Publishable Summary

Problem Statement

The SESAR concept of operations (ConOps) beyond 2020 (SESAR2020+) involves a series of changes relative to conventional Air Traffic Management (ATM). Central to these changes is Trajectory Based Operations (TBO), that stands for the paradigm shift that aircraft should fly according to agreed conflict free 4D trajectory plans which are made known to all actors involved as Reference Business Trajectories (RBT's). A big unknown in this paradigm shift is how everything works under various kinds of uncertainty, as a result of which one or more aircraft may not realize their RBT's. There are several categories of uncertainty (including unexpected disturbances) that cannot be totally avoided, such as: meteorological uncertainties; data related uncertainties; human related uncertainties; and technical systems related uncertainties.

In principle the SESAR2020+ ConOps has been designed to take care of these kinds of uncertainty through the possibility of revising 4D trajectory plans, and also to allow air traffic control to issue tactical flight instructions to pilots if the 4D planning in the TBO layer has run out of time. Although these tactical instructions are quite similar to the established way of working by an air traffic controller, there also are significant differences. For example, under SESAR2020+ an air traffic controller is also expected to handle significantly more aircraft in its sector. Therefore the SESAR2020+ ConOps also foresees dedicated tactical decision support tools for air traffic controllers. The key issue is how to optimize the socio-technical collaboration between the TBO layer and the tactical layer in order to manage air traffic most effectively while taking into account the various uncertainties.

In conventional ATM, medium-term planning is provided by the planning controller, flight crews and their Flight Management Systems (FMS), whereas the tactical loop is formed by the tactical controller and flight crews. Thanks to decades of evolutionary developments, the collaboration between these two layers has been optimized. For SESAR2020+ a similar optimization of the novel TBO layer with the tactical layer is needed. Because the collaboration between these layers involves dynamic interactions between human decision makers, technical support systems, aircraft evolution, weather and other uncertainties, the combined effects result in types of emergent behaviours that cannot be predicted from the sum of the elemental behaviours.

Approach and methodology

During large European research projects HYBRIDGE and iFly, innovative complexity science techniques have been developed and applied to the identification of performance and emergent behaviours of a future ATM ConOps. In order to understand and improve the emergent behaviours of SESAR2020+ at multiple time scales, the EMERGIA project will apply these innovative complexity science techniques.

Within iFly, these innovative complexity science techniques have been applied to the most advanced airborne self-separation ConOps, which is referred to as A3 ConOps. This A3 ConOps also makes use of TBO and tactical layers, though fully airborne. Within iFly it has been shown that the A3 TBO and tactical layers work so well together that this leads to very powerful positive emergent behaviours, even beyond expectations of the concept developers. The three positive emergent behaviours that have been identified for A3 are: 1) Tactical conflict resolution layer is working very well in combination with a TBO medium term resolution layer; 2) No need to use a buffer between TBO resolution minimum and separation minimum; and 3) Even under extremely high en-route traffic demands there are no phase transitions happening. As a result of these powerful positive emergent behaviours, the A3 ConOps can safely accommodate very high en route traffic demands.

EMERGIA addresses the question whether these powerful emergent behaviours can be maintained while moving the TBO and tactical layers to the ground, as is the case with SESAR2020+. This EMERGIA research was organized in three phases. The first phase aimed to develop a ground-based version of the A3 model (shortly referred to as A3G model), to compare this to the SESAR2020+ ConOps, and to use the innovative complexity science techniques to identify the emergent behaviours of this A3G model. The second phase aimed to compare these emergent behaviours to those identified for the A3 ConOps, and to study the possible improvement of the A3G model in case of significant difference in emergent behaviours. The third phase aimed to evaluate the improved A3G (iA3G) model on its emergent behaviours, again by applying the innovative complexity science techniques. These three phases and their outcomes have been reported in the following three reports:

- Emergent behaviour of simulation model, EMERGIA report D2.2, December 2014.
- On the proposed improvements of the A3G ConOps, EMERGIA report D3.1, March 2015.
- Emergent behaviour of improved simulation model, EMERGIA report D4.2, June 2016.

Highlights and key results

During the first phase of EMERGIA, the sub-systems of the TBO and tactical layers in the A3 ConOps have been moved from the air to the ground, and also the tactical and planning controllers have been inserted in the loop. During the development of this A3G ConOps some decisions had to be made regarding the specific procedures to be followed by the tactical and planning controllers. In order to anticipate a large increase of traffic demand, it was decided to use datalink and to replace the current practice of the tactical controller awaiting positive read-back by the pilots by a ground system based verification of FMS downlinked information. Subsequently the innovative complexity science techniques have been applied to evaluate this A3G ConOps.

The results obtained in the first phase clearly showed that in comparison to the A3 ConOps, the A3G ConOps performance is so disappointing that it even was not relevant to compare A3G emergent behaviours against those of A3. Instead, an independent design team directly used the simulation findings as triggering points for the development of significant improvements to the A3G ConOps. The key improvements identified are: i) Better ground adaptation of conflict resolution algorithms in TBO and tactical layers; ii) Tactical ATCo is no longer directly in the loop of passing tactical instructions to pilots; and iii) Prioritizing the uplinking of conflict resolution messages. This is referred to as improved A3G (iA3G) ConOps. Using the innovative complexity science methods, an agent-based simulation model of the iA3G ConOps has been developed and rare event MC simulations have been conducted. The results showed that the improvements make great sense, as a result of which the iA3G model performs much better than the A3G model.

However, iA3G does not perform as well as A3 does. This difference also shows at the level of the indentified emergent behaviours. In the iA3G model, the TBO and tactical layers are able to work well together under the requirement that there is a significant spacing buffer between TBO resolution minimum and separation minimum. Another important emergent behaviour difference is that in contrast with A3, for iA3G ATCo task load may form a serious cap on en route traffic capacity limits. Although these findings do not come as a surprise from a conventional ATM perspective, they do not match up with the powerful emergent behaviours identified for the A3 ConOps.

Finally, there also are potential negative emergent behaviours of A3 and iA3G in need of technical requirements. Regarding the dependability of technical systems, the central organization of iA3G is more demanding than the decentralized A3 model is. In particular, very high iA3G requirements apply to ATC ground system, to ADS-B ground receiver, to Airborne uplink receiver failures, and to simultaneous failures of airborne ADS-B transmitter and SSR transmitter; very low probabilities of frequency occupancy of ATC-uplink and ADS-B; and short ATC Uplink transmitter sending duration.

Future steps based on the outcomes of the project

Although the emergent behaviours of the iA3G model are not as positive as those of the A3 model, for very high en route traffic demands iA3G does not perform bad at all. Therefore the iA3G model can be used as a valuable reference point for the further research and development of the SESAR2020+ ConOps. Important issues to be addressed are the differences between SESAR2020+ and iA3G, such as traffic demand, aircraft equipage percentage; time horizons of TBO and tactical layers; conflict resolution support to ATCo; conflict management architecture; closed-loop versus open-loop in tactical conflict resolution; and roles of ATCo's and pilots.

With the current iA3G model it is possible to investigate many of these differences by simply changing the model parameter values (e.g. traffic demand, time horizons). For some other differences (e.g. aircraft equipage percentage) it will be needed to also change the iA3G simulation model. Complementary to this, the further development of the iA3G model itself also is relevant, e.g. to incorporate climbing and descending traffic in the agent-based safety risk assessment. Another valuable research direction is to conduct bias and uncertainty analysis; this requires the development of a significant extra factor in acceleration of the rare event MC simulations. A third direction of research is to evaluate operational concepts that are mixtures of ground-based and airborne self separation TBO.

Conclusion

In conclusion, the EMERGIA project has shown that the powerful emergent behaviours identified in the pure airborne A3 ConOps are lost in an advanced ground-based ConOps version. This is due to various extra air-ground communication activities that cannot be avoided when adopting a centralized ground-based TBO ConOps instead of the distributed A3 ConOps. However, one would expect that the burden from these extra air-ground communication activities would be compensated in some way by an advantage of making use of a centralized joint conflict resolution capability. The EMERGIA project has shown that the latter advantage is far smaller than the advantage of the distributed nature of the A3 ConOps.

Complementary to this unexpectedly less positive finding for ground-based TBO, the EMERGIA project has also shown that in the large design space of future ATM, an advanced ground-based TBO ConOps, referred to as iA3G, has been identified for which it has been shown that it has the potential to safely accommodate high en-route traffic demands. This makes the agent-based iA3G modelling and simulation environment of value for modelling and analysis of the SESAR2020+ ConOps.