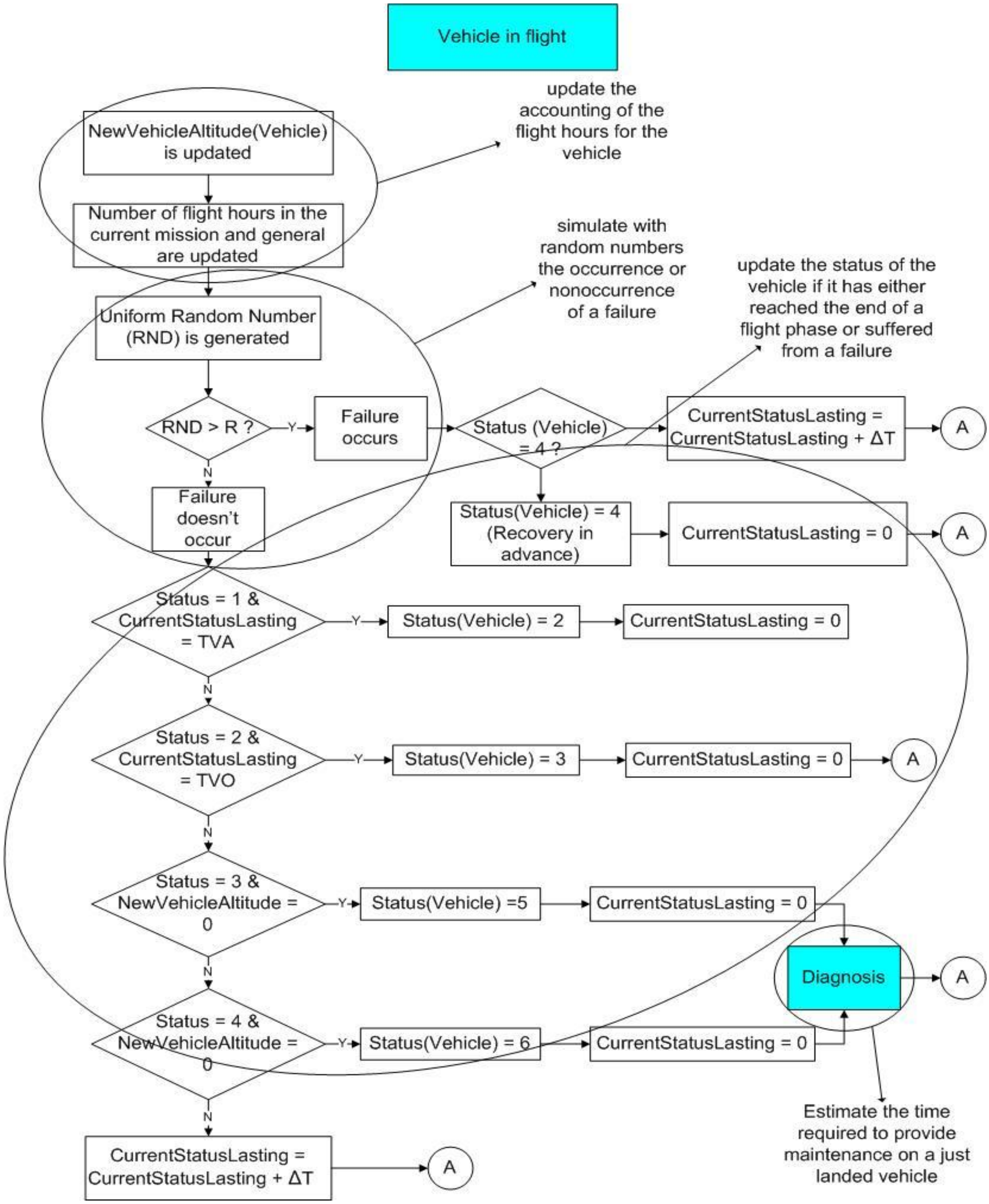

Fig 9. In-flight backup flowchart

The high number of possible choices and strategies necessarily imposed an accurate research work, supported by the experience the team achieved through previous works ([1], [2], [3]).

Fig 9 shows how complicated may a flowchart become, because of the fact that, to correctly build a model, there are to be taken into account all the possible situations that can occur during the UAS' operative life, such as failures, scheduled maintenance and so on.

With the support of the flowcharts and the definition work just described, the team developed the code for the simulation program, using the MATLAB/Simulink suite. The target of the team work was the definition of an environment capable of giving, as a output, a desired value of system efficiency, related to the choices made about the logistic and maintenance strategy previously supposed.

The choices made so far are basically to employ 3 MALE UAVs, in order to achieve a good system operativity using less cumulated flight hours (see Fig 10 for reference), which means to dilute scheduled maintenance tasks over time. The vehicles will operate from a single base (most likely located at the centre of the Piedmont region) which will act both as a operating and a maintenance base, able to perform all levels of scheduled and unscheduled maintenance, for simplification purposes.

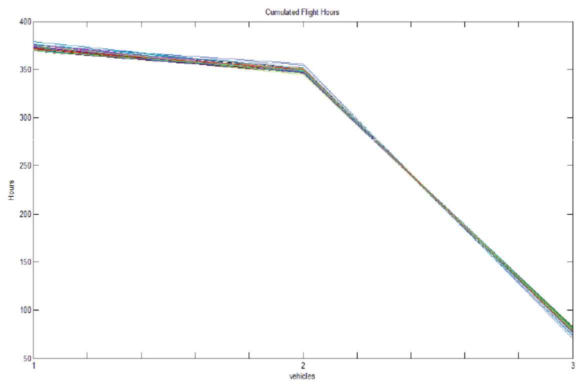

Fig 10. Flight hours vs. vehicle number

The results of the run, which simulated an operational period of 4 days, are those shown in Fig 11: using the default values for the described variables, after a brief transitory period, the system overall operativity adjusts around 93%

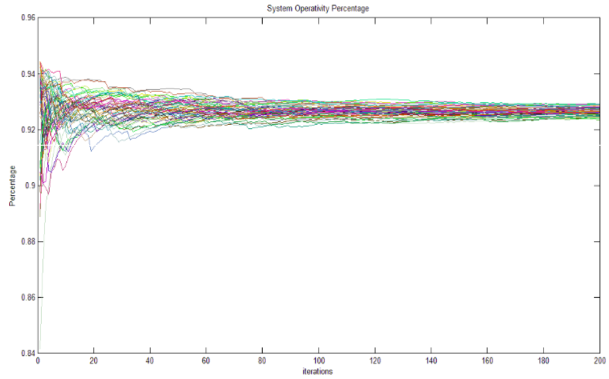

Fig 11. System operativity vs. iterations number

As described, the results in Fig 11 have been achieved using the default values: further analysis could be carried out modifying the number of work teams and/or their shifts, or the logistic support planned for the asset.

3.2 The MAME fleet

The second step to achieve a complete simulated environment for S.M.A.T. program is to define the fleet and the related logistic support for the MAME fleet. As mentioned in section 2, the best candidate to fulfil the MAME mission is the Selex Galileo "Falco" UAV.

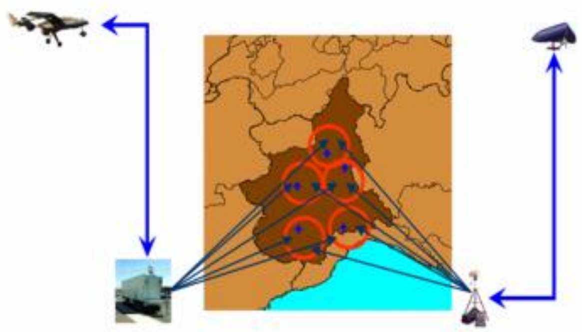

Fig 12. MAME/LASME mission scenario

Defining a correct operative scenario for this kind of vehicle is far more difficult with respect to the work carried out on the MALE fleet, because it is necessary to deal with a larger number of UAVs mutually connected and contemporarily in flight over several areas (as can be seen in Fig 12).

First of all, it has to be taken into account that there are more than one operating base contemporarily active or in stand-by (depending on the observation of the MALE vehicle): the possible basis are to be considered to be arranged as a main operating base (possibly shared with the MALE asset) and three peripheral basis conveniently spread on the regional area.

In opposition to what planned for the first asset, these basis could not be considered also maintenance basis capable of perform all the levels of scheduled or unscheduled tasks, so it has to be considered the possibility of performing certain types of maintenance works far from the vehicle operating base, with significant changes in the size of the logistical support needed for this kind of asset.

In addition to this, it has to be considered that this kind of asset could face multiple types of failures, related to the fact that there is more than one UAV contemporarily flying over the theatre: for this reason the size of the logistic support (mainly in terms of work teams and shifts) may be very different from what planned for the MALE asset.

Due to the higher complexity of the simulation environment, this kind of work is still on the run: as of today the team is committed to modify in the correct way the simulation coded for the first analysis, mainly in terms of assign the right set of variables and their values, considering the great complication in the scenario environment described above.

The activity finds its base principally in scheming a new set of flowcharts, capable of considering all the new choices that can be made with respect to the well defined scenario for the MALE fleet and the research team considers to carry out the simulations in order to achieve the first results in a short time.

Fig 13, which is the main simulation loop for the MAME asset, immediately shows the first great difference with respect to the MALE mode of operation: the MAME can operate from 4 different basis spread across the Piedmont territory and, for this reason, there has to be a function which is able to determine which could be the best location to operate from with respect to the "hot spot" coordinates.

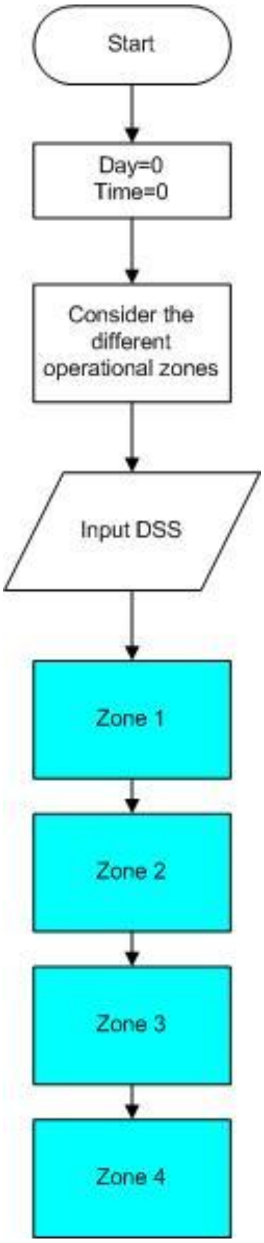

Fig 13. Main loop for MAME asset

At the same time, it is not automatically true that the operating base could serve as a maintenance base (or accomplish with full-level maintenance tasks): another great complication for the definition of the MAME fleet is the fact that there has to be planned a new maintenance net, considering that not all of the tasks can be performed everywhere.

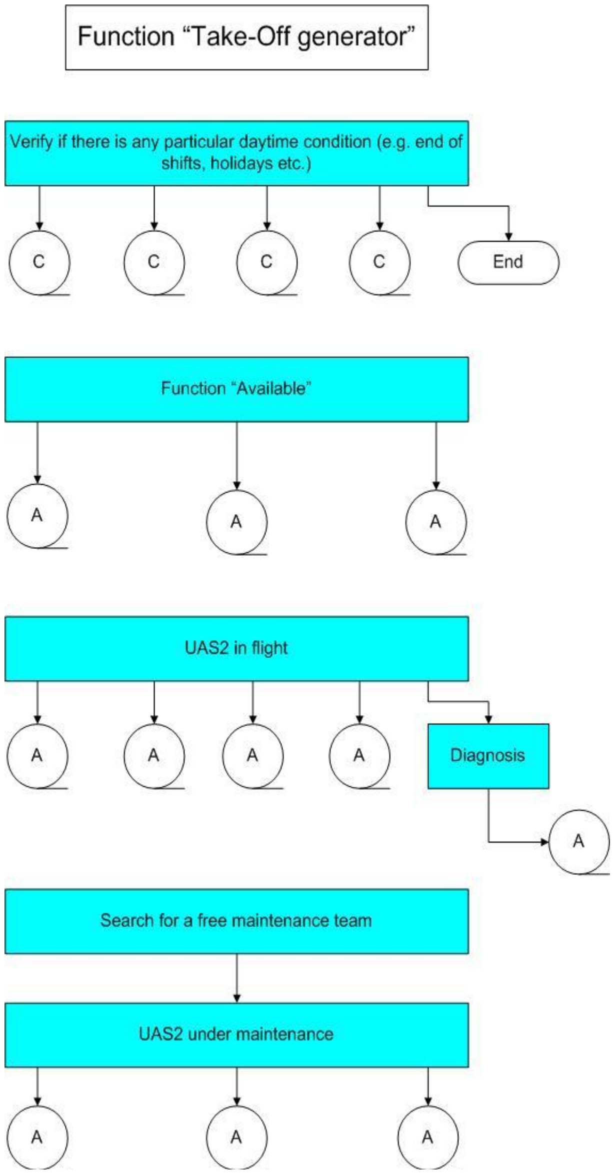

Fig 14. Example of function

As a further example of this new requirements, which have to be met in order to ensure a proper simulation environment and, thus, a correct output, in Fig 14 there is an example of what should be the function that will have governance over the MAME take-off sequence, in terms of finding the right resources and, eventually, providing the correct maintenance task in case of need.

3.3 The LASME fleet

Finally, there is the analysis of the third fleet, made by LASME type of UAVs and whose mission is to overfly the "hot zones" indicated by the MALE and, eventually, the MAME vehicles at low speed and low altitude, in order to acquire high quality imagery and have a quicker response about sudden changes in scenario ongoing situation.

For the reasons stated in section above, the simulation environment is still under construction, and the team thinks it will be ready to use in the future: actually the effort is directed towards the conceptual scheming of the new series of flowcharts, needed to correctly consider the new operational situation.

The simulation software contains all the new variables described in the previous section: there will be multiple vehicles flying contemporarily , coordinated by the SSC and each one with its own mission: it is clear that even this environment will be very challenging to be completed and will need also a new effort.

In fact, the LASME asset is represented by a small UAV, capable of being deployed from remote locations by detached operators (like fire-fighters, rescuers, civil defence personnel) with little or no logistic support (e.g. only from jeeps and other kind of small vehicles, as depicted in Fig 15).

Fig 15. Vehicles for remote operations

For this reason the team will have to consider also the possibility to deploy this asset virtually in every spot of the operating area, thus it will be convenient to design a suitable logistic support, especially in terms of on-site maintenance operations, that is redesigning the model of low-level and minor unscheduled maintenance tasks (which are to be made more frequently than every other task), involving the configuration of working teams and their shifts, considering that a first level support center can be considered the LASME Ground Control Station itself (depicted in **Errore. L'autoriferimento non è valido per un segnalibro.**).

Fig 16}. LASME asset deployable GCS

Following what has been described in the previous sections, it is clear that this kind of analysis has an enormous potential of growth and will lead to results of great interest, because it will give the possibility to optimize an entire surveillance system without the need of extensive and expensive trimming made by trial-and-error tests: the simulation will allow to define the optimal fleet for each asset and will forecast the right size of the related logistical support (in terms of what described in section 1) without wastes and towards the maximum of attainable efficiency with the only use of virtual tools, provided that the correct definition of the scenario and the assets operating in is made at a high detail level.

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