Urban Air Mobility Airspace Dynamic Density

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Airspace safety must be assured for Urban Air Mobility (UAM) to become reality. Emerging operations need to safely integrate with existing and future air traffic. UAM is anticipated to evolve in stages. Early stages, characterized by low-density operations, may be accommodated by traditional air traffic management approaches. However, to enable the scale of UAM operations necessary to reach ubiquitous integration into daily life, new paradigms that utilize collaborative and automated systems are being considered. Correspondingly, traditional approaches for determining a safe number of simultaneous operations in an airspace must be adapted to suit evolving traffic management paradigms. In this paper, we examine dynamic density as an approach to determine when an airspace is excessively populated, and safety may become compromised. We review previous work on dynamic density as it relates to air traffic controller workload and propose factors that may be more fitting for UAMs. Rather than considering controller workload, we propose factors that suggest increased likelihood of loss of separation and may lead to conflicts that require tactical avoidance maneuvers. In addition to monitoring dynamic density for tactical decision making, we endeavor to predict airspace dynamic density with adequate look-ahead to allow for strategic route selection.

Introduction

One of the top contributors of Air Traffic Controller workload is maintaining adequate separation between flights. Determining the number of simultaneous flights that a controller can effectively manage considers not only number of flights and available airspace volume (*sector*), that is, flight density, but also the type of operations in that airspace. A stream of flights following each other along a single airway at one altitude is much easier to manage than the same number of flights with different performance characteristics on vertically and laterally crossing paths while also avoiding bad weather. To ensure controller workload remains within manageable levels under normal circumstances given the typical interactions between flights in that sector, each sector has a customized empirically set maximum number of allowed flights with alerts issued if that number is predicted to be exceeded.

In sociology, the combination of population density and the amount of social interaction within that population is known as *dynamic density* (DD). The dynamic density of a sector, that is, the traffic and sector characteristics that are most relevant to accurately predicting controller workload, have been well studied and numerous combinations of factors have been found to have varying levels of predictive success.[1-3] The idea of DD may also be applicable to UAM.

Unlike traditional aviation, UAM operations will likely primarily be controlled by automated systems, not humans.[4,5] Thus, controller workload is not anticipated to be an issue (except perhaps in the low-maturity, initial stage of UAM implementation). Conflicts between flights will remain an issue, however, and excessive deconflictions

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may lead to an unsafe state due to unanticipated energy (battery) depletion, other vehicle health related issues, or the computation requirements of tactical multi-vehicle deconfliction. Much like in traditional aviation, considering either population density or amount of interaction within the UAM population alone is insufficient. The population density in a UAM corridor could be low, yet if much of the population is clustered within a narrow area, potential conflicts are increased. Conversely, if that same number of flights is well separated in the corridor and flying at the same airspeed, few conflicts are expected.

Dynamic Density Goal

The goal of our work is to design an airspace-level metric that measures and predicts the dynamic density of the airspace and thereby the increased likelihood of loss of separation between flights. To be operationally useful, DD must fulfill several requirements, as follows:

1. DD needs to support medium and high operational tempo stages of UAM maturation. Low operational tempo stages are likely to be controlled by traditional air traffic management methods. This implies that DD must be fast to compute. Moreover, it must support operations uncertainty. Pre-departure (anticipated) trajectories may change (e.g., a flight's arrival time at a waypoint may differ due to winds encountered vs forecast). Strategic deconfliction without effective uncertainty management requires conservative separation standards, potentially unnecessarily decreasing operational tempo. Thus, DD computations that incorporate uncertainty management desired.
2. DD must provide situational awareness for a proactive response. Reactive responses may waste energy (battery) and may result in secondary and tertiary conflicts, leading to increased on-board Detect and Avoid (DAA) computational requirements. Further, conflict resolution may adversely affect trajectories, leading to increased conflicts near constrained vertiport airspace, resulting in arrival delays, and impinging on energy reserves. Operators (including automation) need a reasonable look-ahead to select flight routes, departure timing, efficiently schedule avoidance maneuvers, and switch to contingency plans.
3. DD must be intelligible to operators. In addition to predicting DD, justification should be provided so that operators can select a suitable response to mitigate the situation.

Approach

Our work is inspired by previous dynamic density research conducted by NASA, FAA, and others. As previously stated, that work focused on predicting controller workload. We instead focus on traffic conflict, defined as loss of separation, not necessarily a collision. The two may seem quite different. However, given that the most significant portion of controller workload is due to keeping at least minimum separation between flights, loss of separation is a reasonable proxy.

We also constrain the pertinent traffic and airspace characteristics by the UAM concept of operations [6,7]. We assume an airspace mostly separated into corridors. A corridor has multiple tracks. All aircraft on a track travel in the same direction. (Aircraft on different tracks in the same corridor may be traveling in a different direction.) Aircraft fly on routes defined by waypoints through the various corridors/tracks from an origin vertiport to a destination vertiport. Some airspace may not require the corridor/track structures; in that airspace, flights may navigate as desired.

We make the following assumptions for the initial DD prototype:

- Calm wind, or steady wind that matches the forecast.
- No adverse weather areas to avoid.
- Performance of all aircraft is the same. All aircraft will be able to maintain required navigation tolerance. A faster aircraft will not be passing a slower aircraft.
- All flights are flying a similar climb-cruise-descent profile using the same indicated airspeed per flight phase (but different speed for different flight phases).
- All flights in the relevant airspace will be cooperative and share flight intent.
- Special operations, e.g., priority aircraft, will not disturb the normal flow of traffic and cause a ripple effect of conflicts.

Dynamic Density Factors

Our initial DD computation is defined as a weighted sum of flight density, proximity of flights, and clustering of flights (both number and size of clusters). The contribution (weight) of each factor, currently heuristically set, will be determined by comparing computed DD with conflict rate in simulated scenarios. We will also vet the results with subject matter experts. Further, we will vary the set of factors, including others yet to be selected, to distill the most predictive traffic characteristics. DD and supporting justification will be shown graphically.

Scenarios will utilize the simulations developed for the Advanced Air Mobility National Campaign[8] test series, specifically X4 testing [https://www.nasa.gov/feature/nasa-sets-stage-for-future-flights-auditions-advanced-air-mobility-tech]. One of the primary goals of X4 is to evaluate how UAM operators will communicate with each other and with the FAA. In the paper, we will describe the development environment, designed to be representative of the integrated demonstrations of realistic operational scenarios that will be conducted in X4.

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