The objective of this study has been to demonstrate the risk assessment methods for UAS/UAM operations and the scope has been limited on purpose. Examples of possible extensions of the scope are: strategic deconfliction of flight plans (thus avoiding peculiar conflicts); tactical conflict resolution by UTM; interaction between UTM and ATM; geofencing systems. This study focused on assessment of the risk of close proximities and collisions between drones. The scope may be extended to other types of risks, such as ground risk, airspace infringement risk, and collision risk with manned aircraft. Also other (e.g. flight-efficiency) indicators may be employed such that the agent-based modelling can be used for studying resilience of drone operations for performance variability in nominal and off-nominal conditions. Other DAA systems may be incorporated, such as ACAS sXu that is being developed for small UAS with hovering functionalities [17]. If the scope is broadened, related agent-based models would have to be extended, e.g. incorporating more complex routes, geospatial models of buildings and obstacles, or population density models.

A limited number of illustrative simulation results have been provided in this paper (chosen from a broader set in [15]), mostly showing the impact on close proximity events by the DAA system and by the type of PIC response. These types of results provide valuable insights in the safety of the UAS/UAM operations, but clearly the particular quantitative results depend on the scope (e.g. excluding strategic deconfliction), on the modelling assumptions, and on the large set of parameter values in the agent-based model. In a quantitative safety assessment of a particular operational concept, appropriate choices have to be made for all these aspects. Nevertheless, at this stage of the development of UAS and UAM concepts, the most important contribution of the agent-based dynamic risk modelling is to provide structured understanding in the safety impact of different choices and settings in a range of operational concepts. Comparison of simulation results for different scopes and sensitivity analysis for variations in parameter settings provide such safety feedback to design and they can provide a basis for the development of operational performance standards.

In conclusion, this paper has shown that agent-based dynamic risk modelling and rare-event Monte Carlo simulation are effective methods for quantifying and analysing levels of safety of UAS and UAM operations. We expect that application and continued development of the models and the D(emo)-CRAT software tool can effectively support understanding and improving the safety of this new era of air transport.

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