of aircraft; the heading range allowed in each vertical layer was reduced when it is detected that a high number of aircraft will travel within that range. Limiting the traffic density at each vertical layer had a positive effect of limiting conflicts and LoSs, thus increasing safety. Moreover, the scenarios ran with the supervised learning model, without conflict resolution, had fewer LoSs than the scenarios run with an evenly distributed heading range per layer with conflict resolution activated. This shows that conflict prevention may be the best form of conflict "resolution"; in a situation with several multi-actor conflicts, conflict resolution algorithms can encounter deadlocks, which prevent them from resolving all conflicts.

However, the supervised learning model can still be further improved. First, the number of aircraft assigned to a layer is occasionally zero. This is a misallocation of useful vertical space, causing more stress on the other layers. It is likely that a more complex discretization of the current traffic scenario, or even focusing on the number of conflicts on each layer instead of the total number of conflicts in the airspace, may mitigate this issue. Second, performance of the LHN is dependent on the performance of CEN, as the number of conflicts estimated by the latter is used to train the former. Optimizing conflict information, will also optimize the output of the LHN. Third, training focused solely on the number of conflicts. Considering also LoSs, or even efficiency factors such as increased flight path or flight time, may further optimize the structures found by the supervised learning model. Lastly, since the objective is to minimize the number of conflicts, this can be seen as improving a cost function as typically used with reinforcement learning. This represents a different approach from the work herein performed; it is of interest to compare both.

This work assumed a fixed number of vertical layers. This is a simplification that favoured optimal convergence of the supervised learning model. Although it is fair to assume that a certain range of flight levels is allocated for air transportation and that aircraft must adhere to these limits, it may also be that controlling the number of vertical layers may further optimize capacity of the airspace. Naturally, adopting fewer or more layers has an impact on the segmentation of traffic. For the cruising phase, more layers are expected to improve segmentation and thus potentially decrease the number of conflicts. However, in future work, the effects of climbing and descending towards the correct layer must be considered. Climb and descent phases account for a large portion of conflicts and LoSs in environments with non-linear routes [11], [12]. Considering vertical deviations will likely help improve safety in the airspace. However, it will also add complexity to the training of a machine learning model. It is likely that reducing conflicts during cruise, climb, and descent phases requires different approaches, and consequently, models with different learning policies.

Future work should explore fuel consumption, and resulting environmental impact, of climbing, descending, and allocating aircraft to sub-optimal altitudes. Moreover, before a real-world implementation, the method must be further tested with different traffic densities and trajectories, improving its capability to generalise. There is also potential for this method to be applied to unmanned aviation, where it may have a bigger impact given the higher variability of trajectories and traffic types. Finally, no machine learning application can be blindly implemented into a real-life scenario. Further examination is necessary to explain the choices made by the model, as well as safeguards for potential bad decisions when applied to aircraft densities/trajectories not previously seen.

VII. Conclusion

This work focused on using neural networks to create a safer, dynamic version of the layered airspace concept adapted to the current traffic scenario. Results showed that a supervised learning model is capable of optimally dividing aircraft per the available airspace in function of their heading distribution, thus increasing safety. Proper segmentation of traffic even had a greater effect on safety than employing a conflict resolution model. Multi-conflict situations are extremely difficult to resolve; preventive action towards limiting the occurrence of these situations may be the only to way to resolve them.

Future research should consider non-linear trajectories, which will likely create density "hotspots", heavily increasing the number of conflicts as well. This will likely a require a more complex representation of the environment, as to identify heading changes. Finally, the research presented herein can be extended towards more competitive operational environments with a different number of layers, differences in the performance limits, as well as preference for efficiency over safety.

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