NExCT Cooperative Operating Practices Framework

Memorandum

POC: Will Cummings-Grande
Document Status: Version 1.0
Reviewed: 8/31/2024

Note: This document has been created to facilitate foundational research and does not recommend any single solution to the problem of extensible traffic management.

NExCT Cooperative Operating Practices Framework Introduction

This memorandum introduces a framework that will be used as a reference for the development and evaluation of Cooperative Operating Practices (COPs) for NASA's National Airspace System (NAS) Exploratory Concepts and Technologies (NExCT) subproject. NExCT is a sub-project of Aviation Operations and Safety Program's (AOSP's) Air Traffic Management eXploration (ATM-X) project. COPs are "Industry-defined, FAA-approved practices that address how operators cooperatively manage their operations within an xTM domain, including conflict management, equity of airspace usage, and demand/capacity balancing." [1] For this work, multi-xTM-domain COPs are of interest and therefore the definition is extended to consider operations within and across multiple xTM domains.

The framework is organized into sections containing COP category and topic definitions, research assumptions made to enable foundational research on the interactions between COPs, and open research questions that will help direct evaluations and demonstrations of COPs. This research does not seek to define specific COPs for any single xTM domain. Instead, it provides general definitions that are applicable across multiple domains. Commentary specific to individual xTM domains is included as relevant, as are potential areas for the interaction between xTM and traditionally managed air traffic (xTM-ATC Interactions). This framework and its ensuing evaluations seek to demonstrate a future state in which cooperative traffic management enables safe, efficient, and equitable usage of airspace by emerging aviation operations. The framework identifies what rules are needed, how they are expressed, and how they are managed.

Concept of Operations

This framework is targeted to apply to a future concept of operations in which diverse, optionally crewed operations occur in a cooperative area as described in both the UTM and UAM Concept of Operations documents published by the FAA [2, 3]. Operators participating in the cooperative management of airspace will be responsible for management but will in turn receive enhanced access to the airspace, allowing operations Beyond Visual Line of Sight (BVLOS) and at higher densities than possible with conventional air traffic management. Interactions of operations from multiple xTM domains are considered within the context of a well-established, far-term environment. Within this concept, UAM and UTM operations occur at a high tempo with high levels of autonomy.

The UTM and UAM architectures have been generalized to encompass the generic xTM concept as illustrated in the diagram below.

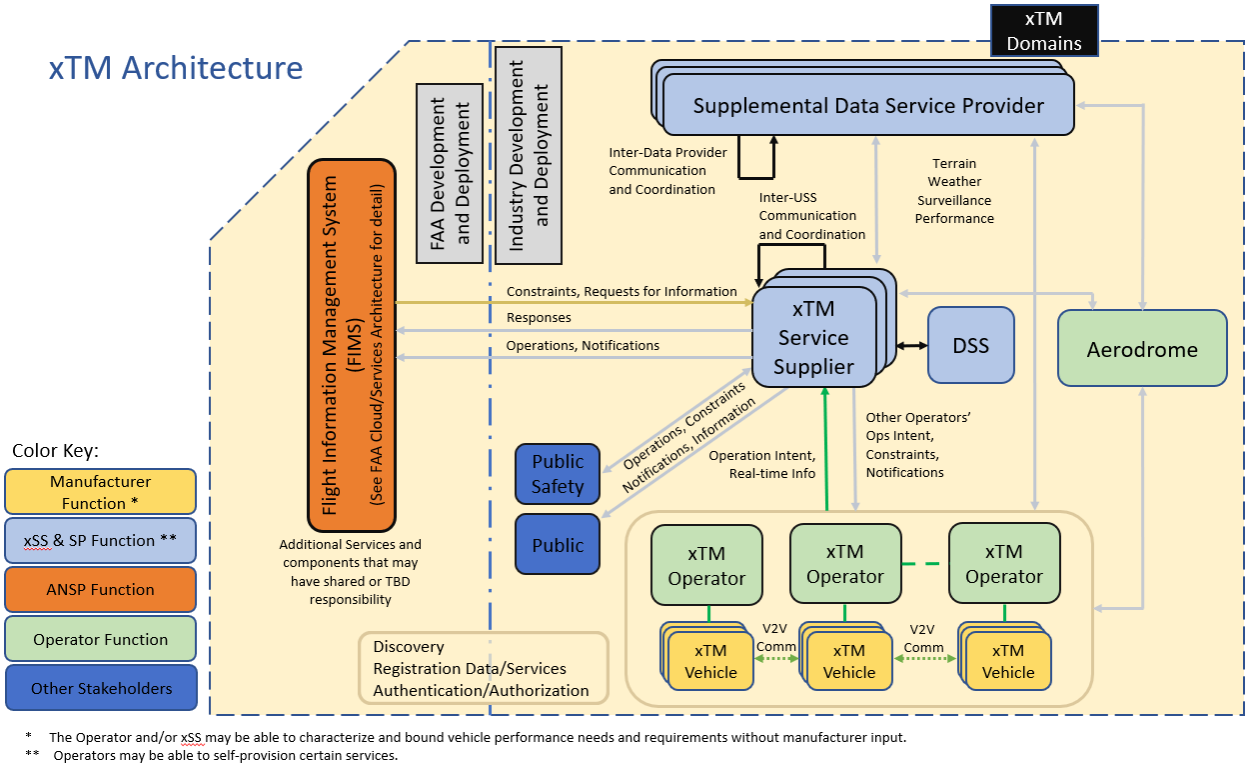

Figure 1 - Generalized xTM Architecture Concept

Definitions

To facilitate meaningful research, terms that have been previously used in similar research are defined specifically for the context of multi-xTM-domain cooperative air traffic management.

Operator

For this framework, operators are defined as entities responsible for the decision-making of a system actor. In the context of UTM or UAM vehicle operations, this may refer to a fleet manager that performs the coordination and scheduling for a fleet of piloted or unpiloted vehicles. If a vehicle is piloted either onboard or remotely, the pilot may be referred to as a vehicle operator. A vertiport operator is responsible for the management of the respective infrastructure, and therefore may perform functions such as scheduling, communication, and contingency management.

Operators are expected to participate in cooperative air traffic management due to the benefits that it brings in terms of system efficiency and scalability. Safety is a requirement whether the operators in a cooperative area operate cooperatively or not.

xTM Service Supplier (xSS)

The generic xSS is defined as a system actor responsible for providing, at a minimum, intent comparison and communication. Communities researching different domains have proposed different levels of service that fall into this category. For example, in the UAM domain the Provider of Services for UAM (PSU) provides intent coordination and communication in addition to conformance monitoring, conflict resolution, and contingency management. In the UTM and ETM domains, the UTM Service Supplier (USS) provides a much more limited set of services, and the other functions are delegated to operators or Supplementary Data Service Providers (SDSPs). Multiple xSS's may provide services in the same geographic area and in this case must coordinate both with each other and with other system actors.

Discovery and Synchronization Service (DSS)

The DSS is defined as a system actor responsible for coordination within and across xTM domains. The DSS enables operators to learn which other operations will be occurring in their vicinity, as well as how to coordinate with those actors to manage air traffic.

Cooperative Areas (CA)

A Cooperative Area (CA) is a volume of the airspace in which the FAA delegates traffic management to the users of that airspace, including flying and ground-support entities, for the safe, fair, and efficient utilization of the airspace. The FAA maintains superseding authority for the airspace and therefore reserves the right to allocate and restructure the cooperative area and to set the baseline policies for its utilization. Finally, a cooperative area may allow utilization from non-cooperating users with a necessary set of information sharing from such users, meaning that CAs are not inherently exclusive use airspace. However, participation in the Cooperative Agreement offers operational, efficiency, and safety benefits including the enabling of Beyond Visual Line of Sight (BVLOS) operations for sUAS.

The advanced, integrated xTM system envisioned in this concept features geographically large cooperative areas. For example, the UTM CA is expected to be composed of all airspace below 400 ft AGL except where defined otherwise, most often due to the presence of an airport, vertiport, area of particular safety interest, or piece of critical infrastructure. UAM CAs are expected to be composed of a network of routes through class B, C, or D airspace and the surrounding urban airspace. Upper E CAs are expected to be very large regions but not span the entirety of the airspace above 60,000 ft.

Cooperative Operating Environment (COE)

A COE, sometimes shortened to a Cooperative Environment, refers to the broader system of actors cooperating to manage traffic, the airspace in which those operations occur, and the information available across the distributed system to facilitate the operations.

Research Approach

Existing research for distributed air traffic management systems has most often been considered in single domain context. To achieve the goal of a truly extensible traffic management system, foundational research must be undertaken that seeks to explore the impact of different traffic management concepts in an integrated system. The research in scope of this framework considers the interaction of multiple xTM domains, and specifically the COPs required to allow safe, equitable, and efficient usage of shared airspace by operations from dissimilar domains.

The approach taken to learn about these COPs is structured around this framework, which defines the categories and topics for COPs. Candidate COPs will then be considered and studied based on existing and future research. Much of this existing literature comes from other NASA and industry led efforts to generate COPs for each domain. Studies are expected to be built around scenarios that are evaluated in workshops or simulations and are repeated with different sources of uncertainty imposed on the system. Uncertainty sources include schedule variation, atmospheric impacts on vehicle performance and communications, vehicle capabilities, and non-cooperative traffic. The framework itself is anticipated to evolve with ongoing research into three driving questions:

1) What COPs are needed to enable safe, equitable, and efficient operations in cooperatively managed, multi-xTM-domain airspace?
2) How are COPs expressed such that all actors know what is required of them at all times?
3) How are COPs managed in a complex, scalable, and integrated multi-xTM-domain environment?

These questions are posed with the intent to gather information such that informed decisions can be made as industry creates COPs and works with the FAA to gain approval for the growth of operations.

Framework Structure

The COPs are considered in three overall categories: Airspace Management COPs that define the administration of COPs and practices related to maintaining the airspace, Information Management COPs that define how the community will share and handle information required to cooperatively manage the airspace, and Traffic Management COPs that define cooperative traffic management within the CA. The definitions and research assumptions included in the framework describe the concept for each COP topic area. In future versions of this document, research implementations of example COPs will be included in App. A as applied to a UTM-UAM use case. Table 1 proposes COP topics within these three categories and indicates their applicability to nominal and off-nominal states. Nominal operation is defined as operations within the expected capacity limits of the system, without the presence of any bad-actors, and during favorable weather conditions. Nominal operations also include interactions with legal, non-cooperative traffic, xTM-ATS interactions, and high priority operations conducted for public good missions. Off-nominal operations include reaction to illegal, non-cooperative traffic, unfavorable weather conditions, contingent cooperative aircraft, or failures of xTM systems and infrastructure.

Table 1 - COP Framework Categories

Cooperative Operating Practices	Nominal	Off-Nominal
Airspace Management		
Cooperative Agreement	X	X
Consequences for Violation of Agreement		X
Weather Response	X	X
Dynamic Airspace Constraint Management	X	X
xTM Service Contingency		X
Information Management		
Intent Sharing	X	X
Telemetry Sharing	X	X
Information Exchange	X	X
Traffic Management		
Strategic Conflict Management	X	X
Tactical Conflict Management	X	X
*Collision Avoidance		X
Non-Cooperative Traffic	X	X
Cooperative Off-Nominal		X
Priority	X	X
Schedule Priority	X	X
Demand Capacity Balancing	X	X

* Collision avoidance is a last line of defense that ensures system safety. As such, this topic is likely to be regulated rather than delegated to industry. However, for the sake of foundational research, technologies that provide the function of collision avoidance may be considered as cooperatively selected by industry as the common adoption of enhanced technologies may afford a system benefit. The interactions of these technologies in multi-xTM-domain cases will therefore be considered in scope for research purposes.

COP Topic Definitions

This section provides definitions, research assumptions, and open questions for each of the proposed COP topics. These are working definitions and assumptions, expected to evolve as detailed research is completed. Definitions, assumptions, and open questions are documented both for single and multi-xTM-domain cases. Exploration and development of each COP topic will be conducted through workshops and simulation. The results of these demonstrations will be used to enhance and mature the framework.

COP Expression

COPs in all topics are expected to contain, at minimum, the following information:

Title: A descriptive or hierarchical name for the COP. Hierarchical names will identify the relevant topic and category for individual COPs.
Summary: The summary contains a plain English description of the COP.
Action: The action section describes how the COP is implemented. This will take the form of a technical specification that is machine readable and a corresponding written description.
Actor: The components of the system responsible for taking action to accomplish the COP.
Trigger: The situations in which this COP is active.
Rationale: COPs will be accompanied with a written description of the operational benefits associated with their implementation.
Dependencies: COP dependencies include any assumptions or requirements that enable the COP, including other COPs or system actors.
Exceptions: Cases in which operators may deviate from the COP.
Traceability: Link to coverage of underlying ATM requirements.

An example COP for interdomain priority between UTM and UAM operations is presented in Table 2.

Table 2 - Example COP

Title: Interdomain.TM.Priority	Summary: In situations of in-flight priority disputes between sUAS and UAM, uninhabited vehicles shall yield to vehicles with humans onboard.
Action: <Machine Readable> Aircraft yielding to other aircraft shall modify their trajectory to fly below, behind, or to the port side of the aircraft with priority.	
Actor: sUAS and UAM vehicle operator	
Trigger: In-flight conflict detected between uninhabited and habited vehicles.	
Rationale: Clear identification of maneuvering expectations for interdomain priority disputes	
Dependencies: Inter-domain tactical conflict management and collision avoidance - Interdomain.TM.TCM - Interdomain.TM.CA Interdomain intent and telemetry sharing - Interdomain.IM.Intent - Interdomain.IM.Telemetry	
Exceptions: - An uninhabited vehicle performing an emergency service, public good mission shall have priority over all other non-emergency vehicles.	
Traceability: Reqt link to ATM function for priority	

Airspace Management COPs

The Airspace Management COP category includes COPs that establish a means for a community of cooperative operators to self-organize, respond to long-term changes in the operating environment, and document the COPs by which they share information and manage traffic. The category also includes COPs specifying the community response to weather events, temporary airspace restrictions, and non-flight-related failures within the xTM system.

Cooperative Agreement

Definition: A Cooperative Agreement is a document created and maintained by the users of a cooperative operating environment that defines how community members will cooperatively manage the airspace. This document includes at a minimum COPs, a directory of participating operators, a description of the relevant cooperative area, and provisions for maintenance of the agreement. The agreement may also contain information regarding other Cooperative Agreements that exist in nearby airspace.

It is expected that the Near Term Approval Process (NTAP) and Letter of Authorization (LOA) process that has been used for current efforts to establish cooperative operations will be replaced by a longer-term solution. This solution may feature Cooperative Agreements that are created and maintained by a community of operators with oversight from the FAA. The FAA is expected to provide approval for COPs related to safety, conflict management, equity of airspace usage, and demand capacity balancing.

Any Cooperative Agreement must be created and maintained in such a way that all prospective operators or users know what is expected of them to enable their participation in cooperatively managing the airspace. In the future, localized Cooperative Agreements may be replaced by a combination of standards and regulations that perform the same function in a nationally or internationally consistent manner with tailoring for the needs of individual communities performed only as needed.

Research assumptions:

- Operators participating in the Cooperative Agreement will act in good faith to follow the COPs.

Rationale: (To be added in later revisions)

Open Questions:

- Can non-cooperative traffic interact with the system?
    - Can non-cooperative traffic access information from the DSS? For self-separation purposes?
    - Do participating actors have access to different information compared to external actors?
- How are Cooperative Agreements structured for interactions between multiple xTM domains?
- How do operators find out about the other operators in their area to form a Cooperative Agreement? Is this a DSS function? Will the FAA facilitate the identification of operator groups?
- How are Cooperative Agreements terminated? Should they have terms at which they need to be re-visited or re-written?
- Are there COPs associated with operator training?
- What is the benefit of joining a Cooperative Agreement?
    - For UTM, is BVLOS restricted to operators who have joined a Cooperative Agreement?
- Can a Cooperative Agreement include a list of required services or equipage for participating operators?
    - Can required equipage be specified by an agreement for multi-domain interactions?
    - Can COPs include rules about aircraft performance?
- How big (Geographic? Number of operators? Number of operations?) is a Cooperative Area? Are there limits? Can a single Cooperative Agreement be used for discontinuous geographical areas?
    - In cases where a cooperative area is carved from existing exclusive use airspace, how does ATC interact with the cooperative operators? This may be most relevant in cases when ATC

needs to shut down the cooperative area (different flow configurations, emergency management, etc…)

Consequences for Violating a Cooperative Agreement

Definition: Cooperative Agreements will be enforced partially by the FAA and partially by the cooperating operators. The FAA may choose to retain or delegate enforcement of any portion of the agreement. Consequences for violations of the agreement are defined and agreed upon as part of creation of the Cooperative Agreement. Operations, particularly at low altitudes over urban environments, will also likely have input from local communities and law enforcement agencies. The local authorities may contribute to the agreement in the form of noise abatement and privacy practices and establish enforcement plans for these practices.

Research assumptions:

- The FAA and the community will determine the appropriate enforcement of a Cooperative Agreement. NASA research will not include this area.

Rationale: (To be added in later revisions)

Weather Response

Definition: Communities of emerging operations will face different challenges due to weather events than existing aviation operations. COPs describing operator response to weather-related phenomenon will be defined that enable operations within the cooperative area. Weather impacts and associated COPs may vary between domains due to different vehicle capabilities.

Weather data at higher resolution or tailored to xTM operations may be provided by SDSPs but will not necessarily be a required product for all operators. COPs should address varying access to high fidelity weather data.

Research assumptions:

- ATIS-style weather data is available at all aerodromes and is available to all operators.

Rationale: (To be added in later revisions)

Open Questions:

- What amount of vehicle performance will operators share to inform their weather tolerance? Do operators need to share this data with others or can they make weather-related decisions internally and cancel/reschedule flights as required?
- Are there unique weather phenomena that will impact specific xTM domains differently?
    - For example, UAM vehicles may have a higher wind tolerance than sUAS vehicles due to performance differences. On a day with winds in this critical range, UAM and sUAS may have to interact differently than normal to enable to continuation of safe operations.
    - How does solar or other space weather impact the ability of ETM operators to maintain COPs?

Dynamic Airspace Constraint Management

Definition: Segments of a cooperative area may be closed during operation to react to planned or unforeseeable events and circumstances. A closure may be initiated by the FAA for any reason or by the community as agreed upon in COPs for different closure scenarios. The most common closures are assumed to be UAM cooperative areas in the departure or arrival corridor for different runway configurations in a terminal airspace. It is critical that all operators are able to determine airspace available for cooperative operations at all times.

Research assumptions:

- The FAA will retain the authority to close any cooperative area at any time for reasons related to safety.

Rationale: (To be added in later revisions)

Open Questions:

- How is a constraint created, communicated, and terminated?
    - Who can create or terminate a constraint?
- How is airspace constraint information stored and distributed?
- Does the xTM system need a minimum time interval to react to the closure of an area?
    - How does this time interval vary between different domains?

xTM Service Contingency

Definition: xTM Service Contingency COPs address how operators will respond to the failure of a service supplier within the system. These may range from loss of SDSPs such as weather prediction to loss of DSS.

Research assumptions:

- Services identified in COPs will be defined by function, not provider.

Rationale: (To be added in later revisions)

Open Questions:

- Can services be specified as required?
- Can COPs identify a common service provider?

Information Management COPs

Information Management COPs describe the information that a community will publish, save, and consume to enable cooperative traffic management. The information required to maintain safe, equitable, and efficient cooperatively managed operations may also be referred to as the Integrated Operating Picture (IOP).

Intent Sharing

Definition: Operators within cooperative areas will share operational intent information. When a cooperative area includes operators from multiple xTM domains, intent will be shared such that it is

accessible by relevant operators. However, it is acknowledged that the implementation of intent sharing will vary across different xTM domains and vehicle types as best fits that operation type. In cases where intent is volume based, the volumes will be sized based on the performance of the vehicle, with more capable vehicles able to maintain lower flight path uncertainty and therefore remain within a smaller intent volume. Intent information is shared via an xSS, and xSS share information with a DSS to identify inter-domain interactions.

Research assumptions:

- Operators will not share intent at a level of resolution that compromises their business case or technical assets.

Rationale: (To be added in later revisions)

Open Questions:

- How is intent shared across multiple xTMs? Do operators talk to an xSS? Does the DSS talk to an xSS?
- When can operators choose how much information they will share? Is this captured within the Cooperative Agreement?
    - Can system performance (safety, throughput, efficiency) be enhanced by the sharing of additional data?
- Can non-cooperative entities be added to the system so that their intent is available to cooperative operators?
- Can non-cooperative entities view intent information from the system? Should this information be intentionally diluted for security or the protection of proprietary data?
    - For multi-domain interactions (including xTM-ATC), is the amount and means of intent sharing specified in the relevant Cooperative Agreements?
- Can COPs for intent sharing capture specific data sharing methods? Should these be left to the specification of the operator?
- Can operators be rewarded for sharing more specific intent information?
    - Information above a standardized minimum will enable more efficient operation of the system.

Telemetry Sharing

Definition: Cooperative operators will share state information at a level of precision and rate appropriate to facilitate operations in their environment. The level required to facilitate operations is expected to vary depending on operation type, density, and other factors.

Research assumptions:

- Operators will protect proprietary data by generalizing telemetry before sharing
- Operators will record their operation history and make data available to the NTSB and/or community in the event of a mishap.

Rationale: (To be added in later revisions)

Open Questions:

- How does the level of telemetry sharing impact system efficiency and safety?

Information Exchange

Definition: Operators will exchange information other than for traffic management purposes that enhances the safety and efficiency of the airspace.

Research assumptions:

- Operational hazards may be shared with the community so that other operators may plan to avoid them.

Rationale: (To be added in later revisions)

Open Questions:

- Is the xSS or DSS used for sharing this information?

Traffic Management COPs

Traffic Management COPs define rules for conducting flight operations in a cooperative area.

Strategic Conflict Management

Definition: Strategic Conflict Management (SCM) COPs provide options and strategies for operators to mitigate potential air-to-air conflicts outside of an operation appropriate time horizon. Conflict detection and resolution methods are included in strategic conflict management and may include demand capacity balancing practices. The goal of SCM is to mitigate potential conflicts with minimal impact to system operation. The density of operations will have an impact on when strategic conflict management actions are required.

Research assumptions:

- For UTM and UAM, SCM will take place during pre-flight planning due to the short duration of each mission.

Rationale: (To be added in later revisions)

Open Questions:

- Should Operational Intent (OI) volumes be soft or hard boundaries?
    - If a corridor is used as an operational intent, should it be flexible with changing weather and/or FAA needs, how do they interact with other cooperative areas?
- Different route structures are proposed as a method for managing different levels of traffic density. Is this concept a strategic conflict management practice? Does this concept fall under dynamic airspace constraint management?
- When is SCM needed – are there methods other than conflict prediction or detection that can inform when SCM methods should be employed?

- Do OI intersection always necessitate resolution via some SCM method?
- Where are conflicts defined?

Tactical Conflict Management

Definition: Tactical Conflict Management (TCM) COPs provide methods for mitigating potential conflicts on a time scale between SCM and collision avoidance. Tactical methods allow for adaptation of the strategic plan to information that becomes available after the plan is created. The goal of TCM is to mitigate potential conflicts with operation safety as the primary concern. Conformance monitoring may be employed within the system and will assist with TCM through the identification of operations or conditions that were not part of the strategic plan.

Research assumptions:

- Operators are responsible for taking action based upon agreed-upon TCM COPs

Rationale: (To be added in later revisions)

Open Questions:

- Who needs to receive off-nominal situation information? How is this determined in real time?

Collision Avoidance

Definition: Collision Avoidance COPs include guidance to provide the last line of defense to prevent a collision. Collision Avoidance typically takes the form of See And Avoid (SAA) or Detect And Avoid (DAA) methods. Collision Avoidance systems are always active but only result in maneuvers if strategic and tactical conflict management methods have failed. Collision Avoidance is a safety critical function and is therefore expected to be regulated by the FAA.

Research assumptions:

- All cooperating aircraft will be capable of collision avoidance.

Rationale: (To be added in later revisions)

Open Questions:

- Can SAA be used when UAM and UTM traffic are interacting?

Non-Cooperative Traffic

Definition: COPs providing guidance for cooperative operators to react to traffic that is not participating in an xTM environment. This may include legal or illegal operations within a cooperative area. Cooperative operators will report any non-participating operation to the community to allow for a coordinated response.

Research assumptions:

- Legal non-cooperative traffic will be operating in a predictable manner and, depending on the operation type and cooperative area, will be broadcasting some sort of information (ADS-B, remote ID, etc…)

Rationale: (To be added in later revisions)

Open Questions:

Cooperative Off-Nominal Traffic

Definition: COPs providing response to cooperative traffic that fails to meet its published operational intent for any reason. This may be broken down into categories such as non-conformance, vehicle emergency, or passenger emergency.

Research assumptions:

Rationale: (To be added in later revisions)

Open Questions:

- Should off-nominal situation COPs be organized by failure type or failure effect?
    - Are off-nominal procedures really COPs or operator responsibility?
- Do some failures (e.g., loss of C2 link) result in the traffic becoming non-cooperative rather than cooperative off-nominal?

Prioritization

Definition: Prioritization COPs define which cooperative operator will yield to the other in the case of a predicted conflict within the cooperative area. In some cases, the action associated with yielding may also be defined.

Research assumptions:

- Priority is relevant in both strategic and tactical conflict management cases.

Rationale: (To be added in later revisions)

Open Questions:

- How is priority decided for xTM operations?
    - Based on fuel/energy state? Based on criticality of mission?
    - If the concept is applied within operators instead of based on shared information, do we need to make sure that operators are being honest?
    - How are the weights/buckets for each factor determined?

Schedule Priority:

Definition: Schedule Priority COPs provide general guidance to settle priority disputes in the pre-flight planning phase, analogous to the Prioritization COPs used during flight. This may also be referred to as flow management or traffic synchronization as it results in the steady flow of traffic in a coordinated fashion.

Research assumptions:

Rationale: (To be added in later revisions)

Open Questions:

- How is infrastructure scheduled in multi-xTM-domain cases?

Demand Capacity Balancing (DCB)

Definition: DCB COPs maintain safe limits on operational density in a cooperative area.

Research assumptions:

Rationale: (To be added in later revisions)

Open Questions:

- How do DCB COPs interact with SCM, TCM, and Prioritization/Schedule Priority COPs?

Discussion

Moving forward, the team will explore each COP category and topic, and the relevant COPs will be evaluated in relation to the following objectives:

A) Does the vernacular and specification of a COP match its implementation?
B) Is the set of COPs complete to ensure safe, equitable, and efficient traffic management in the cooperative area?
C) What are the limits beyond which COPs loose efficacy?
D) What is the system robustness to sub-optimal conditions, off-nominal events, service disruptions, and non-cooperative activities?
E) Will COP concepts be acceptable to industry and lead to implementations that match their and other community stakeholders' needs?

References

1. Extensible Traffic Management (xTM) Framework Analysis xTM Lexicon, FAA, June 2022
2. Urban Air Mobility Concept of Operations v2.0, FAA, April 2023
3. Unmanned Aircraft Systems (UAS) Traffic Management (UTM) Concept of Operations v2.0, FAA, March 2020