Task Analysis for Feasibility Assessment of a Collaborative Traffic Flow Management Concept

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A far-term collaborative traffic flow management concept has been proposed for mitigating flow constraint situations that result in imbalance between demand and capacity in the National Airspace System. This paper presents a scenario-based task analysis of core attributes of the concept in the expected future traffic environment. These attributes include a dynamic allocation of some traffic flow management responsibility to airline operation centers, while the traffic flow managers maintain a supervisory role, monitoring performance and intervening increasingly as time-to-constraint decreases. This analysis proposes a three-tier time horizon with different collaboration schemes between traffic flow managers and airlines within each tier. In the outer tier, the airlines are responsible for modifying flight trajectories to mitigate the constraints identified by the traffic flow managers, before any flow plan is needed. In the middle tier, the traffic flow managers collaborate with the airlines to select and impose a flow plan, while the airlines continue to modify trajectories according to the flow plan. In the inner tier, the flow managers take over responsibility for modifying flight trajectories while incorporating airline preferences for flights, reroutes, and delay. The task analysis describes the activities in each tier to the level required for identifying the communication and information sharing between the airlines and the traffic flow managers. It also identifies benefit mechanisms and feasibility issues. Some key benefits mechanisms include reducing the traffic flow manager workload by shifting some responsibilities to airlines and increasing airline satisfaction by increasing their proactive participation and incorporating their preferences. Some key feasibility issues identified include the ability to delegate responsibility for flight trajectory changes to airlines and to coordinate among them. Addressing these issues avoids creating constraints elsewhere and ensures equity. Implications of the task analysis on future research related to feasibility and benefit assessments of the concept are discussed.

Nomenclature

4-D	= four-dimensional	FACET	= future ATM concepts evaluation tool
AFP	= airspace flow program	FEA	= flow evaluation area
AOC	= airline operation center	FP	= flow planning
ARTCC	= air route traffic control center	FI	= flight implementation
ATC	= air traffic control	IA	= impact assessment
ATCSCC	= air traffic control system command center	MAP	= monitor alert parameter
ATM	= air traffic management	NAS	= national airspace system
ATSP	= air traffic service provider	NextGen	= next generation

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CI	= constraint identification	SUA	= special use airspace
CTFM	= collaborative traffic flow management	TCA	= tactical customer advocate
EDCT	= expected departure clearance time	TFM	= traffic flow management
ETA	= estimated time of arrival	TMU	= traffic management unit
FAA	= Federal Aviation Administration		

I. Introduction

TRAFFIC flow management (TFM) is the air traffic management (ATM) function that balances demand and capacity at airspace resources, such as airports, airspace fixes, routes, and sectors. Imbalances occur when traffic demand exceeds resource capacity because of numerous events including convective weather, special use of airspace (SUA), excessive traffic complexity, pass-back restrictions from other ATM facilities, or over-scheduling by users. In the current U.S. National Airspace System (NAS), the TFM function is centralized and provided by the Federal Aviation Administration (FAA), introducing flow initiatives to reestablish the demand-capacity balance. The Air Traffic Control System Command Center (ATCSCC) develops strategic TFM initiatives or flow plans over a planning horizon of 2 to 8 hours for the NAS. The Traffic Management Units (TMUs) of the 20 Air Route Traffic Control Centers (ARTCCs or Centers) develop tactical plans, consistent with ATCSCC initiatives, to manage the air traffic within their local airspace over a planning horizon of typically up to 2 hours.[1] The users of the NAS, mostly airlines, but including general and business aviation, are impacted by the TFM restrictions included in these strategic and tactical plans, but their involvement in the decision-making process is limited.[1-6]

TFM is a complex process with multiple decision-makers with conflicting interests and interdependent actions. Idris et al.[1,4] described a number of inefficiencies in current operations including the lack of collaboration particularly in local TFM situations. For example, the Air Traffic Service Provider (ATSP) lacks accurate demand information for developing a mitigation plan. Therefore, they often act conservatively. They may at times respond reactively due to the uncertainty and lack of coordination, resulting in unpredictable and volatile TFM actions. In addition, the ATSP does not have adequate information about users' preferences and economic impacts for individual flights, despite the fact that operational planning teleconferences are held bi-hourly between flow managers and airline dispatchers. As a result, imposed TFM restrictions do not consider user preferences adequately, leading to numerous requests from Airline Operations Centers (AOCs) to traffic managers that are time consuming and usually not granted due to high traffic manager workload.[4,7] On the other hand, users desire timely and highly certain options from the ATSP to plan proactive changes according to the expected restrictions, which they do not always receive. The result is that airlines are passive rather than proactive in providing information and requesting preferences. Meanwhile TFM decisions, as well as implementation of TFM plans through modifying flight trajectories, are made entirely by the ATSP with limited information about airlines' impacts and preferences and with limited participation from airlines.

Decentralization by involving users in the TFM decision-making process to enable user preferences and increase capacity has been proposed.[2,3,6] Most proposed concepts for Collaborative Traffic Flow Management (CTFM) preserve the TFM function centralized with the ATSP and increase the users' input to select more efficient TFM initiatives.[5,6,8] For example, Klopfenstein et al.[5] proposed a concept that allows the users to send a prioritized list of alternative routing options, and the traffic managers, supported by decision support tools, incorporate the preferences in reroutes assigned to flights. Wojcik[8] used agent-based modeling to study decision-making interactions in TFM. He concluded that the ATSP cannot make the best decision without collaboration from airlines. However, if airlines make decisions independently, they cause excess congestion. Idris et al.[4,7] have proposed a new CTFM concept to address TFM issues identified from extensive field observations[1] as well as the needs of expected future demand under the Next Generation Air Transportation System (NextGen).[9] This proposed CTFM concept considers a new range of collaboration schemes that advocates shifting, when possible, some of the TFM responsibility to users both in selecting and in implementing TFM plans. The ATSP assumes a supervisory role, monitoring the system performance, and intervening only if needed. This responsibility shift is proposed with certain limits as the role of an ATSP rationing intervention is retained. The expected benefits are that proactive users' actions can reduce the need for ATSP intervention and reduce ATSP workload, thereby facilitating more efficient TFM initiatives.

The proposed CTFM concept requires feasibility and benefit assessments to prove its viability and merits. This is planned to be done through a series of simulations where the main concept attributes are modeled. To support these analyses, this paper refines the high-level concept description[4,7] by conducting a task analysis. The analysis details responsibilities and their allocation to the main decision-makers, i.e., AOCs and ATSP. It identifies feasibility issues and benefit mechanisms, in more detail relative to previous efforts,[10,11] and forms the basis for modeling the collaboration schemes of the concept.

This paper starts with a brief summary of the CTFM concept of operation and its core attributes in Section II as proposed by previous work.[4,7] Then, the task-analysis framework is introduced in Section III. Section IV presents a traffic scenario as a generic flow constraint situation and the application of the CTFM core attributes to manage the situation – namely to instantiate the CTFM concept in a given traffic scenario. Then the task analysis is presented with discussion of the resulting range of allocations of responsibility between the AOC and ATSP, their specific task sequences, and the information exchanged between them. Also discussed are potential feasibility issues raised by the collaboration schemes that have been chosen, as well as feasibility issues that ruled out alternative schemes. Finally, this paper ends with the task analysis implications on future experimentation in terms of example factors and parameters that are modeled in a CTFM simulation platform.

II. Summary of Collaborative TFM Concept of Operation

This section summarizes the core attributes of the CTFM operational concept subject of analysis.[4,7] The concept advocates for higher information exchange and collaboration between the AOCs and the ATSP to facilitate a more dynamic, flexible, and adaptive TFM process. It advocates shifting, when possible, some of the TFM responsibility to users both in selecting and in implementing TFM plans. The ATSP assumes a supervisory role, monitoring the system performance, and intervening only if needed. The expected benefits are that proactive users' actions can reduce the need for ATSP intervention and reduce ATSP workload, thereby facilitating more efficient TFM initiatives. Five core attributes that are at the heart of the CTFM concept:[7]

1. Extending ATSP-User collaboration throughout the geographic, time, and activity horizons

Collaboration between the ATSP and the users in current operations is substantially focused on strategic planning or on tactical planning in emergencies. During strategic planning, collaboration is performed mainly through teleconferences held every 2 hours mediated by the ATCSCC and though swapping Expected Departure Clearance Times (EDCTs) during Ground Delay Programs (GDPs) or Airspace Flow Programs (AFPs). During tactical planning, collaboration is mostly limited to extreme and emergency situations (e.g., to solve low-fuel emergencies). In the CTFM concept, the collaboration, particularly between AOCs and TMUs, is extended to fill this gap. The collaboration extends throughout the time-space horizon covering local TFM situations (where a constraint can be mitigated within one center), regional TFM situations (where a constraint is mitigated by multiple adjacent centers), and national situations (which extend NAS-wide and involve the ATCSCC). Collaboration is also extended across all TFM activities, where the ATSP and AOCs share accurate and timely relevant information to achieve a common view of a flow constraint situation and iteratively coordinate the planning and the implementation of actions as the traffic and the constraint evolve.

2. Enabling direct collaboration between parties most concerned with a TFM situation

Enabling direct collaboration between the most concerned parties with a TFM situation (AOC-TMU for local, TMU-TMU-AOC for regional, ATCSCC-TMU-AOC for national) solves the inefficiencies and high workload of ATCSCC-centralized practices, which are currently limited to planning teleconferences and use of the Tactical Customer Advocate (TCA) position at the ATCSCC.

3. Expanding the role of users in TFM decision-making, particularly moving the locus of TFM planning and implementation towards users

The current centralization of the TFM function with ATSP limits the ability to assess and mitigate the impact of flow constraints and initiatives on users. Moving some responsibility to the AOCs for preemptively finding flow solutions and making 4-D trajectory changes will enhance the user's ability to choose their preferred solution and will result in a reduction of user's uncertainty about flow initiatives. In addition, ATSP workload, and particularly TMU's workload, will be reduced, as user actions preempt and reduce the need for ATSP action. The ATSP maintains the responsibility to ensure equitable distribution of resources.

4. Decreasing ATSP intervention while increasing user flexibility and options as time-to-constraint increases.

The concept foresees that collaboration and responsibility shifting between AOCs and ATSP is dynamic and iterative, changing their level of involvement and their roles as time to flow constraint changes. When the time-to-constraint is large, users are afforded high level of freedom to decide how to mitigate the constraint. As time-to-constraint decreases, the ATSP involvement increases, taking over flow planning and flight implementation, while the AOCs' options become more restricted. AOCs acting without central regulation may cause inefficient solutions creating congestion elsewhere. Therefore, the CTFM concept retains the central, supervisory role of ATSP to oversee AOC actions, but it advocates for a gradual ATSP intervention.

5. Enabling users to provide preferred solutions as inputs to ATSP planning decisions

As the ATSP (TMU for local/regional and ATCSCC for national TFM situations) provides solutions to flow constraints, especially as time-to-constraint decreases, users collaborate by submitting preferences, proposing alternative solutions, and making specific requests for planning flows as well as individual flights. The user inputs to the ATSP occur in a proactive manner before the ATSP starts broadcasting TFM plans. These inputs aim at aligning flow plans and 4-D trajectories selected by the ATSP with user preferences and needs. Since the ATSP maintains the responsibility to ensure equitable distribution of services, this dynamic mediation based on explicit user needs as opposed to presumed equitable and justifiable rules such as First Come First Serve (FCFS) or certain exemptions in current operations, will help ensure equity.

III. Methodology and Analysis Approach

This task analysis identifies collaboration schemes between the ATSP and the users to resolve a capacity-demand imbalance, defining their task sequence and the responsibility allocation between them in the context of the CTFM concept described in Section II. A tasking abstraction framework has been established[1] in support of developing the CTFM concept of operations and used to categorize the handling of a TFM constraint situation. Four high level tasks were used in this analysis (see Figure 1) to describe the tasks each decision-maker has to execute when handling TFM events. The four tasks serve as the backbone to characterize AOC and ATSP roles and responsibilities, their operating procedures, and their coordination and communication flows, both in current operations and under the CTFM concept. These tasks are:

- *Constraint identification (CI)*, which includes monitoring the traffic and constraints, prediction of the capacity and demand of the constrained airspace resource, i.e., an airspace, an airport, a route, or a fix, and identifying the imbalance between them.

- *Impact assessment (IA)*, which estimates the impact of the demand-capacity imbalance using performance metrics relevant to the ATSP and the users, such as delay or equity. This task involves "what-if" evaluations to estimate the impact of alternative measures that are elaborated in the flow planning task below to solve the TFM constraints.

- *Flow planning (FP)*, which involves planning for a flow level solution to mitigate the impact, imposing restrictions as the constraint worsens and removing them as it improves. FP specifies the resources that are available for use (i.e., airports, sectors, fixes, and route segments) by specific flows (e.g., use of a fix for departures or arrivals, or use of a route segment for either West or East inbound traffic) and the acceptable capacity (e.g., maximum densities or flow rates) for their usage. The output of this task feeds IA to evaluate the best solution.

- *Flight implementation (FI)*, which involves implementing the flow plan at the level of individual flights, calculating the new 4-D trajectories and communicating them to pilot/controller for execution.

As shown in Figure 1 both feed-forward and feedback loops tie these tasks together.

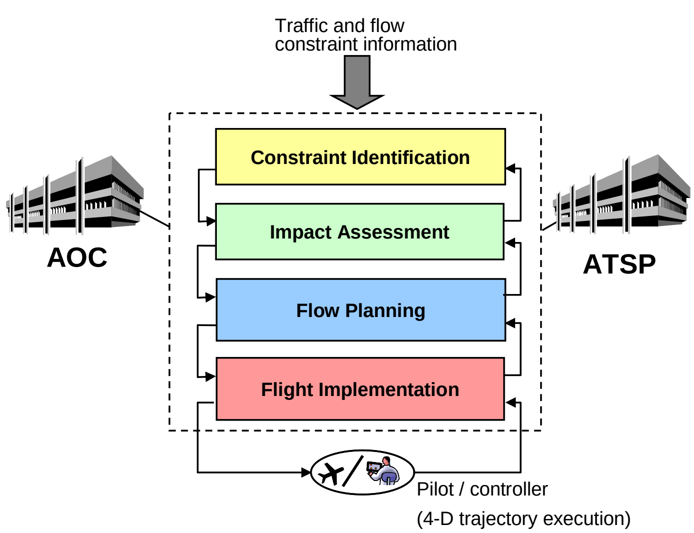

Figure 1. Tasking framework for the CTFM concept

Figure 2 illustrates the approach followed in this research. A scenario-based task analysis is built upon the results of previous research, which applied the tasking framework described above to identify and describe the current operations baseline and the CTFM concept core attributes. In addition to the core attributes of the CTFM concept described in Section II, these results included benefit mechanisms[10] and preliminary functional requirements.[11] Building on these inputs, a task analysis was conducted by instantiating the CTFM core attributes in the context of a generic constrained traffic scenario compatible with a wide set of causes, such as convective weather, excessive traffic complexity, SUA, and pass-back restrictions. The high level tasks depicted in Figure 1 were subdivided into subtasks, and the allocation of responsibilities and the collaboration between the ATSP and the users were established. The subtasks were described in terms of the goals of the ATSP or the AOC (representing an individual, a team, or an automation tool.) The breakdown into subtasks was carried out until no further breakdown was needed to highlight ATSP-AOC interactions. By applying this criterion, some tasks resulted in higher number of subtasks than others. A task that is performed completely by a single entity and that does not require ATSP-AOC interaction during the development of the task was not broken down into further subtasks since the focus of the breakdown is on participant interaction. The task can be performed in different manners depending on the internal model of the AOC or ATSP.

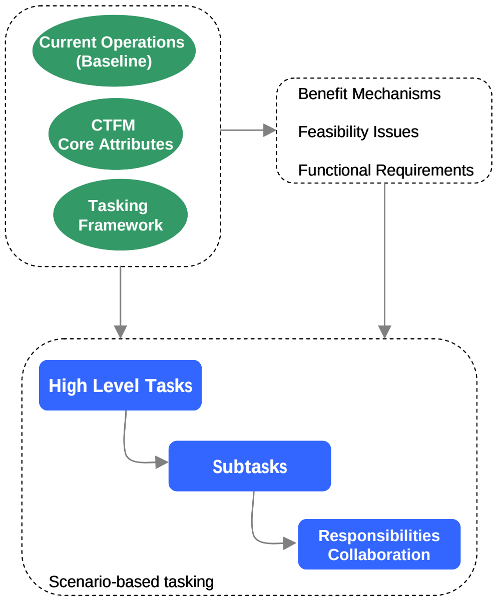

Figure 2. Task analysis approach

The analysis involved identification and refinement of the benefit mechanisms that the CTFM concept would enable, the information requirements that a subtask would impose, and potential feasibility issues the new collaboration scheme would face. Based on this information, this analysis proposed how the ATSP and AOC would perform a set of subtasks allocated to them according to the new responsibility and collaboration schemes. The analysis retained only those collaborations whose feasibility was not jeopardized due to apparent reasons, e.g., restrictions to access key data resources by one decision-maker to accomplish a subtask.

IV. Task Analysis of CTFM Concept

The solution space for collaboration schemes that incorporate these core attributes is wide. Different responsibility allocations are possible under the same concept principles. The task analysis reported here aims at refining the basic concept. For example, core attribute 3 proposes shifting the responsibility for TFM planning and flight implementation toward users, but the level of responsibility can vary along a wide spectrum. On one extreme, the AOCs could agree on a desired flow plan and implement 4-D trajectories accordingly, while the TMU monitors and intervenes if the TFM constraint does not improve or the result of AOCs actions is not equitable. On other extreme, the TMU could provide a flow plan allowing AOCs relative freedom in 4-D trajectories implementation. This section reports the task analysis and the final collaboration schemes selected for further evaluation in a simulation environment.

First, an illustrative scenario that instantiates the core attributes of the CTFM concept is described. This instantiation considers a three-tier time horizon with a different ATSP-AOC collaboration scheme within each tier. This scenario outlines the responsibilities on the four high level tasks across tiers. Then, a detailed task analysis is given for each tier, starting with subtasks that cover elements common across tiers and then subtasks that cover elements that are different among them.

A. Scenario-based instantiation of CTFM Concept

Given the CTFM concept core attributes outlined in Section II, a generic scenario is used to describe how the concept is applied, what tasks need to be performed, and what collaboration scheme is required. This scenario also helps contextualize the responsibilities and tasks of AOCs and ATSP. It should be noted that this scenario is notional and, thus, contains a generic airspace with the minimum elements necessary to represent ATSP-AOC collaboration to solve a TFM constraint.

The scenario used to facilitate the task analysis of the CTFM concept is illustrated by Figure 3. As shown, a flow of traffic is effected by a constrained airspace resource (e.g., a sector capacity is reduced as result of convective weather). In this scenario, at time t_0 an imbalance between demand and capacity at the resource is predicted between t_1 and t_2. The aircraft that contribute to this imbalance at t_0 are physically far from the resource (in bold) or spatially close to the resource but on ground waiting for their take off (such as the bold aircraft at the airport C). Other aircraft are flying towards and through the resource (grey aircraft) at the time the prediction is made, but they do not occupy the resource at the time the constraint is predicted. Note that for simplicity, the scenario is deterministically depicted, but the expected time and magnitude for the resource capacity to drop may have an associated uncertainty. Similarly, predicted demand is stochastic.

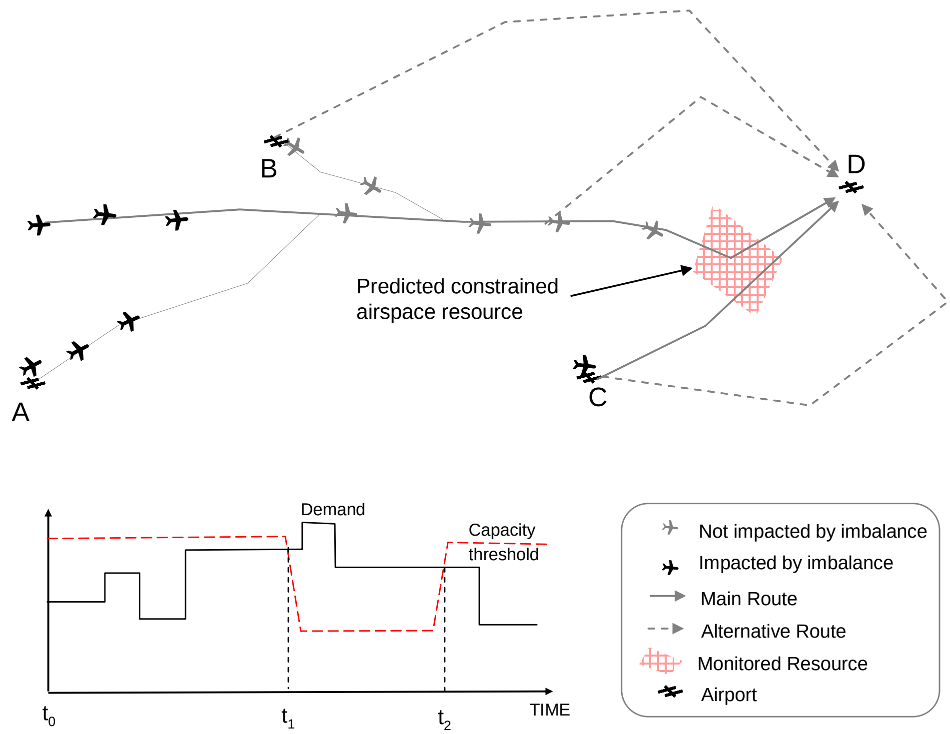

Figure 3. Basic scenario used for CTFM task analysis

To capture core attributes 1 and 2 (i.e., extending the collaboration across the time and space horizons and enabling direct collaboration), the scope of the scenario is generic and may cover local, regional, and national horizons. The ATSP represents either the ATCSCC or the TMU depending on the scope of the constraint. The ATSP represents the TMU and collaboration occurs directly between the AOCs and the TMU without the ATCSCC mediation when the impacted traffic can be managed locally, within one center or with coordination with an adjacent center. The ATSP's tasks will be performed by the ATCSCC in coordination with TMUs and user collaboration occurs between AOCs and ATCSCC when the constraint requires flow plans that extend beyond two centers.

To capture core attribute 3, AOCs taking preemptive actions with regard to TFM planning and implementation, and core attribute 4, dynamically restricting this ability as the time to the constraint decreases, a three-tier time horizon is introduced. It divides the airspace into three regions by time intervals relative to the constraint, namely outer, middle, and inner tiers. Each tier is characterized by a different responsibility scheme increasing the ATSP responsibility and decreasing the AOCs' responsibility for handling flights in successive tiers. AOCs have higher freedom to take preemptive actions for flights temporally distant from the constraint, either in the air or on the ground, than for flights that are temporally closer to the constraint. In Figure 4, the three tiers are depicted as spatial areas around the constraint, where the size of these areas corresponds to the appropriate time interval needed for each tier. Note that for flights on ground the tier limits are related to the estimated time of arrival to the constraint; therefore aircraft physically close to the constraint but scheduled to arrive later (such as the flight in airport C) would belong to outer tiers. In operation, within structured airspace, these tiers may be tied to airspace boundaries. Finally, to capture core attribute 5, user inputs are incorporated in ATSP decisions in all tiers as described below.

The tasks performed by the ATSP and the AOC in each tier are discussed in terms of the four high level tasks introduced in Section III: CI, IA, FP, and FI. The responsibility and task assignment within each tier are represented in Figure 4 by assigning a coded block to the decision makers that participate in the task. There are three possible roles represented:

- Filled grey block: decision maker holds responsibility to perform that task

- Striped grey block: decision maker performs some actions in the task in collaboration with the counterpart decision maker
- Dotted empty block: decision maker does not play any role in that task

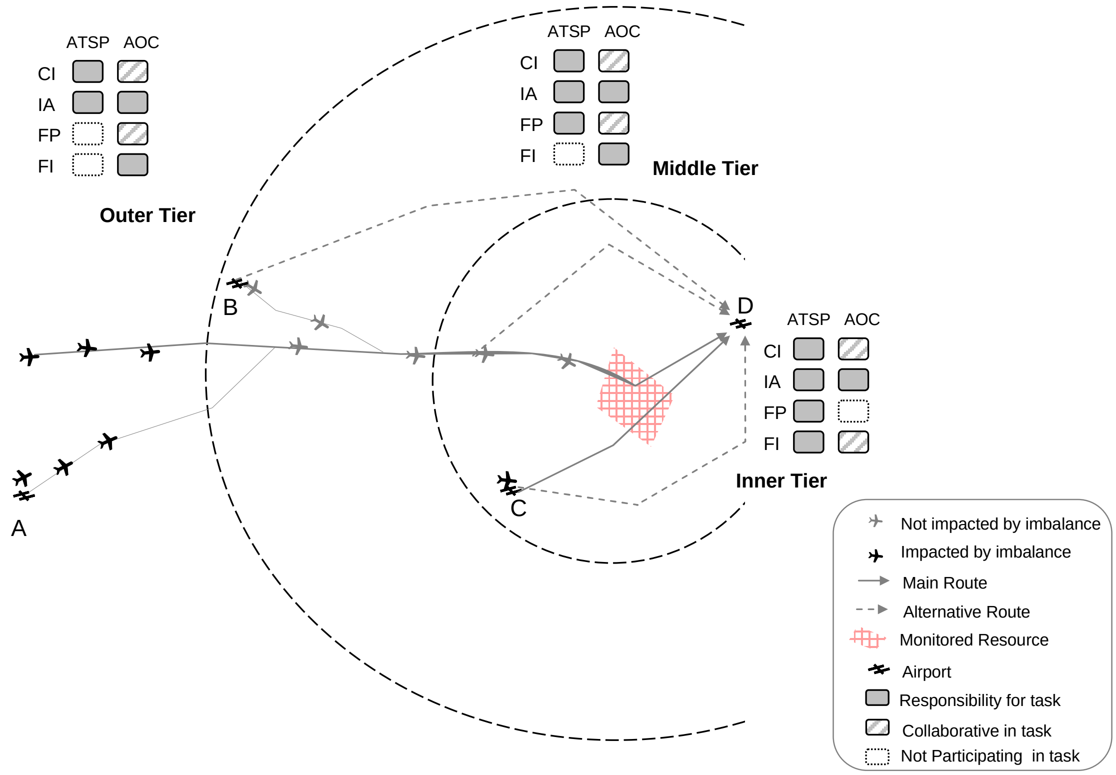

Figure 4. Three-tiered, dynamic allocation of responsibility as time-to-constraint decreases

Flights in the *outer tier* that are contributing to the demand-capacity imbalance are sufficiently far from the constraint that no flow plan is required yet for them. During this tier, the ATSP provides an opportunity to the AOCs to eliminate the imbalance preemptively through their own flight planning and implementation. Therefore, the temporal boundary between the outer and middle tiers is determined by the time the ATSP can afford to wait without a flow plan in place. During this time, the ATSP monitors constraints and assesses their impact on traffic, and shares this information with the AOCs to support their actions. Given the constraint and impact information shared by the ATSP, the AOCs may change their flight trajectories to preemptively resolve the imbalance. Preemptive actions will lead to smaller deviations from AOC preferred 4-D trajectories and to higher freedom to choose what flights are affected. Although no flow plan is applied in this tier, the AOC 4-D trajectory changes are restricted to those that abide by the existing use and route structure of the airspace. Since no flow plan is applied in this tier, the ATSP plays no FP role, while the AOC plays a partial FP role as shown in Figure 4. This partial role represents the AOC generation of flow plan preferences that they communicate to the ATSP for consideration in the middle tier.

As the ATSP monitors the constraint, if the AOC preemptive actions did not resolve the imbalance, the ATSP decides that a flow plan is needed. At this time the flights impacted by the imbalance enter the *middle tier* mode of operation, where a flow plan has to be formulated and applied. The ATSP and AOCs collaborate on selecting a flow plan. For example, the ATSP may assess a preferred flow plan and send it to the AOCs. The AOCs either agree on an alternative flow plan that solves the constraint or send separate suggestions to the ATSP. The ATSP retains the responsibility of the final decision. The ATSP evaluates the AOCs' proposals and, based on NAS performance metrics, develops the final flow plan. Once the ATSP imposes the flow plan, the flight trajectories have to abide by it. This flow plan gives AOCs flexibility to choose among multiple routes (shown as dotted routes in Figure 4) by setting route options and flow rates for specific airspace assets rather than imposing specific reroutes on flights. Within this middle tier, the AOCs have the responsibility to modify flight trajectories abiding by the flow plan.

These preemptive actions can alleviate the constraint and reduce the need for further ATSP intervention through changing flight trajectories. In the middle tier the ATSP continues to modify the flow plan if needed based on the constraint evolution. The AOCs also continue to make flow plan change suggestions that the ATSP may take into consideration.

Finally, as flights approach the constraint area, they reach the *inner tier*, where the ATSP takes over responsibility to implement flight trajectory changes if the constraint still persists. The boundary between the middle and inner tiers is determined by the time from the constraint the ATSP requires a stable trajectory, and hence cannot afford to allow the AOCs to change trajectories without prior approval. This time interval corresponds to different distances from the constraint and different transition times into the inner tier for each flight. The AOCs limit their activity to communicating, with the appropriate automation support, to the ATSP their preferences and requests for trajectory changes. The ATSP changes of 4-D trajectories comply with the flow plan and incorporate as much as possible users' preferences.

In summary, the defining characteristic of the transition from one tier to another can be summarized as follows:

- From the *outer* to the *middle* tier: the ATSP decides that a flow plan is needed and starts collaborating with AOCs on formulating one.
- From the *middle* to the *inner* tier: when a flight reaches a time interval from the constraint, the ATSP takes over responsibility to implement 4-D trajectory changes.

A tier system (set of inner, middle and outer tiers) is defined with respect to a constraint situation. A constraint situation may include multiple resource imbalances, whose proximity requires only a single tier system. The tier limits are determined by the ATSP based on the combined effect of the imbalances. However, if a flight passes through multiple constraint situations, each with its own tier system, it may fall in the inner tier of the constraint it is closer to and, simultaneously, in the middle tier of the next constraint. Therefore, the immediate part of its trajectory up to the first constraint is under ATSP control (due to inner tier rules) while the AOC has the freedom to change the later part of the trajectory beyond the first constraint (due to middle tier rules). These AOC changes have to abide by the flow plan set by the ATSP for that constraint. Therefore, when multiple tier protocols overlap a segment of a trajectory, the more ATSP-restrictive rules prevail. Another fundamental question is the optimal size and dynamic nature of the tiers. In particular, the size of the tiers is dependent on the severity of the imbalance and therefore is adjusted as this severity evolves over time. The details of determining the tier systems, the tier limits, and their dynamic nature are subjects of the future feasibility and benefit analyses.

B. Common Collaboration across Tiers: Constraint Identification and Impact Assessment

CI and IA are two tasks performed by both the ATSP and AOCs across tiers with no change in responsibility. The ATSP holds the responsibility to identify any constraint and distribute the information. The ATSP protects common airspace resources against overload by monitoring demand-capacity imbalances at the NAS resources and taking actions that preserve the performance of the ATM system. In addition, the AOCs monitor the state of NAS resources to identify and implement preemptive actions before any constraint materializes or the ATSP takes action. By timely broadcasting of constraint information, the ATSP enables the AOCs to gain access to resource capacity and aggregate demand information to support such preemptive actions.

With regard to IA, the assessment of the impact of a TFM constraint is the responsibility of the decision maker who has better information regarding the constraint and the parameters required to calculate its consequences. The impact on airline operations is evaluated by AOCs, while the impact on the NAS is done by the ATSP. However, with appropriate information exchange in specific situations, both agents can estimate the impact of a given action on airline and NAS operations. The following paragraphs describe the breakdown of the high level tasks of CI and IA into subtasks, as well as the collaboration scheme between the ATSP and the AOCs and the main benefit mechanisms involved. Table 1 of the Appendix summarizes the analysis of these CI and IA subtasks.

1. Constraint Identification

Both decision makers perform CI tasks periodically. CI is subdivided in four subtasks: identify resources to monitor, identify capacity of resources, identify demand for resources, and evaluate demand-capacity imbalance. The following paragraphs present each CI subtask.

<u>Identify resources to monitor.</u> The identification of constraints requires identifying the resources that need to be monitored. The ATSP holds the responsibility of identifying these resources because it directly manages them. In general, these resources are predefined and continuously monitored, such as sectors, jet routes, fixes, or airports. In addition, customized regions of airspace can be defined and monitored, for example, around convective weather in a similar manner as done today with Flow Evaluation Areas (FEAs). The AOCs, based on the information provided by the ATSP and their own information of weather and operations, can also propose additional resources for monitoring. This can improve the accuracy of the ATSP identification of constraints, reducing overly conservative

and reactive ATSP restrictions. However, to ensure feasibility adequate automation support is required to integrate the AOCs resource suggestions without increasing workload of the ATSP.

Identify capacity of resources. The ATSP holds the responsibility to estimate the capacity of resources in normal operations and constrained situations (e.g., convective weather) because it has direct control over resources and more reliable information about resource limitations. However, the AOCs can provide information to help the ATSP estimate the capacity of some resources, such as pilot weather reports, policy affecting flight into or around a weather constrained airspace, and other in-house weather predictions. As a result, estimation of capacity reduction will be more accurate, reducing conservative and reactive restrictions imposed by ATSP. This is likely to result in user-estimated ability to fly through weather. The user-estimated ability to fly through weather depends on flight equipage, pilot preferences, and company policies. To ensure feasibility, adequate automation support is required to integrate the AOC's resource suggestions without increasing workload of the ATSP. In current operations, capacity is estimated in terms of the Monitor Alert Parameter (MAP) for sectors, but other metrics that better reflect controller workload, e.g., dynamic density,[12] could also be used to estimate capacity in NextGen.

Identify demand for resources. Proprietary reasons make it unlikely for the AOCs to share directly demand information among themselves. Thus, the ATSP holds responsibility to collect and aggregate demand information from all users. The users provide timely and early intent information about cancellations, departure times and routing changes. This results in reduced uncertainty in demand estimation, increasing the accuracy of constraint identification, and thus reducing overly conservative and reactive restrictions imposed by ATSP. The aggregate demand prediction is shared so that the AOCs can use it for impact assessment and in support of their preemptive actions. A key feasibility concern to achieve the demand information sharing and integration this task requires is the willingness of the users, AOCs and non-airlines, to share information. Although high quality demand information will benefit all users, additional incentives such as equity guarantees may be needed. Automation may also be required to integrate demand information without increasing ATSP workload.

Evaluate demand-capacity imbalance. The ATSP holds the responsibility of identifying demand-capacity imbalances. After evaluating and integrating demand and capacity information, the ATSP broadcasts the period of time and the magnitude of the imbalance together with a preliminary list of flights that can be affected by the imbalance. The AOCs use this information to evaluate the impact on their own flights and build their decisions to preemptively solve the imbalance, reducing ATSP workload and conservative restrictions. In order to ensure feasibility, the AOCs need to become equipped with automation support for their evaluation of imbalances and integration of the evaluation information in their flight planning without a substantial increase in the AOC workload.

2. Impact Assessment

This task is performed by both the ATSP and the AOCs upon receiving constraint information. In addition to assessing the impact of the constraint with no mitigating action, it aims at supporting trial planning evaluation of alternative actions by the ATSP and AOCs. It is broken down in three subtasks: compute NAS impact metrics, compute airline impact metrics, and establish the limits of the tiers. The following paragraphs present each IA subtask.

Compute NAS impact metrics. The ATSP is responsible for estimating the impact of constraints and alternative initiatives on NAS operation metrics, such as complexity, equity, or aggregate delays. These metrics can be used in ATSP decision making or distributed to the AOCs. For example, the ATSP calculates expected delays and a corresponding measure of uncertainty for flights flying through the constrained resource. This information is broadcast to AOCs so that they can incorporate it into their own impact assessment and decision making process. In some situations, the AOCs will estimate NAS impact metrics (e.g., traffic congestion after changing 4-D trajectories) that, once they are integrated into their decisions, will align AOC planning with NAS impacts. Thus, it will increase ATSP acceptability of the AOCs' preemptive actions and reduce ATSP workload. However, the ability of AOCs to estimate NAS impact metrics is limited without significant information from the ATSP and enabling automation support.

Compute airline impact metrics. Conversely, the estimation of the impact of the imbalance on AOC operations is performed by the AOCs since the ATSP has no knowledge of the economic impact of a given delayed flight over an AOC's fleet operations. Although the AOCs do not send explicit airline metrics to the ATSP, they submit flow plan and flight trajectory change requests and preferences to the ATSP to align subsequent ATSP TFM initiatives with AOC impacts, thus increasing user satisfaction. Therefore, these impacts should be integrated with and well presented in the AOC preferences. Additional details about the submission of these requests and preferences are given below in the description of FP and FI.

Establish limits of tiers. A constraint that impacts the NAS capacity and requires a TFM plan triggers both AOC and ATSP actions. A system of tiers, which defines the responsibilities for the AOCs and the ATSP, is set up to support and facilitate these actions, as was described in the scenario in Figure 4. The existence and limits of the tiers depends on the severity of the demand-capacity imbalance and its impact. For example, the ATSP may determine that it can afford to provide outer and middle tiers, allowing the users the ability to participate in mitigating an imbalance, under one or more of these conditions: (1) when an imbalance is identified early in time, (2) the probability of imbalance occurrence is medium to low, or (3) the imbalance severity is moderate. The ATSP would analyze the situation and establish the limits for the tiers. For example, in the scenario illustrated in Figure 4, the ATSP establishes the time interval required for taking over 4-D trajectory decisions in the inner tier and the time interval it can afford to provide for user preemptive flight planning in the outer tier without a flow plan. These time intervals then correspond to spatial boundaries based on average speed and/or based on structured airspace boundaries. In determining the tier limits, the ATSP also considers multiple imbalances within a constraint situation and the interaction between multiple constraint situations. The setup of the tier system is revisited periodically and adjusted as constraint severity changes over time. The specific algorithms for determining the tier limits are subjects of future research. Providing these tiers enables proactive and dynamic involvement of the AOCs in mitigating the constraint, which increases user satisfaction and reduces ATSP workload by preempting the need for ATSP planning. However, the transitioning between tiers introduces new AOC and ATSP activities that may require procedural or automation mitigation methods. For example, identifying flights belonging to different tiers may cause confusion. This confusion may be alleviated procedurally by tying the tier limits to structured airspace boundaries or with appropriate automation and visual aids.

The difference among tiers resides in the FP and FI activities of both decision makers and the responsibility and collaboration established between them, which are described in the next sections. The structure of the tiers suggests a chronological description of tiers starting from the one earlier in time, i.e., the outer tier then the middle tier and finally the inner tier.

C. Tasking and Collaboration Schemes on Flow Planning and Flight Implementation in the Outer Tier

In the outer tier, traffic is far enough from the constraint and the uncertainty of the imbalance is high enough that the ATSP does not engage yet in formulating a flow plan or in any task related to FI. In contrast, the AOCs perform preemptive activities related to FP and FI. This section describes the subtasks that compose FP and FI in the outer tier, as well as the collaboration scheme between the ATSP and the AOCs. Table 2 of the Appendix summarizes the analysis of these FP and FI subtasks in the outer tier.

1. Flow Planning

There are no primary tasks related to FP in the outer tier because flow planning to solve the constraint starts in the middle tier as decided by the ATSP. This decision is a result of the task establishing the tiers in IA, based on the success or failure of the AOC actions in the outer tier, described below in FI. Although no flow planning is performed to mitigate the constraint, there is always a default airspace configuration and route structure that is maintained by the ATSP, as in current operations.

While the ATSP does not engage in FP activities until the middle tier, the AOCs can start formulating their preferences for a flow plan and send them to the ATSP for consideration in the middle tier. Therefore, only one FP task is performed by the AOC in the outer tier: <u>Formulate AOC flow plan preferences and send them to ATSP.</u> If the AOCs predict that their flight trajectory changes are insufficient to solve the constraint, they start analyzing solution flow plans to solve the constraint and to meet their business objectives. This task is similar to the AOCs collaboration with the ATSP in formulating the flow plan in the middle tier and is, therefore, described in more details in the middle tier below.

2. Flight Implementation

Within the outer tier only one subtask related to FI is identified:

<u>Identify and implement 4-D trajectories for impacted flights.</u> The ATSP does not perform any activity modifying aircraft trajectories. Conversely, the AOCs, based on their own assessment, change trajectories of impacted flights while abiding by the current configuration and route structure of the airspace. These AOC preemptive actions often mitigate the constraint, alleviating the need for future ATSP action, reducing ATSP workload, and increasing user satisfaction. Three major feasibility issues need to be addressed to enable this task. First, to enable AOC trajectory changes in the outer tier without ATSP approval, these changes should not be disallowed by the current rule which makes any change in a flight plan beyond 45 minutes prior to departure time the responsibility of the ATSP. Therefore, appropriate procedural changes are required. Second, the AOCs have to consider estimates of NAS impact metrics to increase the likelihood that no demand-capacity imbalance is created elsewhere as consequence of their trajectory changes. Therefore, NAS impacts should be integrated into the AOCs decision process which requires the AOCs to use ATSP IA information or estimate their metrics to decrease resource imbalance probability. For example, the AOCs may use capacity and demand predictions broadcast by the ATSP and make flight

trajectories changes that favor using resources that are farther from being congested. And third, this task requires an effective coordination process among the AOCs to achieve an agreement when competing for the same resources, in an equitable manner. The final execution of 4-D trajectory changes is subject to coordination between pilots and ATC, which should ensure maintaining safe operations by constraining the AOC 4-D trajectory changes. For example, AOC 4-D trajectory changes should provide sufficient freeze time horizon where the trajectory is stable for the pilot/ATC to safely execute the changes.

D. Tasking and Collaboration Schemes on Flow Planning and Flight Implementation in the Middle Tier

Within the middle tier, the ATSP starts formulating a flow plan collaboratively with the AOCs. This includes the initial establishment of a flow plan and continuously reviewing and modifying it. The ATSP does not modify flight trajectories. The AOCs hold the responsibility for changing flight trajectories while abiding by the flow plan imposed by the ATSP. This section describes the subtasks that compose FP and FI in the middle tier, as well as the collaboration scheme between the ATSP and the AOCs. Table 3 of the Appendix summarizes the analysis of these FP and FI subtasks in the middle tier.

1. Flow Planning

Within the middle tier three subtasks related to FP are identified:

Coordinate and identify preferred flow plan to solve constraints. In the middle tier, the ATSP searches for a potential flow plan to be implemented and sends it to the AOCs. This flow plan specifies routes to use and acceptance rates at the resources, leaving freedom to the AOCs to accommodate their flights. The AOCs are actively analyzing a solution flow plan to solve the constraints and to meet their business objectives. IA of both decision makers supports the evaluation of alternatives to find the optimal according to their own optimization function. The AOCs will most likely identify modifications to the ATSP's flow plan suggestion rather than create a completely different flow plan, because the probability to be approved by the ATSP is higher. An AOC proposed flow plan is more likely to increase airline options and satisfaction as their business objectives are incorporated more accurately. It increases predictability for the AOCs as well, who will be more willing to take preemptive actions on their flights. The AOCs, with competing objectives and self-interest behavior, have to achieve a common agreement, thus an effective coordination or negotiation process may be required. Individual AOC requests to the ATSP would likely increase the ATSP workload and would decrease the chances of approval. Therefore, the main feasibility question in this task is the development of an effective coordination process among the AOCs with competing behavior to achieve a common flow agreement. This process is subject of future research.

Identify and implement flow plan to solve constraints. The flow plan(s) proposed by the AOCs is evaluated by the ATSP, based on NAS impact metrics and its own objectives. The ATSP holds responsibility to impose the final plan, which defines what resources are available, what traffic flows can use them, and the acceptance rates of these resources. The flow plan can be identified using predefined templates, introducing them manually, or through automated algorithms that search for an optimal flow plan. The final flow plan gives AOCs flexibility to choose among multiple routes by setting route options and flow rates for specific airspace assets rather than imposing specific reroutes on their flights. The AOC's preferred flow plans are incorporated as much as possible, increasing user satisfaction and reducing uncertainty. The key feasibility question is the design of automation support required to enable the ATSP to incorporate the AOCs suggestions without increase in workload.

Further modification of the flow plan as a result of the constraint evolution. Once the flow plan is implemented, the ATSP will still look for improvements and dynamically change this plan. The final responsibility to implement any change falls on the ATSP, but AOCs can also identify desired changes and request them from the ATSP. As in the initial plan, these changes can be identified and introduced manually using predefined templates or through automated algorithms that dynamically search for adjustments to the traffic flows. This subtask helps to increase the dynamic nature of the flow planning, mitigating uncertainty, as well as continuing to incorporate user suggestions. The key feasibility questions are the integration of NAS impacts into the AOCs flow plan suggestions and the design of automation support required to enable the ATSP to incorporate the AOCs suggestions without increase in workload.

2. Flight Implementation

Within the middle tier only one subtask related to FI is identified: Identify and implement 4-D trajectory for each impacted flight. Similarly to the outer tier, the ATSP does not perform any activity modifying aircraft trajectories. It is the AOCs, based on their impact assessment, that change trajectories of impacted flights abiding by the flow plan. The information sharing, collaboration, and benefit mechanisms are the same as described in FI in the outer tier. The feasibility issues are the same as in the outer tier.

E. Tasking and Collaboration Schemes on Flow Planning and Flight Implementation in the Inner Tier

Within the inner tier the AOCs have limited ability to change 4-D trajectories. Due to the close proximity of the constraint, any AOC decision of changing 4-D trajectories needs ATSP approval and AOCs do not perform any flow planning task, as in current operations. Table 4 of the Appendix summarizes the analysis of the FP and FI subtasks in the inner tier.

1. Flow planning

Only one subtask in FP is performed by the ATSP: Identify and implement changes to flow plan. This task aims at searching for adjustments to the current flow plan in place as a result of constraint evolution over time. At any given time and triggered by CI and IA results, the ATSP is looking for alternative TFM plans that resolve remaining demand-capacity imbalances, if they still exist. At this stage, the traffic is close to the constraint and no AOC input related to flow planning is expected.

2. Flight implementation

There are two subtasks related to FI: generation of AOC preferences and identification and implementation of 4-D trajectories for impacted flights.

Generate preferences. The AOCs identify a set of preferences and send them to the ATSP for incorporation in the 4-D trajectory changes. In this task analysis three types of preferences were identified and will be investigated in the future feasibility and benefit assessments: priorities between flights, preferences of alternative routes, and when to absorb delay for each flight. The AOCs determine these preferences according to metrics estimated by the IA tasks and their objective functions, which are different for different AOC models. The AOCs give priority to certain flights of its fleet that might compete for a common resource under anticipated TFM constraints. In addition, the AOC ranks the alternative routes available to a flight as predefined by the flow plan imposed by the ATSP. The AOCs will rank the alternative routes internally depending on their policies and business model, providing a ranked list to the ATSP to use in rerouting decisions. For example, a risk-averse airline would be willing to pay an additional cost of flying a route with some delay that it is certain to receive, in order to avoid the low probability of a high cost outcome of flying another route with low expected delay but high uncertainty. The third kind of user preferences is given by specifying when the flight prefers to absorb a given delay along a route. Absorbing delay on the ground or at higher altitude (i.e., upstream of the constraint) reduces operating cost; however, under high uncertainty of receiving delay, some airlines may prefer absorbing the expected delay later downstream along the route hoping the constraint will not materialize as predicted, thus saving delay and increasing throughput as a result. The preference to absorb delay might be specified in several methods which is subject of future research. For example, it may be specified as a binary choice of whether to absorb delay either upstream or downstream, or in a more sophisticated manner, the AOC would send a distribution of delay along the route, e.g., by specifying proportions of delays in the sectors along the flight route. The ATSP will honor the AOC preferences when possible with respect to the NAS metrics and if the result is equitable among airlines, i.e., maintaining fair allocation of resources to flights as consequence of granting preferences. Several metrics of fairness may be investigated in future research. By providing these preferences, and with the support of automation to enable the ATSP to incorporate them without impact on workload, user satisfaction is increased. The key feasibility issues are related to the design of automation to assist the AOCs in generating the preferences and the inclusion of NAS impact metrics in their evaluation to align preferences with the ATSP criteria.

Identify and implement 4-D trajectories for impacted flights. The ATSP has put in place a TFM plan from the middle tier, which is likely to stay relatively constant as time progresses. The AOCs also had their chance to modify their flight 4-D trajectories to abide by the flow plan and eliminate the imbalance. In the inner tier, the ATSP takes over the responsibility to make any further adjustment to 4-D trajectories to abide by the flow plan, if needed. Since the ATSP incorporates the AOCs' preferences in the 4-D changes required by the flow plan, explicit requests by the AOCs will be reduced and thereby reducing ATSP workload. The key feasibility issue is the design of the automation support required to enable the ATSP to incorporate the AOCs preferences in an equitable manner without increase in workload.

Concluding Remarks

A task analysis has been presented to define the collaboration between the TFM authority and the users to solve TFM constraints in the context of a far-term CTFM concept of operation. This task analysis will be used as input to future feasibility and benefit assessments of the CTFM concept, which require two main activities: the design of experiments and the development of a CTFM simulation platform. This paper is concluded with implications on these two activities.

Experiment design. The design of experiments considers two types of parameters: those introduced by the ATSP-AOC collaboration spectrum representing the CTFM concept, as outlined in this paper, and external parameters such as the different demand levels that are expected under NextGen operations. The experiments will identify which parameters are most influential in CTFM process performance and what interactions exist between them. The following are three examples of experimental parameters that stem from the task analysis:

1. The size of the tiers and their dynamic nature matters. This involves comparing scenarios with inner-tier collaboration only with scenarios containing inner-tier and middle-tier collaboration, and finally, scenarios containing all three tiers. The experiments will also compare different sizes of the tiers in relation to the severity of the demand-capacity imbalance in order to identify the feasible and most beneficial scenarios.

2. In the inner tier, three levels of AOC preferences to be incorporated in the ATSP decision making can be identified from the task analysis. The ATSP makes 4-D trajectory changes: a) without incorporating AOC preferences (representing current operations baseline), b) using AOC preferences that are based exclusively on an AOC business objective function, and c) using AOC preferences that are based on an AOC business objective function and the effect on NAS metrics (e.g., AOC giving higher ranking to alternatives that avoid increasing congestion or creating imbalance elsewhere). The development and modeling of a negotiation process is an area of future research and key in the assessment of the concept.

3. In the middle tier, the task analysis indicates that the feasibility of the AOC maintaining responsibility for modifying 4-D trajectories depends on the existence of a coordination mechanism. Therefore, two levels of AOC 4-D trajectory generation can be analyzed: 1) AOCs change trajectories based on their own preferences with no modeled negotiation to resolve competition, and 2) AOCs make trajectory changes with a modeled negotiation process among them.

CTFM simulations. The experiments to analyze the feasibility and benefits of the CTFM concept are planned through a series of fast time simulations. A CTFM simulation platform is being developed to emulate the dynamic behavior of the CTFM process over time, with emphasis on the ability to simulate different collaboration schemes between ATSP and AOCs. The platform leverages the capabilities of the Future ATM Concepts Evaluation Tool (FACET)[13] using it primarily as an engine for modeling the NAS resources and aircraft trajectories. The platform is connected to FACET through its Application Programming Interface (API) to get NAS and traffic information and to communicate ATSP and AOC decisions for simulation. The task analysis presented in this paper serves as the underlying basis for this platform by supplying the module subtasks of the ATSP and AOC and the protocols of communication between them. Each of the subtasks identified in this paper will be instantiated in the platform through models that reflect a range of ATSP and AOC behaviors. The platform is built to support a wide range of experimentation with the ability to substitute different models for each subtask. For example, AOC risk averse or risk seeking behavior can be modeled in the platform by setting different AOC objective functions in the subtask that identifies and implements 4-D trajectories. In addition, the communication protocol in the platform is built to support the range of collaboration schemes presented in the paper as well as variations on these schemes.

Appendix

This appendix contains a set of tables summarizing the task analysis in each tier. Each table includes a breakdown of tasks into subtasks, the decision maker who holds primary responsibility, the information sharing, how this concept differs from current operations, what the main benefit mechanisms are, and a preliminary list of feasibility issues that the concept raises.

In the tables, the role of a participant/decision maker is defined as primary, support, limited, or none. This differentiation should be interpreted as follows:

- Primary: the participant holds responsibility of performing the task without approval of the counterpart, and shares information result of the task or
- Support: the participant performs activities related to the task and shares information to support its counterpart
- Limited: the participant has a limited ability to perform the task completely
- None: the participant does not play any role in performing the task

Table 1. Constraint identification and impact assessment tasks

Tasks Subtasks	Role		Information sharing and collaboration	Difference from baseline	Main benefit mechanisms	Feasibility issues
	ATSP	AOC				
Constraint Identification						
Identify resources to monitor	Primary	Support	AOC communication of additional resources to be monitored	Greater AOC ability to propose resources of concern	Improve ATSP ability and accuracy in identifying constraints, thus reducing overly conservative / reactive restrictions	Automation required to integrate AOC resource suggestions without increasing ATSP workload
Identify capacity of resources	Primary	Support	AOC provides information such as willingness to fly through partially constrained resources – ATSP provides capacity estimate information	Greater integration of AOC information impacting capacity estimate	Improve ATSP capacity estimation accuracy, thus reducing overly conservative / reactive restrictions	Automation required to integrate AOC capacity suggestions without increasing ATSP workload
Identify demand on resources	Primary	Support	AOC and non-airline users provide earlier, timely demand, including cancellations and trajectory changes – ATSP provides aggregate demand estimates	Greater integration, timeliness and completeness of demand information	Improve demand estimation accuracy, thus reducing conservative / reactive restrictions and increasing equity	Integration of airline ground surveillance information Inclusion of non-airline user information Incentives to share information
Evaluate demand-capacity imbalance	Primary	Limited	ATSP holds responsibility to estimate and broadcast imbalance and broadcast – AOC will estimate the imbalance with this input and its internal information for own planning	Greater use of resources imbalance information by AOC	Increase AOC ability to proactively plan to eliminate imbalances, thus reducing ATSP workload and overly conservative restrictions	Automation for AOC evaluation of imbalance and integration in AOC flight planning without increase of AOC workload
Impact Assessment						
Compute and share NAS impact metrics	Primary	Limited	ATSP shares NAS impact estimates (e.g., aircraft sector count) – AOC estimates/uses ATSP shared NAS impacts in order to incorporate them into their flight planning and preferences	Greater integration of NAS impact metrics in AOC evaluation of flight planning alternatives	Alignment of AOC planning with NAS impacts, thus reducing ATSP workload and overly conservative restrictions	Ability of AOC to estimate NAS impact metrics is limited without significant information from ATSP
Compute airline impact metrics	Limited	Primary	AOC does not send explicit metrics to ATSP, rather implicitly through planning preferences – ATSP estimates minimal airline metrics, making use of AOC preferences for most decisions	Greater implicit integration of AOC calculated metrics in ATSP decisions	Alignment of ATSP actions with AOC impacts, thus increasing user satisfaction	Ensuring that AOC impacts are sufficiently integrated with and represented in the AOC preferences
Establish limits of tiers	Primary	None	ATSP responsible for establishing dynamically the collaboration tiers and communicates them to AOC	Extension of collaboration throughout the constraint horizon, with gradual AOC involvement	Dynamic planning to mitigate uncertainty and dynamic involvement of AOC in TFM planning, thus reducing ATSP workload and increasing throughput and user satisfaction	Automation and procedures required for transitioning between tiers, particularly in the presence of multiple interacting constraints

Table 2. Outer Tier: Flow Planning and Flight Implementation tasks

Tasks Subtasks	Role		Information sharing and collaboration	Difference from baseline	Main benefit mechanisms	Feasibility issues
	ATSP	AOC				
Flow Planning						
Coordinate and identify preferred flow plan to solve constraints	None	Support	The AOCs identify preferences for a flow plan. They send them to the ATSP for consideration in the middle tier.	AOCs propose flow plan(s) that optimize their objectives	Increase AOC optimality and user satisfaction; reduce ATSP workload; and increase flow plan predictability and stability	AOCs, with competing objectives and self-interest behavior, have to achieve a common agreement, thus an effective coordination process may be required Ability of AOC planning to incorporate NAS impacts
Flight implementation						
Identify and implement 4-D trajectories for impacted flights	None	Primary	AOC changes flight trajectories abiding by the current airspace configuration, ensuring that no imbalance is created elsewhere	AOC trajectory changes abided by the use of airspace do not need ATSP approval	Reduce ATSP workload Increase AOC options (optimality) Increase user satisfaction	Automation and procedures required to enable AOC to make trajectory changes beyond 45 minutes prior to departure time. Need to take NAS impacts into account to avoid creating imbalances elsewhere. An effective coordination process may be required to ensure equity among users

Table 3. Middle Tier: Flow Planning and Flight Implementation tasks

Tasks / Subtasks	Role: ATSP	Role: AOC	Information sharing and collaboration	Difference from baseline	Main benefit mechanisms	Feasibility issues
Flow Planning						
Coordinate and identify preferred flow plan to solve constraints	Support	Primary	The ATSP and AOCs collaborate on selecting a flow plan. The ATSP provides the most preferred flow plan to the AOCs, who identify modifications for ATSP consideration	AOCs propose flow plan(s) that optimize their objectives	Increase AOC optimality and user satisfaction; reduce ATSP workload; and increase flow plan predictability and stability	AOCs, with competing objectives and self-interest behavior, have to achieve a common agreement, thus an effective coordination process may be required Ability of AOC planning to incorporate NAS impacts
Identify and impose flow plan to solve constraints	Primary	None	ATSP evaluates the AOC proposed plan(s) based on NAS impact metrics and imposes on AOCs	Incorporate formally AOC flow plan suggestions in ATSP plan	Increase AOC optimality, user satisfaction and certainty about flow plan	Automation required to enable ATSP to incorporate AOC suggestions without increase in workload
Modify flow plan	Primary	Support	AOCs request from ATSP desired changes to the flow plan – ATSP modifies flow plan dynamically to mitigate uncertainty incorporating AOC suggestions when appropriate	AOCs propose changes to the implemented flow plan that minimizes their costs	Increase AOC optimality, user satisfaction and certainty about flow plan Increase dynamism of flow planning to mitigate uncertainty, thus increasing throughput	Automation required to enable AOC to incorporate NAS impacts in their suggestions; Automation required to enable ATSP to incorporate AOC suggestions without increase in workload
Flight implementation						
Identify and implement 4-D trajectory for each impacted flight	None	Primary	AOC changes flight trajectories abiding by the flow plan, ensuring that no imbalance is created elsewhere	AOC trajectory changes abided by the flow plan do not need ATSP approval	Reduced ATSP workload Increase AOC optimality and user satisfaction	Automation and procedures required to enable AOC to make trajectory changes beyond 45 minutes prior to departure time. Need to take NAS impacts into account to avoid creating imbalances elsewhere. An effective coordination process may be required to ensure equity among users

Table 4. Inner Tier: Flow Planning and Flight Implementation tasks

Tasks Subtasks	Role		Information sharing and collaboration	Difference from baseline	Main benefit mechanisms	Feasibility issues
	ATSP	**AOC**				
Flow Planning						
Identify and implement changes to flow plan	Primary	None	ATSP makes changes to the flow plan if needed to mitigate constraint changes and imposes changes on AOC	None	None	None
Flight implementation						
Generate preferences	None	Primary	AOC identifies a set of preferences (priorities between flights and preferences of route and delay for each flight) according an optimization function and send them to the ATSP; the route alternatives are predefined in advance by the flow plan imposed by the ATSP	AOC formally communicates priorities to ATSP for inclusion in trajectory modifications	Increase AOC optimality and user satisfaction Reduce ATSP workload	Automation required to assist AOC in generating additional preferences; Inclusion of NAS impacts in generating preferences to increase ATSP acceptability.
Identify and implement 4-D trajectory for each impacted flight	Primary	Support	AOC provides preferences – ATSP retains responsibility of any 4-D trajectory change attempting to incorporate AOC preferences	ATSP incorporates AOC preferences in generating 4-D trajectories to implement flow plan	Increase AOC optimality and user satisfaction Reduce ATSP workload	Automation required to assist ATSP in incorporating AOC preferences without workload impacts

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