NASA/CR-2017-219676

Management by Trajectory Trade Study of Roles and Responsibilities between Participants and Automation Report

Alicia D. Fernandes, Curt Kaler,
Kenneth Leiden and Stephen Atkins
Mosaic ATM, Inc., Leesburg, Virginia

Alan Bell and Todd Kilbourne
Systems Enginuity, Inc., Manassas, Virginia

Mark Evans
Independent Consultant, Tarpon Springs, Florida

October 2017

NASA STI Program . . . in Profile

Since its founding, NASA has been dedicated to the advancement of aeronautics and space science. The NASA scientific and technical information (STI) program plays a key part in helping NASA maintain this important role.

The NASA STI program operates under the auspices of the Agency Chief Information Officer. It collects, organizes, provides for archiving, and disseminates NASA's STI. The NASA STI program provides access to the NTRS Registered and its public interface, the NASA Technical Reports Server, thus providing one of the largest collections of aeronautical and space science STI in the world. Results are published in both non-NASA channels and by NASA in the NASA STI Report Series, which includes the following report types:

- TECHNICAL PUBLICATION. Reports of completed research or a major significant phase of research that present the results of NASA Programs and include extensive data or theoretical analysis. Includes compilations of significant scientific and technical data and information deemed to be of continuing reference value. NASA counter-part of peer-reviewed formal professional papers but has less stringent limitations on manuscript length and extent of graphic presentations.

- TECHNICAL MEMORANDUM. Scientific and technical findings that are preliminary or of specialized interest, e.g., quick release reports, working papers, and bibliographies that contain minimal annotation. Does not contain extensive analysis.

- CONTRACTOR REPORT. Scientific and technical findings by NASA-sponsored contractors and grantees.

- CONFERENCE PUBLICATION. Collected papers from scientific and technical conferences, symposia, seminars, or other meetings sponsored or co-sponsored by NASA.

- SPECIAL PUBLICATION. Scientific, technical, or historical information from NASA programs, projects, and missions, often concerned with subjects having substantial public interest.

- TECHNICAL TRANSLATION. English-language translations of foreign scientific and technical material pertinent to NASA's mission.

Specialized services also include organizing and publishing research results, distributing specialized research announcements and feeds, providing information desk and personal search support, and enabling data exchange services.

For more information about the NASA STI program, see the following:

- Access the NASA STI program home page at http://www.sti.nasa.gov

- E-mail your question to help@sti.nasa.gov

- Phone the NASA STI Information Desk at 757-864-9658

- Write to:
  NASA STI Information Desk
  Mail Stop 148
  NASA Langley Research Center
  Hampton, VA 23681-2199

NASA/CR-2017-219676

Management by Trajectory Trade Study of Roles and Responsibilities between Participants and Automation Report

Alicia D. Fernandes, Curt Kaler,
Kenneth Leiden and Stephen Atkins
Mosaic ATM, Inc., Leesburg, Virginia

Alan Bell and Todd Kilbourne
Systems Enginuity, Inc., Manassas, Virginia

Mark Evans
Independent Consultant, Tarpon Springs, Florida

National Aeronautics and
Space Administration

NASA Langley Research Center
Hampton, Virginia 23681-2199

Prepared for NASA Langley Research Center
Under contract NNL16AA17C

October 2017

Acknowledgments

The Management by Trajectory (MBT) research team gratefully acknowledges the support of the NASA Langley Trajectory Based Operations team and the project participation of Mike Jackson of Honeywell. The MBT team also wishes to thank the participants in the cognitive walkthrough who provided feedback on the MBT concept and on the allocation of roles and responsibilities.

Executive Summary

This report describes a trade study of roles and responsibilities associated with the Management by Trajectory (MBT) concept. The MBT concept describes roles, responsibilities, and information and automation requirements for providing air traffic controllers and managers the ability to quickly generate, evaluate and implement changes to an aircraft's trajectory. In addition, the MBT concept describes mechanisms for imposing constraints on flight operator-preferred trajectories only to the extent necessary to maintain safe and efficient traffic flows, and the concept provides a method for the exchange of trajectory information between ground automation systems and the aircraft that allows for trajectory synchronization and trajectory negotiation.

The participant roles considered in this trade study include: airline dispatcher, flight crew, radar controller, traffic manager, and Air Traffic Control System Command Center (ATCSCC) traffic management specialists.

The proposed allocation of roles and responsibilities was based on analysis of several use cases that were developed for this purpose as well as for walking through concept elements. The resulting allocation of roles and responsibilities reflects both increased automation capability to support many aviation functions, as well as increased flexibility to assign responsibilities to different participants – in many cases afforded by the increased automation capabilities. Note that the selection of participants to consider for allocation of each function is necessarily rooted in the current environment, in that MBT is envisioned as an evolution of the National Airspace System (NAS), and not a revolution.

A key feature of the MBT allocations is a vision for the traffic management specialist to take on a greater role. This is facilitated by the vision that separation management functions, in addition to traffic management functions, will be carried out as trajectory management functions. This creates an opportunity for flexibility, allowing the traffic management specialist to carry out tasks that today can only be carried out by the controller currently in contact with the aircraft.

This additional tasking for the traffic management specialist comes with requirements for workload management. An increased role for the Data-side (D-side) controller relative to the Radar-side (R-side) controller is a potential approach to mitigating workload for the traffic management specialist, as the D-side controller would have similar ability to perform separation management functions in what today might be considered the "trajectory management" timeframe. This analysis did not distinguish between the D-side and R-side controllers since in many cases the R-side controller works unassisted.

Table of Contents

List of Figures

List of Tables

1. Introduction

In the current operational environment, air traffic control (ATC) automation, such as arrival and departure schedulers in the Time Based Flow Management (TBFM) system, develops plans based on aircraft trajectory predictions using available information such as aircraft performance and winds/weather. However, once that plan is in place, controllers tactically manage the aircraft, using vectors, altitude, or speed clearances, to either conform to the schedule at control points or to address other issues that come up, such as maintaining separation, or changing weather conditions. Since these tactical actions are not directly communicated to the automation systems, the underlying trajectories may not be properly updated, which can lead to inefficiencies in the air traffic system. Although aircraft are equipped with many capabilities to predict and fly a trajectory, the controller's tactical instructions often prevent full use of these capabilities.

In order to realize the full NextGen potential, there needs to be better coordination between air navigation service providers (ANSPs) and system users (e.g., pilots and airline dispatchers) in terms of better managing aircraft along planned trajectories. Future automation improvements and increased data communications between aircraft and ground automation would make this idea of Management by Trajectory (MBT) possible. Key components of an MBT concept include:

- The ability for air traffic controllers and managers to quickly generate, evaluate and implement changes to an aircraft's trajectory.
- Imposing constraints on flight operator-preferred trajectories only to the extent necessary to maintain safe and efficient traffic flows.
- A method for the exchange of trajectory information between ground automation systems and the aircraft that allows for trajectory synchronization and trajectory negotiation.

The MBT concept is an evolution of the current National Airspace System (NAS) and describes roles, responsibilities, and information and automation requirements consistent with that vision. This report describes an analysis examining the allocation of roles and responsibilities among human participants and automation. The participant roles considered include: airline dispatcher, flight crew, radar controller, traffic manager, and Air Traffic Control System Command Center (ATCSCC) traffic management specialists. The report seeks to identify the best distribution of roles and responsibilities, as well as information and automation support requirements for each participant.

1.1. Objectives

The objectives of the trade study are to identify the best distribution of MBT roles and responsibilities among human participants, as well as information and automation support requirements for each participant. Since MBT is envisioned as an evolution of the current NAS, the distribution of roles and responsibilities is scoped to provide an evolution from the current responsibilities of a given role to the responsibilities envisioned for MBT. As such, the trade study did not consist of an exhaustive analysis that considered all possible allocations of each responsibility.

1.2. Document organization

This document is organized as follows:

Section 2 describes the approach for carrying out the trade study.

Section 3 provides a high level summary of each of the use cases.

Section 4 provides a high level description of each of the participants and their responsibilities in the current National Airspace System (NAS).

Section 5 summarizes the key MBT functions and their allocation to participants.

Section 6 summarizes the conclusions and recommendations.

Section 7 provides a list of acronyms used in the report.

Section 8 provides the bibliography for the report.

Appendix A describes the use cases that formed the basis of the analysis and the functions and allocations associated with each use case.

2. Trade Study Approach

The trade study started from an assumption that the key participants in the NAS will not change significantly in the future, even if their responsibilities change. In particular, the trade study is focused on the following roles:

- Air traffic controllers
- Flight crews
- Flight dispatchers
- Flight operator ATC coordinators
- Field facility Traffic Management Coordinators (TMC)
- ATCSCC Traffic Management Specialists

The distribution of roles and responsibilities was explored through a series of scenarios and use cases focused on the goals of MBT. These scenarios were derived based on operational reasons why the above concept components are necessary. For example:

- An aircraft's trajectory may need to be modified for a number of reasons; MBT is particularly focused on those that in today's environment result in aircraft operating on open trajectories.
- There are several operational reasons why constraints must be imposed on flight operator-preferred trajectories (e.g., traffic management initiatives); MBT is particularly focused on those that may over-constrain the trajectories.
- Trajectory synchronization supports trajectory conformance monitoring and is required to maintain closed clearances; MBT is focused on operational scenarios that in today's environment result in non-synchronized trajectories.
- Trajectory negotiation is a key aspect of TBO, and negotiation is required in each of the above sets of operational scenarios. Thus, methods for carrying out the negotiation must be considered in each of the scenarios and use cases.

Where relevant, multiple use cases were developed to explore each scenario area.

Note that the process of developing the use cases required the research team to make some concept design decisions that may not be fully documented in the trade study results. The use case development process served to illustrate the MBT concept as it was being defined, and therefore some decisions that were made to solve the problems presented in the use cases made the allocation of roles and responsibilities seem clear, and constraining what the research team considered as candidate allocations. This could be viewed as a flaw in the trade study, since it makes it appear as if alternate allocations were not considered. However, the approach usefully scoped the effort, grounding the trade study (and the MBT concept) in operationally valid contexts. Note that in other cases, such as the example of a weather deviation, the approach actually helped the team to consider a wider range of possible allocations of responsibilities than it might have otherwise.

The scenarios and use cases drove the identification of MBT functions needed to carry out the concept, and the responsibilities associated with those functions. Each use case illustrated a candidate allocation of these responsibilities to different participants and a high level description of required automation capabilities. In many cases, the allocation of responsibilities is context-dependent, and also may vary according to flight operator organizational design (e.g., some flight crews are not supported by a Flight Operations Center).

After developing the use cases and candidate allocations of roles and responsibilities, the research team conducted a cognitive walkthrough to engage subject matter experts (SMEs) in providing feedback on the MBT concept, reviewing the automation support requirements, and validating the allocation of roles and responsibilities.

Note that the candidate allocations of roles and responsibilities are somewhat constrained by what is considered feasible based on the current system design. For example, assigning primary responsibility for separation management to any role other than a controller would be such a departure from the current system design that it would make implementation of the MBT concept much more difficult in the absence of significant justification. Thus, some possible allocations of responsibilities were not entertained.

3. Summary of Use Cases

The use cases and the associated functions are described in detail in Appendix A, but are summarized here for the reader.

Controller Issues a Vector for Traffic: Two aircraft are in conflict. In the current environment, the controller issues a vector that puts one or both aircraft onto an open trajectory. In the MBT environment, the controller has tools that support resolving the conflict while keeping both aircraft on a closed trajectory.

Controller Issues an Interim Altitude for Traffic: This is a variation on the previous use case in which two aircraft are in conflict. In the current environment, the controller issues an interim altitude that puts one aircraft on an open trajectory. In the MBT environment, the controller has tools that support resolving the conflict while keeping both aircraft on a closed trajectory.

Controller Issues Vectors for Miles in Trail (MIT) Sequencing: A downstream Air Route Traffic Control Center (ARTCC) has passed back a 20 MIT restriction. In the current environment, the controller issues a speed reduction and/or a vector to achieve the required spacing before handing the aircraft off to the next ARTCC. In the MBT environment, the controller has tools that support spacing and sequencing while keeping all aircraft on closed trajectories.

Controller Issues Vectors for Time Based Metering: A downstream ARTCC has initiated adjacent center metering. In the current environment, the controller issues a speed reduction and/or a vector to achieve the required metering delay before handing the aircraft off to the next sector. In the MBT environment, spacing and sequencing can be accomplished by applying constraints to aircraft trajectories.

Pilot Requests Deviation for Weather: In this use case, a pilot requests a deviation around weather that he/she sees out the window but is not visible on the ground automation radar. In the current environment, the aircraft is on an open trajectory while deviating, creating significant downstream uncertainty. MBT leverages advanced flight deck capabilities to support the pilot requesting a closed weather avoidance trajectory.

Dispatcher Requests Reroute for Special Activity Airspace Restriction: A dispatcher requests a more efficient route for a flight when a Special Activity Airspace (SAA) is made available. The SAA affects a busy aviation corridor. In the current environment, it is difficult to coordinate reroutes through the SAA, but improved planning capabilities and trajectory predictions in the MBT environment allow more aircraft to negotiate a more efficient trajectory.

Dispatcher Requests Delayed Arrival for Gate Management: A dispatcher requests that a flight crew reduce in flight speed in order to delay their arrival time for gate management. However, the aircraft encounters higher than expected headwind and therefore absorbs more delay than expected. Furthermore, the extra delay pushes the aircraft into a heavy arrival bank that is exacerbated by weather. In the current environment, this aircraft encounters significant delay and airborne holding. In the MBT environment, the aircraft experiences less delay.

Use of Collaborative Trajectory Options Program to Manage Multiple Constraints: A Collaborative Trajectory Options Program (CTOP) Traffic Management Initiative (TMI) is used to manage a large, dynamic weather event that significantly disrupts NAS operations. In the current environment, use of Trajectory Options Sets (TOSs) is limited to pre-departure, and en route adjustment due to changing constraints is difficult. MBT supports a more dynamic response to changing constraints.

4. Management by Trajectory Participants

This section provides a high level description of the MBT participants and their roles in today's NAS.

4.1. Air Traffic Controllers

In today's NAS, air traffic controllers are responsible for maintaining a safe and expeditious flow of traffic. They use various decision support tools to develop a mental image of the traffic operating in their sector and nearing handoff to their sector. They use this image to mentally develop a plan for tactically maneuvering aircraft as needed to maintain safe separation while also meeting traffic management goals such as sequencing and separation. They employ various tactics to achieve those goals, including:

- Vectors to stretch an aircraft's path
- Speed controls
- Altitude constraints, including leveling off during climb or descent

The aim of these tactics is typically to delay the aircraft's arrival to a given point – typically a conflict point, meter fix, or sector boundary – by the required amount.

In today's environment, controllers do not consistently update flight plans to account for tactical maneuvering for separation or weather deviations. Whereas controllers typically have a plan in place for when and how the aircraft in question will return to its flight plan route, they do not routinely communicate that intent to the pilot or to any automation tools. As a result, the ground automation trajectory prediction algorithms attempt to model the aircraft's return to its flight plan route using models of controller behavior built into the tools [1].

4.2. Flight Crew

The flight crew is responsible for safely operating the aircraft and complying with procedures and ATC instructions. They are expected to "see and avoid" other air traffic, and in some limited cases are responsible for maintaining separation with other aircraft (e.g., when operating in uncontrolled airspace).

Flight crews also have business goals associated with their operation of the aircraft. Air transport pilots often are expected by their companies to operate the aircraft efficiently (i.e., minimize fuel consumption and flight time), whereas business aviation pilots may be expected to arrive to the destination as quickly as possible. Other general aviation pilots may operate with other goals, such as enjoying the experience of flying. These goals, along with the aircraft performance characteristics, affect the way in which a flight crew will plan their flight and respond to ATC instructions.

In addition, different aircraft have different capabilities. Thus, any vision for the NAS must address the mix of equipage that is expected in the environment, including aircraft capabilities associated with:

- Navigation precision, such as Required Navigation Precision (RNP) and Area Navigation (RNAV) capabilities
- Time of arrival control, such as Required Time of Arrival (RTA) compliance capabilities
- Use of a Flight Management System (FMS) and its capabilities to manage different phases of flight automatically
- Downlink of data to the ground, including performance and intent data
- Receipt of uplinked data, including ATC clearances

Most domestic air transport flight crews, and some business aviation flight crews, also are required to coordinate flight decisions with a dispatcher. This may increase the time required for a flight crew to accept a clearance received from ATC.

4.3. Airline Dispatcher

Dispatchers are jointly responsible for the safe operation of the aircraft from gate to gate. They produce a flight plan that meets safety, efficiency, and other business goals, including required fuel to account for contingency operations. They coordinate decisions regarding conduct of the flight with the flight crew, providing a wider system view than what is available to the flight crew (especially en route). They incorporate information about route constraints into the flight plan and can provide that perspective to the flight crew during en route decision making.

However, dispatchers are limited by the decision support tools they have, which are typically designed for pre-departure flight planning. (Although note that new generation flight planning tools will have improved support for en route flight reoptimization.) They also have access to a great deal of information about NAS operations and constraints, but they typically must use their judgment when planning a flight to anticipate the effects of those NAS constraints on a given flight. For example, they may not know what reroute a flight will be given to avoid a given weather system, but they must anticipate a reroute in order to plan an appropriate amount of fuel and an appropriate alternative airport(s) in case of a deviation.

4.4. Airline ATC Coordinator

Whereas the dispatcher is jointly responsible for the safe operation of individual flights, the ATC coordinator typically is responsible for managing the flight operator network in response to NAS constraints and Traffic Flow Management (TFM) actions. The ATC coordinator also listens to TFM planning teleconferences and participates to the extent possible (although officially flight operators are listening parties and not given a decision making role). The ATC coordinator also contacts the ATCSCC and ARTCC Traffic Management Unit (TMU) as needed to coordinate specific flights and/or local operations (e.g., where the airline is the dominant flight operator).

The ATC Coordinator uses NAS information made available by the FAA such as through TFMData and Collaborative Decision Making (CDM) tools, as well as company tools to monitor the flight network and manage recovery operations, particularly in response to disruptive events such as large weather systems.

4.5. Traffic Management

The mission of the Traffic Management System is to balance air traffic demand with system capacity to ensure the maximum efficient utilization of the National Airspace System (NAS). A safe, orderly, and expeditious flow of traffic while minimizing delays, is fostered through continued analysis, coordination, and dynamic utilization of TMIs. In an MBT environment, the roles and responsibilities of both the ATCSCC and all field facility TMUs increase due to the importance of TFM in achieving MBT goals.

4.5.1 Air Traffic Control System Command Center (ATCSCC)

The Air Traffic Control System Command Center (ATCSCC) has been delegated the authority to direct the operation of the TFM system. The ATCSCC must, in conjunction with field facility TMUs, users, weather information providers, and airway facilities, as appropriate:

- Implement national TFM programs, when necessary, to ensure the orderly flow of traffic throughout the NAS.
- Monitor and analyze system components and weather patterns for potential system impact.

- Determine when NAS capacity is or will likely be reduced to the extent that the implementation of a TMI is required.
- Monitor TMIs issued throughout the system for effectiveness and take action to cancel or modify initiatives where appropriate.

4.5.2 Air Route Traffic Control Center/Terminal Radar Control Traffic Management Unit

Air Route Traffic Control Center/Terminal Radar Control (ARTCC/TRACON) traffic managers are responsible for monitoring and balancing traffic flows within their areas of responsibility, which is accomplished using a suite of specialized traffic management tools and programs. Field facility Traffic Management Units (TMUs) must:

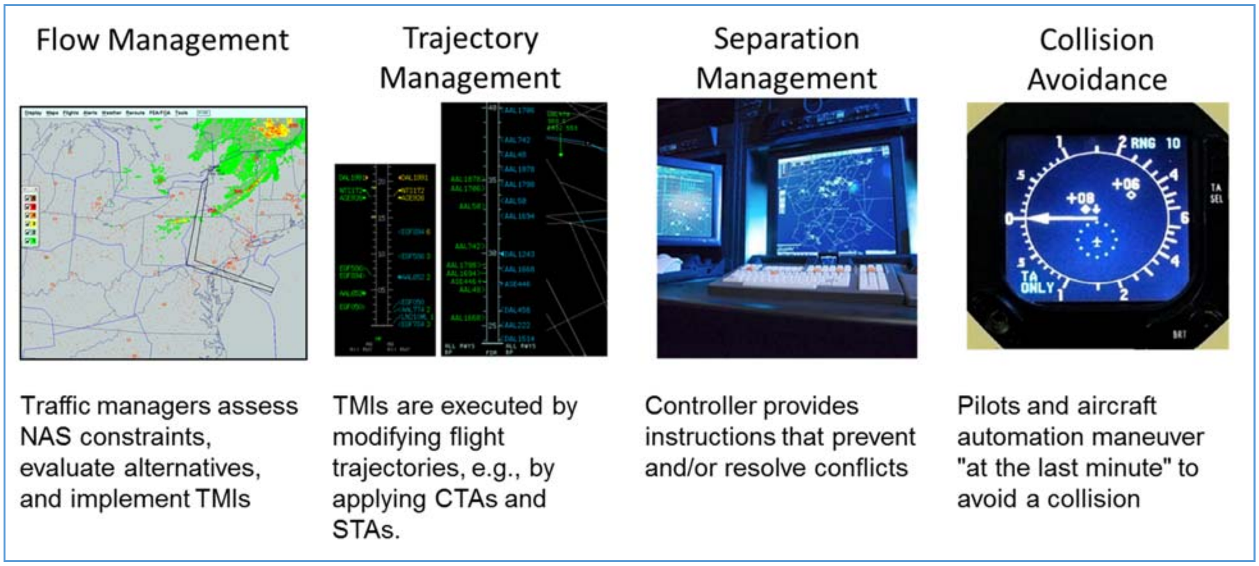
- In conjunction with the ATCSCC, adjacent ATC facilities, air traffic controllers, Area Supervisors/ Managers, weather service providers, and users, implement, monitor, and analyze TFM programs, procedures, and initiatives that are specific to the facility's area of responsibility.
- Work together to develop arrival strategies and deliver aircraft to achieve the Airport Arrival Rate (AAR).
- Actively utilize the Traffic Situation Display (TSD) and the monitor alert function to adjust traffic flows in order to keep all sectors safe and manageable.
- Balance the flow of arrival, departure and enroute traffic by coordinating with the ATCSCC and appropriate adjoining facilities, to ensure that demand does not exceed current capabilities.

5. Key Management by Trajectory (MBT) Functions

This section summarizes the MBT functions and allocations and contrasts the MBT allocations with the current environment. The functions discussed here were derived from the analysis of the use cases described in Appendix A. Only those functions whose allocations are affected by MBT or are otherwise relevant to this report are discussed here. Note that the selection of participants to consider for allocation of each function is necessarily rooted in the current environment, in that MBT is envisioned as an evolution of the NAS, and not a revolution. An additional goal of the allocation is that the role(s) with the best access to the necessary information be given responsibility for carrying out the function [2].

The allocation of a specific function in many cases depends on context. That is why the functions are discussed in context of the use case(s) to which they are relevant, with some generalizations made to a larger context where applicable.

A key feature of the MBT allocations is a vision for the traffic management specialist to take on a greater role. This is facilitated by the vision that separation management functions, in addition to traffic management functions, will be carried out as trajectory management functions (see Figure 1). This creates an opportunity for flexibility, allowing the traffic management specialist to carry out tasks that today can only be carried out by the controller currently in contact with the aircraft.



Traffic managers assess NAS constraints, evaluate alternatives, and implement TMIs

TMIs are executed by modifying flight trajectories, e.g., by applying CTAs and STAs.

Controller provides instructions that prevent and/or resolve conflicts

Pilots and aircraft automation maneuver "at the last minute" to avoid a collision

Figure 1: Current-day Trajectory Timeline

This additional tasking for the traffic management specialist comes with requirements for workload management. An increased role for the D-side controller relative to the R-side controller is a potential approach to mitigating workload for the traffic management specialist, as the D-side controller would have similar ability to perform separation management functions in what today might be considered the “trajectory management” timeframe. This analysis did not distinguish between the D-side and R-side controllers since in many cases the R-side controller works unassisted.

Note that automation is never a responsible stakeholder [3]. In situations in which an automation system is expected to be the primary participant performing a function, the human role being supported by the automation will likely actually be held responsible for ensuring that the function is carried out appropriately. Thus, these functions are allocated to the human participant expected to be held responsible for ensuring that the automation completes the task appropriately. The automation requirements are discussed in the text.

5.1. Amend Assigned Trajectories

This function refers to the act of updating the assigned trajectory in the automation, after the trajectory has been planned and negotiated (if negotiation is appropriate in context). In the MBT environment, this function is allocated to the controller in some cases and the traffic management specialist in others, essentially depending on which participant is closest to the process of identifying and resolving the issue requiring a trajectory amendment.

5.1.1 Controller Responsibility

In the current environment, the assigned trajectory (i.e., the flight plan) is not amended in conflict avoidance scenarios – hence, aircraft are on open trajectories while executing the conflict avoidance clearance. An important change in the MBT environment is that the assigned trajectory will be updated every time an aircraft is required to do something different.

In conflict avoidance scenarios, it is expected that controller automation will amend the assigned trajectory based on the conflict resolution clearance delivered by the controller. That is, the controller’s act of uplinking the clearance to the flight deck and the pilot’s act of accepting the clearance cause the controller automation to update the assigned trajectory with the amendment. Thus, the controller is given primary responsibility for this function in conflict avoidance scenarios (i.e., the controller is responsible for making sure the assigned trajectory is amended when providing a conflict avoidance clearance).

Automating this function will help ensure that the clearances are closed. It is important to note that adding responsibility to the controller for entering all clearances provided by voice into the automation has consequences. First, controllers may be more likely to accept the automated solution to avoid manually entering information into the automation, which requires that the automation provides adequate solutions (and makes it desirable for automation to consistently provide solutions that are as good as or better than those the controller would propose). More consistent use of automated conflict resolution advisories may decrease controllers' skill at detecting and resolving conflicts manually, which could present a safety issue if controllers are expected to be the safety net in the case of automation failure.

If a controller has to enter a clearance manually into the automation, it is important that not only is the automation designed to make that easy, but having the information in the automation also must provide a benefit to controllers. Research has shown that when people are expected to enter data into automation to support others with no benefit to themselves, it is not likely that they will do so [4]. Thus, to support closed clearances, the controller automation should be designed with the following goals in mind:

- Amend assigned trajectory without explicit controller action to the extent possible.
- Facilitate easy assigned trajectory amendment in cases where controller must enter information manually.

5.1.2 Traffic Management Specialist Responsibility

When the trajectory amendment is the result of a dispatcher request and/or negotiation with traffic management, the traffic management automation that carries out the negotiation is expected to amend the assigned trajectory when the negotiation is complete. Thus, the ARTCC or ATCSCC traffic management specialist is primarily responsible for ensuring that the assigned trajectory is amended as the result of the negotiation. The emphasis on traffic management involvement in the negotiation here reflects the desire to identify and resolve issues with the assigned trajectory as early as practical, such that the issue being resolved is far downstream from the aircraft's current position – and the associated trajectory amendment does not affect any controller's planning horizon. Note that the controller would be responsible for amending the trajectory if the trajectory change occurred within the controller's planning horizon.

In the current environment, many flight plan amendments must be entered manually into the controller or traffic management automation by a controller or traffic management specialist. In an MBT environment, it is expected that traffic management automation can engage in trajectory negotiation with flight operators and can thus amend the assigned trajectory at the conclusion of the negotiation according to parameters set by the traffic management specialist.

However, controller automation will not be expected to negotiate this kind of assigned trajectory amendment and therefore the controller would need to take a separate action to use the controller automation to evaluate and amend the assigned trajectory. Note that this is similar to the conflict avoidance maneuvers discussed above, in which the explicit action taken by the controller was to uplink a clearance to the aircraft and this action also triggered amendment of the assigned trajectory.

Traffic management specialists will have equal authority to amend the assigned trajectory to what they have today, but it is expected that in the MBT environment they will be primarily responsible for managing the process by which the traffic management automation negotiates trajectories and amends the assigned trajectories.

5.2. Apply Constraints to Aircraft Trajectories

A key differentiator of MBT from other concepts is the use of trajectory constraints to implement TMIs and other effects of airspace constraints. This function applies at two levels: 1) associating NAS constraints with affected aircraft trajectories; and 2) specifying the effect of the NAS constraint on the trajectory by adding or modifying trajectory constraints.

5.2.1 Apply NAS Constraints

Since NAS constraints are applied by traffic management, only the traffic management specialist was considered to carry out the responsibility of associating NAS constraints with individual aircraft trajectories. Traffic management automation does this today for TMIs that are effected through CDM processes as well as TBFM; the automation identifies affected aircraft and computes control times – trajectory constraints – for them to meet.

However, MIT is a frequently used TMI in the current environment. Traffic management specialists create the TMI and controllers are expected to hand off aircraft at the specified location with the required spacing. This is a manual process for the controllers. In the MBT environment, the traffic management automation also should automatically apply a reference to the MIT constraint to the affected aircraft when the traffic management specialist implements the MIT constraint.

The case of an SAA that reopens highlights the importance of associating NAS constraints with the trajectory independently of the specific trajectory constraints. In this use case, assigned trajectories avoid the affected airspace, but it is desirable to have some way to quickly identify aircraft that could use the airspace once it becomes available. This creates opportunities to make more efficient use of the NAS.

5.2.2 Apply Trajectory Constraints

As for applying trajectory constraints reflecting the effect of the NAS constraint on individual trajectories, the participant responsible depends on the type of NAS constraint and what is required of the aircraft to meet the constraint. For TMIs like the CDM programs noted above, the traffic management automation already performs this function and therefore the traffic management specialist is responsible in the current environment. No need to change this allocation is suggested in the MBT environment.

Constraints are not applied to trajectories to implement MIT in the current environment, but it is expected that they will be in an MBT environment. There are multiple different constraints that can be applied to individual aircraft trajectories to achieve the desired spacing. For example, aircraft can be provided crossing time constraints that would provide 20 MIT between pairs of aircraft on the same flow, or appropriately equipped aircraft could maintain the necessary spacing using interval management. Traffic management automation could identify and apply either kind of trajectory constraint when the traffic management specialist implements the MIT TMI. Thus, the traffic management specialist would be responsible in this case.

Alternatively, the controller could be given flexibility to choose the approach to take. Or, as in the Vectors for MIT Sequencing use case, the aircraft could be handed off to the controller without the necessary spacing. In such cases, the controller must take responsibility for identifying the pairs of aircraft to be sequenced and achieving the needed spacing.

Both traffic management and controller automation need to identify pairs of aircraft that require trajectory amendments to achieve the spacing requirement. A key open question is a precise definition of the handoff of responsibility for this function from the traffic management specialist to the controller such that both do not simultaneously attempt to solve the same problem.

Whether it is the controller or the traffic management specialist identifying the affected aircraft, automation should support precise calculation of the spacing that will be achieved without trajectory amendments, immediate identification of aircraft that require trajectory amendments to achieve the required spacing, as well as support for planning the trajectory amendments.

5.3. Deliver Clearance

In the current environment, only the controller can deliver a clearance to an aircraft. However, Data Link and other forms of advanced data exchange create the possibility for other approaches to delivering clearances. The primary approach to delivering clearances in an MBT environment will be delivery from the controller via controller automation (i.e., Data Link). But when constraints are applied to trajectories due to traffic management programs, the trajectory amendment could be delivered by the traffic management specialist via traffic management automation. Previous research has proposed the following requirements for traffic management delivery of a clearance [5]:

- The reroute does not affect the aircraft route or speed in the sector of the controller currently responsible for the aircraft.
- The trajectory change point is at least two sectors away and one hour of flight time away.
- The controller currently responsible for the flight needs to have access to information about the downstream trajectory change in case the flight crew asks about the new clearance.
- If the ARTCC TMU does not issue the clearance early enough, the clearance is sent to the controller to deliver.
- The aircraft must be within the geographical boundary of the ARTCC TMU delivering the clearance and under direct control of one of its sectors.
- The automation should prevent situations in which both the TMU and the controller in charge of the aircraft simultaneously issue a clearance.
- The flight crew acknowledgment of the amended clearance should only be received by the TMU that issued the clearance.

Further research is needed to quantify performance associated with traffic management delivery of clearances in various scenarios, including application of constraints to aircraft trajectories to meet traffic management program goals.

5.4. Detect Conflict

Controllers will retain responsibility for conflict detection in the MBT environment, but MBT will allow the automation they use to be much more reliable than it is today. Cognitive walkthrough controller participants stressed that in the current environment they are not likely to use their strategic conflict detection capability for several reasons. Critically, the strategic tool does not have access to all of the data it needs to produce an accurate trajectory prediction. For example, if a climbing aircraft has been leveled off by the controller in the previous sector, the controller receiving the strategic conflict alert knows that the previous sector controller will continue the aircraft’s climb before handing it off. However, the strategic conflict probe does not know the aircraft will continue its climb. MBT conflict detection automation will require access to the updated assigned trajectory and the ability to share trajectory changes across sectors. The core of the MBT concept, i.e., applying constraints to the assigned trajectory to effect change in the trajectory, will support the controller automation in meeting these requirements.

The controller participants also noted that if controller automation is to effectively detect conflicts based on a trajectory prediction, it must be able to very quickly detect when an aircraft deviates from the predicted trajectory. Note that the introduction of ADS-B Out for surveillance data will provide much more frequent track updates than the current radar surveillance, and will enable must faster detection of trajectory nonconformance. Further, trajectory nonconformance will be detected as early as possible using downlinked aircraft intent.

In the MBT environment, it is expected that improved trajectory predictions will support longer look ahead times on reliable conflict detection. This, in turn, will support more strategic conflict detection and resolution approaches that could be carried out by what today is the D-side controller.

5.5. Evaluate Amendment Requests

One reason that reroutes are so time-consuming and difficult in the current environment is that there are several manual steps involved in receiving and evaluating flight operator reroute requests. In a scenario like the SAA becoming available, each reroute request (for en route flights) must be received by a controller via voice, manually entered into the controller automation, and evaluated by the automation and the controller. Only a controller working in the affected ARTCC can process the reroute. This concentrates the workload associated with processing requests on a few controllers, creating a bottleneck that can lead to the controllers not accepting any reroute requests at all because they do not have time to process them.

In an MBT environment, the flight operator can request the reroute at any time, allowing many of the reroute requests to be processed before the aircraft enters the affected ARTCC. The dispatcher sends these requests directly to the traffic management automation, which can evaluate the requested trajectory against known constraints. In many cases, the traffic management automation will be able to approve the requested route. Where necessary, the traffic management automation will request review by a traffic management specialist. The automation will need to have parameters indicating when to request traffic management evaluation, and which facility or facilities – e.g., which ARTCC or the ATCSCC – should do the evaluation [5].

Note that use of the TOS as discussed above would imply that the traffic management automation periodically evaluates the TOS for each flight – even in the absence of a CTOP – to determine if a different trajectory in the TOS is acceptable and preferred.

5.6. Evaluate Clearance

When a clearance is received by the flight deck, it must be evaluated to ensure that the aircraft can safely execute it before it can be accepted. In the current environment, the pilot takes on the bulk of the work associated with receiving a clearance by voice, writing it down, reading it back to the controller, and manually loading it into the FMS for evaluation (or evaluating the aircraft's ability to execute the route in autopilot). The ability to receive clearances via data link and auto-load them into the FMS will reduce the pilot's work associated with receiving and evaluating a clearance, but the primary responsibility will remain with the pilot.

In addition, in the MBT environment the controller automation is expected to provide conflict resolution advisories. The controller is expected to evaluate such an advisory before providing it to the pilot.

However, the mix of aircraft capabilities in the near term is expected to be so broad that it will be infeasible to expect controllers to have the necessary knowledge to quickly determine whether a given aircraft has a certain set of capabilities. Thus, the controller automation must compare clearances prepared for each aircraft with the aircraft's capabilities. For example, an aircraft that can receive clearances via Data Comm and auto-load them will be able to receive more complex clearances than an aircraft that cannot auto-load a clearance.

5.7. Plan Conflict Resolution Clearance

Note that the function "Plan conflict resolution clearance" is allocated primarily to the controller, but also to the pilot, in the current environment. This is because when time permits, many controllers will provide pilots two alternative conflict resolutions from which to choose. It is noted that this is a desirable feature of the current environment to retain in the MBT environment. However, the current development arc of advanced conflict resolution and data exchange tools, including CPDLC and automated conflict resolution advisories, does not seem to consider this alternative. In order to support this feature, the CPDLC message set must be expanded.

There was a consensus among the cognitive walkthrough's controller and pilot participants that providing the option is a desirable goal for MBT. The pilot has access to information about the aircraft capabilities that is not available to the controller. For example, the controller may instruct the aircraft to climb due to traffic but the aircraft may not be able to climb. In other cases, the pilot may prefer the climb over a lateral path solution to a conflict. Providing the option was considered more efficient than the controller providing a clearance, the pilot rejecting it because the aircraft is unable to execute it, and the controller providing an updated clearance.

In the MBT environment, the controller will retain primary responsibility for planning the conflict resolution advisory. But the controller will have significantly more automation support, with the automation providing resolution advisories as discussed elsewhere.

5.7.1 Cross-Sector Coordination

An important aspect of the earlier detection of conflicts expected in MBT is that conflicts are likely to be detected before the conflict aircraft are operating within the sector where the conflict occurs (unless sectors are expanded from their current design). Thus, it is important to determine not only that the controller is responsible for planning the conflict resolution clearance, but *which* controller. Figure 2 illustrates the situation where two aircraft are predicted to conflict in a sector that is downstream for both aircraft (from [6]).

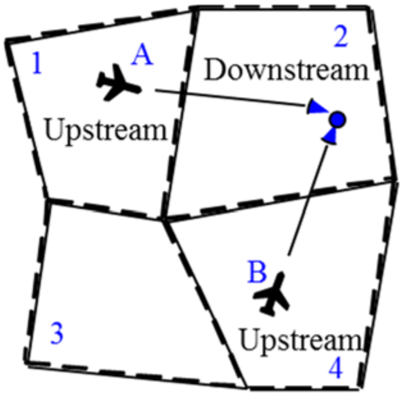


Figure 2: Inter-sector Conflict (from [6])

Previous research into this question has provided different recommendations depending on the purpose of the research. Green and Leiden [6] suggested that the upstream controller team, (i.e., the controller team responsible for the sector where the aircraft is operating at the time the conflict is detected) should be responsible for resolving the conflict and delivering that resolution to the aircraft. This was chiefly to minimize coordination requirements and relieve workload in the downstream sector, which was expected to be busier.

Other work has suggested that the conflict be resolved by a new role, the Multi-Sector Planner (MSP) [7]. The MSP would not be a controller, and therefore would not have direct communication with the aircraft, and so the MSP would create a conflict resolution plan and provide the clearance to the controller currently responsible for the aircraft to deliver.

A similar alternative to the MSP role is a reorganization of traffic management specialists such that they take on a greater role in flow management and conflict resolution across sector and facility boundaries. These traffic management specialists could be oriented toward flows and conflicts needing resolution rather than strict geographical boundaries like they are today. They could be located in field facility ARTCCs or at the ATCSCC. They would be responsible for responding to conflicts and driving the negotiation to update each aircraft's trajectory constraints accordingly.

These previous results beg the question: What should the controller of, for example, Sector 1 in Figure 2 be responsible for? Should that controller be monitoring the predicted (downstream) trajectories of the aircraft currently operating in Sector 1 to identify and resolve conflicts between those aircraft and other aircraft currently operating in yet other sectors (e.g., Sector 4 in Figure A-2)? If this is the case, coordination and/or procedures would be required between the Sector 1 and Sector 4 controllers to ensure that the conflict between Aircraft A and Aircraft B is resolved.

Green and Leiden [6] suggested that automation determine which controller should be notified of the conflict, with the other controller notified only after a period of time with inaction. On the other hand, the MSP would be responsible for adjusting both aircraft trajectories as needed to resolve the conflict and providing the clearances for both aircraft to the respective sector controllers to deliver to the aircraft [7].

Alternatively, the MSP, a traffic management specialist, or some other position could use Data Comm to uplink the clearance directly to the aircraft if certain conditions are met [5]. The chief consideration in these conditions is that the change in either aircraft's trajectory is sufficiently downstream from its current position that it is outside any tactical controller's planning horizon.

However, MBT cognitive walkthrough participants preferred an approach by which the Sector 2 controller be responsible for identifying and resolving the conflict, and then providing the clearances for Aircraft A and B to the Sector 1 and 4 controllers, respectively, to deliver to the aircraft. Note that Green and Leiden [6] rejected this approach because of the coordination required among the sector controllers and the potential that the downstream sector's clearance (e.g., Sector 2) would be made obsolete by an action taken by the upstream controller (e.g., Sector 1). The latter concern would be lessened by the MBT approach to resolving conflicts by modifying the assigned trajectory, in which the amended assigned trajectory is provided to all relevant stakeholders, and automation supports participants in avoiding trajectory amendments that introduce new problems.

It must be noted, however, that the cognitive walkthrough participants' preferred approach, in which the downstream controller is responsible for resolving the conflict, aligns best with the current environment in which conflicts are detected and resolved within a single sector (i.e., the conflict shown in Figure A-2 would not be acted upon until one or both aircraft had entered the control of Sector 2). The cognitive walkthrough participants may have been biased by their experience with the current environment, characterized by poor trajectory predictability such that it is not effective to act early on a detected conflict.

MBT allocates this responsibility to the upstream controller, at least in the near term. The controller is responsible for solving problems related to the trajectories of the aircraft under his/her control. It is desirable to resolve conflicts as early as practical, and with improved trajectory predictability they can be resolved much earlier than today. If the controller responsible for the aircraft at the time the conflict is detected is responsible for resolving the conflict, then the downstream controller will take responsibility for an aircraft *after the conflict has been resolved* and likely will never know the aircraft had been involved in a conflict. The conflict resolution clearance must conform to all existing constraints on the assigned trajectory if at all possible, minimizing the chance that the conflict resolution will introduce any new problems.

It is reasonable to expect that as conflict detection horizons increase, controllers will find themselves increasingly working on trajectory issues outside their sector. At such a point, it is desirable to reconsider controller responsibilities, and possibly shift to an approach like the geographically-neutral traffic management specialist discussed above.

Further research is required to determine which upstream controller should be responsible for resolving the conflict in all cases, including situations like that illustrated in Figure A-2 in which the conflicting aircraft are currently operating in two separate upstream sectors. This is a key requirement for the conflict detection automation. Automation might use a prioritization scheme to identify the controller to notify of the conflict that includes factors such as controller workload and whether the conflict resolution advisory modifies the trajectory of one or both aircraft. The prioritization scheme also should consider the goals of MBT, including:

- Resolve problems as early as practical to minimize the magnitude of trajectory changes and allow time for negotiation
- Allow fully equipped aircraft to remain on their trajectories without controller intervention to the extent possible (best equipped, best served)
- Keep aircraft on closed trajectories to the extent possible
- Evaluate the downstream effects of a proposed trajectory amendment to avoid introducing new conflicts
- Manage controller workload

ANSP ground automation already has aircraft performance information, but these detailed models do not support controllers in identifying conflict resolution clearances. In an MBT environment, the assigned trajectory object will contain more detailed information about aircraft capabilities, and advanced data exchange capabilities could update this information for the controller automation in real-time that would be used in constructing and/or trial planning a conflict resolution.

A key aspect of planning the conflict resolution clearance is determining the best way to "translate" the controller's plan into a clearance that is appropriate for a given aircraft's capabilities. The expected mixture of aircraft equipage associated with receiving clearances (via Data Link or voice), auto-loading a Data Link clearance into the FMS, executing clearances (e.g., RTA, interval management, Dynamic RNP, execution of 4DT clearances), etc., will require more knowledge about specific aircraft capabilities than what is available to the ATC system today. Further, this level of knowledge about specific aircraft is likely too much for controllers to process in developing a conflict resolution plan. Thus, it is important that controller automation utilize information about aircraft capabilities to support controllers in constructing a conflict resolution plan and associated clearance.

Some additional automation capabilities would support the controller in effectively and efficiently resolving conflicts. For example, the controller automation should automatically update the proposed clearance if the controller amends the resolution advisory.

Also, there was consensus among controllers participating in the cognitive walkthrough that a coordination countdown timer should ensure that all controllers know how much time is available to approve the amendment before the solution is no longer valid. One controller noted, however, that a long lead time on the coordination countdown timer will require that the automation keep up with any changes made to other aircraft trajectories that might affect the validity of the solution. Note that this latter requirement is valid for all of the functions related to selecting, negotiating, and implementing a trajectory amendment.

5.8. Execute Step Climb

In one of the conflict detection and resolution use cases, the controller provides the aircraft an interim altitude to resolve the conflict. A key part of the interim altitude solution is the aircraft executing the climb after leveling off or descending to avoid traffic. In the current environment, the controller tells the aircraft to descend (or stop its climb), and then when it is time for the aircraft to climb again the controller instructs the aircraft to climb. However, a closed 4DT should include the step climb. An important question is who is responsible for ensuring that the aircraft executes the step climb. In the current environment, the responsibility is clearly the controller's. But in the MBT environment, it is not clear whether the controller or the pilot should be responsible for prompting execution of the step climb.

No FMS currently is designed to execute the vertical profile automatically the way they execute the lateral profile (except in specific phases of flight), and the standards for future FMS do not envision such behavior either. Cognitive walkthrough participants expressed that expecting the aircraft to execute the vertical profile in the same way it executes the lateral profile would entail "quite a learning curve" for pilots and "a big change" for controllers. One pilot who participated in the cognitive walkthrough cautioned that he would prefer that ATC tell him to climb “when I need to do it.” Unless there is an upfront reminder, he said it is “probable” that he will not remember to do it. In fact, this is in line with anecdotal evidence that controllers are discouraged from providing conditional clearances because pilots frequently forget to execute them. It may be true that responsibility for the step climb should remain with the controller except for aircraft that can automatically execute the vertical profile.

The cognitive walkthrough participants did provide suggestions for useful ways to construct the clearance such that the aircraft could execute it. Namely, they suggested the use of clearances such as:

- “REACH [altitude] BY [time]” or “REACH [altitude] BY [fix]”
- “CROSS [fix] AT [altitude]”
- “AT [fix] CLIMB TO FL [altitude]”
- “CROSS [fix]/[distance] AT [altitude]/S”

These are clearances that can be used today, although the first two are the only ones that are typically used. The third is rarely used, and the fourth cannot currently be loaded in an FMS.

It would be a philosophy shift for aviation, but part of the vision of MBT is that aircraft operate along their assigned trajectories without intervention from controllers. Of course, the premise of this use case is that controller intervention was required to maintain separation. However, controllers typically prefer to provide one clearance to resolve a conflict and move on to their next task. Once the capability is available for the controller to resolve the conflict by amending the aircraft’s assigned trajectory, this capability should support minimizing controller intervention and workload to the extent possible. Thus, the automation should support the controller providing the interim altitude clearance in one step using any of the clearances discussed above. Similarly, it should support the pilot in executing that clearance in minimal steps; the pilot should be able to auto-load the clearance and the aircraft follow the vertical profile indicated in the clearance.

5.9. Plan Path Stretch

In today’s environment, the controller manually determines whether a path stretch is needed to meet a trajectory constraint (e.g., MIT spacing or metering delay) and plans the path stretch based on knowledge of the effects of winds aloft on earlier aircraft ground speeds. In an MBT environment, controller or traffic management automation could plan the path stretch and provide a recommendation to the user. Whether the path stretch should be a controller or traffic management responsibility would depend on the amount of delay that needed to be absorbed. If the path stretch spans multiple sectors, it may be a traffic management responsibility to support cross-sector coordination. However, given the discussion in Section 5.7 about cross-sector coordination of conflict resolution actions, it may be sufficient for the controller first notified of the time constraint to plan the path stretch and have automation that supports coordinating the planned path stretch with other affected controllers. This is a potential subject for future research – namely, the situations in which it is more appropriate for such a plan to be a traffic management versus controller responsibility and the performance characteristics of each approach.

If a path stretch is required to achieve the trajectory constraint (i.e., speed reduction is insufficient), controller automation is expected to support controllers in planning a path stretch to achieve the goal. However, the controller will be required to be in the loop in planning the path stretch, especially in the near term. Cognitive walkthrough participants noted that in order to be helpful in designing the path stretch, the automation must have accurate wind models and good predictions of the effect of wind on the aircraft’s capabilities.

Note that in the near term, controllers may not be comfortable with automation-proposed path stretch solutions. This is an expected near- or mid-term TBFM controller tools capability. One controller participant in the cognitive walkthrough said, “I would rather tell the automation what to do than have it suggest something," and suggested tools to support controllers in easily defining a path stretch instead.

5.10. Plan Speed Adjustment

If time constraints are applied to the aircraft trajectories for flow management, the preferred approach is to uplink an RTA to the aircraft. Thus, the pilot will be primarily responsible for selecting the speed schedule to meet the time constraint. The pilot also will be responsible for using aircraft automation for managing speed if interval management were used to meet a spacing goal. However, if an aircraft is not equipped to perform these functions with sufficient precision, the controller would provide a speed advisory and could use automation to identify the appropriate speed (note that GIM-S is capable of this today in support of metering constraints).

Note that a speed constraint for metering can be provided by GIM-S in today's environment, but since the flight plan assigned speed is not changed, the trajectory is still open. Implementing metering by applying a time constraint to the assigned trajectory, and sharing that time constraint with all relevant participants and automation systems, effectively closes the trajectory since the time at the meter fix will be known throughout the system.

5.11. Monitor Conformance with the Assigned Trajectory

In the current environment, pilots are primarily responsible for operating the aircraft in conformance with the clearances provided by the controller, including the flight plan, and notifying the controller of the intent to deviate from this shared plan. Some operations already require aircraft to be equipped to monitor conformance with various aspects of a trajectory. For example, RNP requires conformance monitoring with a lateral path, and time of arrival control (TOAC) requires monitoring conformance with an arrival time at a waypoint. In both cases, the pilot is notified when the aircraft is UNABLE. Similarly, vertical navigation (VNAV) provides the pilot information consistent with the spirit of conformance monitoring. In such cases, the pilot is responsible for either adjusting operation of the aircraft to return to conformance, or coordinating an alternative with the controller.

Controller automation also monitors the aircraft trajectory for conformance with the flight plan in order to support sector controllers in coordinating the handoff. It is not concerned with downstream ETAs. In this use case, the downstream ETAs are not constraints on the assigned trajectory; rather, they are estimates used by the various automation systems for planning purposes. In a previous focus group with pilots, the concept of onboard versus ground responsibility for conformance monitoring was explored [8]. Participants in that activity stated that they would prefer to be notified first of nonconformance, before the controller, allowing them the opportunity to correct the nonconformance and coordinate with the dispatcher as needed. They noted that downlinked aircraft intent would include the nonconforming trajectory, and so there would not be much time between the pilot notification and the controller and dispatcher notification.

This (limited) feedback from pilots is consistent with TBO concepts in which the 4DT is considered a contract between the ANSP and the flight operator, and consistent with a goal of MBT that aircraft follow the assigned trajectory without controller intervention. Thus, the pilot is given primary responsibility for trajectory conformance, including conformance monitoring. This also gives the pilot primary responsibility for resolving trajectory nonconformance, as discussed in the next section.

However, a key aspect of this use case is the stronger than predicted headwind. In such a case, not only does the aircraft have a low-resolution wind forecast, but that forecast is incorrect. Ground automation, on the other hand, uses surveillance data to monitor the aircraft ground speed and has higher resolution winds than the aircraft. In this case, the ground automation may more quickly detect the trajectory nonconformance, particularly as it uses trajectory predictions to monitor demand at the downstream constrained resource. Further, the controller is ultimately responsible for separation management, which requires close monitoring of trajectory conformance.

Thus, it is clear that a ground automation conformance monitoring capability is required, in addition to onboard automation, to support controllers and traffic managers in achieving MBT. However, additional research is necessary to determine whether this should be a standalone capability or if it should be incorporated into one or more other automation systems (e.g., traffic management and/or controller automation).

5.12. Resolve Trajectory Nonconformance

In the current environment, detecting and resolving trajectory nonconformance is not as important as it is expected to be in an MBT environment, particularly in the time dimension. To the extent that a controller identifies trajectory nonconformance as an issue, the controller will provide instructions to the aircraft that will return it to its flight plan route. In the process, the controller may ask the pilot to explain the situation.

Managing aircraft by trajectories requires that there is a consistent view across all participants and automation systems of the aircraft's planned trajectory. When nonconformance is detected, the pilot will have the most information about the reason for the nonconformance in most cases. A significant delay due to a poor wind forecast such as in this use case is an exception. In such a case, the dispatcher and controller will likely have access to better information about the winds.

Since the pilot is expected to have the most information about the reason for the nonconformance, as well as the most information about what the aircraft can do to resolve the nonconformance, the pilot is allocated primary responsibility for this function in the MBT environment. However, the dispatcher in many cases has access to relevant information such as all of the published NAS data reflecting the ground system trajectory predictions, the aircraft data, and the flight operator preferences to determine how to resolve the nonconformance. Thus, the dispatcher is allocated secondary responsibility. Note that flight operators typically have procedures in place for pilot-dispatcher coordination when route amendments are needed, and it is expected that each flight operator organization will identify situations in which the pilot or the dispatcher has primary responsibility for this function. The key for MBT is that automation to support trajectory conformance monitoring, trajectory amendment, and negotiation must be able to accommodate either pilot or dispatcher participation in this function.

However, not all aircraft are supported by a dispatcher. In such cases, the pilot will need to resolve the nonconformance, possibly by explaining the situation to ATC. If the pilot is unable to resolve the nonconformance, the controller may need to intervene to ensure that the aircraft and ground automation have all of the appropriate data to ensure consistent trajectory predictions.

5.13. Request Trajectory Amendment

In the current environment, flight plan amendment requests for en route flights typically come from the pilot, although the dispatcher may coordinate reroutes in cases such as dynamic weather that is significantly downstream from the aircraft's current location. In the MBT environment it is expected that there will be some distance from the Trajectory Change Point (TCP) at which the aircraft will be considered too close to the TCP for the trajectory amendment to be coordinated by the dispatcher (e.g., an aircraft already operating within the controller's planning horizon). In such cases, the pilot will continue to request the trajectory amendment and not the dispatcher. Such requests will be downlinked to the controller.

However, for flights that are farther from the TCP, the dispatcher will be able to request the trajectory amendment directly from the traffic management automation, which is expected to be capable of evaluating most requests and agreeing to the requested change, rejecting the request, and/or negotiating with the flight operator until an amended assigned trajectory is agreed upon. In fact, it is expected that Flight Operations Center (FOC) automation will be capable of requesting an amended trajectory and even negotiating with the traffic management automation on the flight operator's behalf.

Note that the TOS associated with CTOP and flight operator and traffic management automation to manage TOS submission and evaluation are current-day examples of such capabilities. In the near- to mid-term MBT environment, it is expected that flight operators will be capable of maintaining an up to date TOS. Even when no CTOP is in place, the traffic management automation would evaluate the TOS to determine whether the current set of airspace and trajectory constraints render a different trajectory on file to be preferred by the flight operator.

5.14. Plan Weather Deviation

In the current environment, pilots request deviation parameters from the controller (e.g., 20 degrees left of course), and the controller will provide the pilot as much discretion as possible to safely operate the aircraft. Anecdotally, controllers often note that their displays only show radar returns, and so they only see weather systems on their displays if there is precipitation. Meanwhile, pilots can see weather systems out the window of the aircraft and can identify cloud formations (e.g., the "anvil" of a thunderstorm) that indicate treacherous airspace. However, controllers (and pilots) also note that the flight deck radar displays are limited in scope, and so pilots requesting a deviation may not see a system behind the one they are trying to avoid.

Thus, pilots are primarily responsible for planning a weather deviation path in the current environment, and controllers support pilots to the extent that they can in planning safe and efficient weather deviation routes. This is not expected to change in the MBT environment, since pilots are ultimately responsible for safely operating the aircraft and their out the window view of the weather, coupled with their knowledge of how to handle the aircraft, are given significant weight (even though the pilot's assessment of the weather may be incorrect). While it is expected that both pilots and controllers will have access to better weather information in the future, including advanced aircraft automation that supports identifying a weather avoidance path, it is likely that the pilot and controller will still need to collaborate to identify the best weather deviation route.

Defining the best approach to maintaining a closed clearance while the aircraft deviates around the weather is a major challenge for MBT. In addition to the heading used today, two alternatives are presented in the weather deviation use case: 1) the pilot requests an offset that essentially increases the lateral tolerance on the trajectory; and 2) the pilot uses advanced onboard automation to request a specific deviation path. In all alternatives, the pilot is responsible for planning the deviation path. Two additional alternatives were considered in which the controller and the dispatcher, respectively, used a ground based automation capability to propose a weather avoidance route.

Two of the pilot cognitive walkthrough participants noted that it may be difficult for pilots to identify the lateral distance offset shown in Figure 3, although this is already the procedure in oceanic airspace (and one of the two pilots routinely operated in oceanic airspace). The two pilots said that they are reasonably confident that their initially requested heading will allow them to "skirt" the weather they see out the window, but they hesitated to commit to an offset until they were able to see what might be behind the weather they could see on the radar.

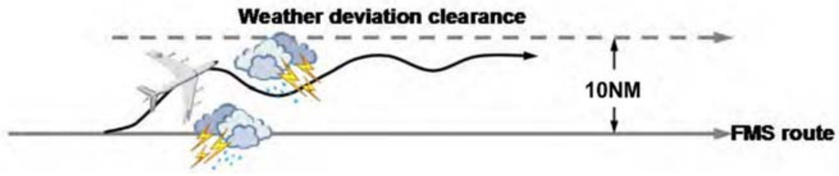


Figure 3: Weather Deviation Offset Clearance (Modified From [9])

An advantage of the lateral offset is that it defines a volume of airspace to be protected for the deviating aircraft and thus preserves the spirit of performance-based navigation. However, this approach would create significant downstream uncertainty because the FMS would not have a reliable route it could use to estimate downstream ETAs. It is hard to say whether such a trajectory is really closed since the time dimension is uncertain.

All of the cognitive walkthrough participants expressed enthusiasm for the variation in which the pilot requested a specific weather deviation route using advanced aircraft automation. Participant statements included:

- Pilot: “Seems like the pilot would have more certainty than today.”
- Controller: “At least there is structure there so now I know and may be able to run aircraft closer to him… Uncertainty is bad for controllers.”

However, there still would be potentially significant uncertainty associated with the trajectory. As with the lateral offset, the pilot would need to estimate a specific route based on the available (imperfect) weather information. If the estimated route is too close to the actual weather, the pilot will need to request an alternate; thus, the trajectory may be predictable but unstable. On the other hand, if the pilot requests a trajectory that is more conservative than necessary the system benefits from a potentially more stable, closed trajectory, but the aircraft is not operating as efficiently as it could.

The ground-based alternatives suffer the same predictability, stability, and efficiency issues, but without the pilot’s out the window view. Note that controllers today sometimes provide weather avoidance routes, typically to maintain uniformity within a flow of aircraft, but they may be more conservative in selecting such routes than necessary. Other concepts have been designed to support dispatchers and even traffic managers in selecting weather avoidance routes [10], but the focus has been on reducing the flight time/distance associated with weather reroute TMIs as opposed to identifying a route around weather that has not already been anticipated to affect a given aircraft. Ground based alternatives are preferred when the need to deviate can be predicted well in advance, typically before the weather is visible on the flight deck radar.

Yet another alternative is for the pilot to propose the deviation trajectory – either a lateral offset or complete trajectory – and for the other participants to support negotiation such that the amended assigned trajectory takes into account both the pilot’s assessment of the out the window view and the more comprehensive radar data available on the ground.

5.15. Plan Reroute

In the current environment, airborne reroutes require a traffic management specialist to manually enter the reroute. In addition to other efforts to increase automation support for managing airborne reroutes, MBT can make use of the TOS and traffic management automation that is already designed to manage changes to the preferred trajectory option after departure. A key part of this is FOC automation that keeps the TOS up to date throughout the life of the flight, adding responsibility to the dispatcher for ensuring that the TOS is appropriately maintained. In the event that a reroute is required – or a more efficient route comes available – the traffic management automation can quickly identify a trajectory in the TOS and offer it to the flight operator.

5.16. Negotiate Trajectory

Roles and responsibilities associated with trajectory negotiation have been explored in the NextGen Trajectory Negotiation (NTN) ConOps [5]. That work proposed that trajectory negotiation be handled by FOC and traffic management automation to the extent possible to minimize workload for all participants and to ensure that negotiation takes place with a system-oriented view. The expectation is that trajectories negotiated by dispatchers and traffic managers would be less likely to create new downstream problems than trajectories negotiated by controllers and pilots.

CTOP has been implemented since the NTN ConOps was written, and provides a negotiation approach that is in line with the NTN ConOps. Dispatchers are responsible for providing the TOS to the traffic management automation, which selects the flight operator preferred TOS option for a given situation and offers it to the FOC, which evaluates and then re-files the newly awarded trajectory. In the future environment, more of the negotiation is expected to be handled by automation, and it is not expected that the dispatcher/ATC coordinator will need to re-file the awarded TOS option.

One cognitive walkthrough participant suggested considering the use of a TOS at all times, even in the absence of a CTOP program. Negotiation via the TOS would work the same way whether there was an active CTOP or not. This implies that the allocation of responsibility for trajectory negotiation would be consistent with that proposed for this use case in many other use cases as well.

5.17. Maintain and Update Trajectory Options Set (TOS)

In the current (or near-future) environment, flight operators have automation to support dispatchers in maintaining and resubmitting the TOS as conditions and preferences change.

While the pilot does not submit TOS options, the pilot does coordinate preferences and options with the dispatcher. The pilot should be in the decision-making loop and therefore is included as a participant with responsibility for this function.

The allocation of responsibility ostensibly does not change in the MBT environment. However, the expanded access to information and automation capabilities on the flight deck may increase the role of the pilot. It is conceivable that advanced aircraft automation can support TOS maintenance.

6. Conclusions and Recommendations

The key changes in allocation of responsibilities between the current environment and the MBT environment are associated with increased automation capability and increased flexibility for different participants to take on certain tasks in different situations. For example, increased data exchange infrastructure creates the possibility of flexibility in delivering information – including clearances – to the aircraft, such as from traffic management automation in addition to controller automation.

In many cases, the primary assignment of responsibility is not expected to change in the MBT environment, but the way in which the participant is expected to perform the function and/or the automation support provided is expected to change. For example, the use of trajectory constraints to manage airspace constraints associated with MBT will require a different approach to managing airspace constraints. In particular, use of MIT would require a way to “translate” the in-trail separation requirement into specific trajectory constraints. This could be accomplished using flight deck interval management for appropriately equipped aircraft, or it could be accomplished by applying crossing time constraints to individual trajectories reflecting the required separation. The latter approach implies that the airspace constraint could (and possibly should) be managed using time-based metering instead.

The trade study identified some automation requirements beyond what is included in the current arc of development. For example, when time permits in the current environment, many controllers will provide pilots two alternative conflict resolutions from which to choose. The cognitive walkthrough participants noted that this is a desirable feature of the current environment to retain in the MBT environment. However, the current development arc of advanced conflict resolution and data exchange tools, including CPDLC and automated conflict resolution advisories, does not seem to consider this alternative. In order to support this feature, the CPDLC message set must be expanded.

Similarly, MBT envisions sufficiently capable aircraft being able to fly their assigned trajectories without intervention from the controller. Aircraft are capable of doing this in the lateral dimension, but no FMS currently is designed to execute the vertical profile automatically the way they execute the lateral profile (except in specific phases of flight), and the standards for future FMS do not envision such behavior either. Automatic execution of the vertical profile would be quite a change in philosophy for pilots and controllers and may not be within the MBT vision for the near term. However, it is a desirable goal for the end state so that aircraft are operating on closed 4DTs more frequently.

7. Acronyms

Acronym	Definition
ABRR	Airborne Reroute
ADS-B	Automatic Dependent Surveillance-Broadcast
ADS-C	Automatic Dependent Surveillance-Contract
AFP	Airspace Flow Program
ANSP	Air Navigation Service Provider
ARTCC	Air Route Traffic Control Center
ATC	Air Traffic Control
ATCSCC	Air Traffic Control System Command Center
ATM	Air Traffic Management
ATN	Aeronautical Telecommunications Network
ATOP	Advanced Technologies & Oceanic Procedures
ATSP	Air Traffic Service Provider
CDM	Collaborative Decision Making
CPDLC	Controller-Pilot Data Link Communications
CTOP	Collaborative Trajectory Options Program
EDCT	Expect Departure Clearance Time
EFB	Electronic Flight Bag
EPP	Extended Projected Profile
ERAM	En Route Automation Modernization
FMS	Flight Management System
FOC	Flight Operations Center
FRD	Fix/Radial/Distance
FSM	Flight Schedule Monitor
GDP	Ground Delay Program
ICAO	International Civil Aviation Organization
IFC	In-Flight Connectivity
MAP	Monitor Alert Parameter
MBT	Management by Trajectory
MIT	Miles in Trail
NAS	National Airspace System
NCR	NAS Common Reference
NOTAM	Notices to Airmen
NTML	National Traffic Management Log
NTN	NextGen Trajectory Negotiation
RNP	Required Navigation Performance
RTA	Required Time of Arrival
RTP	Required Time Performance
RTCA	Radio Technical Commission for Aeronautics
SAA	Special Activity Airspace
SWIM	System Wide Information Management

TAP	Traffic Aware Planner
TASAR	Traffic Aware Strategic Aircrew Request
TBFM	Time Based Flow Management
TBO	Trajectory Based Operations
TCP	Trajectory Change Point
TFM	Traffic Flow Management
TFMData	Traffic Flow Management Data
TFMS	Traffic Flow Management System
TFR	Temporary Flight Restriction
TMI	Traffic Management Initiative
TMU	Traffic Management Unit
TOD	Top of Descent
TRACON	Terminal Radar Control
TSD	Traffic Situation Display

8. References

[1] S. C. Johnson and B. E. Barmore, "NextGen Far-Term Concept Exploration for Integrated Gate-to-Gate Trajectory-Based Operations," in *16th AIAA Aviation Technology, Integration, and Operations Conference*, Washington, DC, 2016.

[2] P. J. Smith, A. L. Spencer and C. E. Billings, "Strategies for designing distributed systems: Case studies in the design of an air traffic management system," *Cognition, Technology, and Work,* vol. 9, pp. 39-49, 2007.

[3] D. D. Woods and E. Hollnagel, Joint Cognitive Systems: Patterns in Cognitive Systems Engineering, Boca Raton, FL: CRC Press, 2006.

[4] J. Grudin, "Why CSCW applications fail: Problems in the design and evaluation of organizational interfaces," in *Proceedings of the 1988 ACM Conference on Computer-Supported Cooperative Work*, New York, 1988.

[5] FAA, "NextGen Trajectory Negotiation Concept of Operations," Federal Aviation Administration, Washington, DC, 2014.

[6] S. Green and K. Leiden, "A Trajectory Orientation Approach to En Route Strategic Planning," in *3rd USA/Europe Air Traffic Management R&D Seminar*, 2000.

[7] N. Smith, T. Prevot, A. Kessell, J. Homola, H. Lee, J. Mercer, C. Brasil, M. Mainini and P. Lee, "A human-in-the-loop evaluation of multi-sector planning in mixed equipage airspace (MSP III)," NASA Ames Research Center, Moffett Field, CA, 2011.

[8] A. Fernandes, S. Vail, J. Rebollo and J. Brown, "Oceanic Flights and Airspace: Improving Efficiency by 4-Dimensional Trajectory-Based Operations Year End Report," Mosaic ATM, Inc., Leesburg, VA, 2015.

[9] ICAO, "Global Operational Data Link Document (GOLD), 2nd Edition," International Civil Aviation Organization, Montreal, 2013.

[10] K. Sheth, D. McNally, A. Morando, A. Clymer, P. Somersall and F.-T. Shih, "Assessment of a National Airspace System airborne rerouting tool," in *11th USA/Europe Air Traffic Management Research and Development Seminar (ATM2015)*, Lisbon, Portugal, 2015.

[11] FAA, "NAS Target Top Level Systems Requirement Document (Target RD), Version 4.0," Federal Aviation Administration, Washington, DC, 2014.

[12] FAA, "Dynamic Required Navigation Performance Preliminary Concept of Operations," Federal Aviation Administration, Washington, DC, 2014.

[13] J. Henderson, "Traffic Aware Strategic Aircrew Requests (TASAR) Concept of Operations," NASA Langley Research Center, Hampton, VA, 2013.

[14] J. M. Maris, M. A. Haynes, D. J. Wing, K. A. Burke, J. Henderson and S. E. Woods, "Traffic Aware Planner (TAP) Flight Evaluation," NASA Langley Research Center, Hampton, VA, 2014.

Appendix A: Management by Trajectory Use Cases Analysis

There were eight main use cases used to identify the key Management by Trajectory (MBT) functions for which the distribution of roles and responsibilities should be evaluated:

- Controller issues a vector for traffic
- Controller issues an interim altitude for traffic
- Controller issues vectors for miles in trail (MIT) sequencing
- Controller issues vectors for time based metering
- Pilot requests deviation for weather
- Dispatcher requests delayed arrival for gate management
- Dispatcher requests reroute for Special Activity Airspace (SAA) restriction
- Use of Collaborative Trajectory Options Program (CTOP) TMI to manage multiple constraints

In each use case, the present day procedures and automation support capabilities were summarized and then an approach to resolving the associated issues in an MBT environment was proposed.

This section describes the use cases – present day procedures and in an MBT environment, the key MBT functions identified, and the participant assigned responsibility for the function in the MBT environment.

Controller Issues Vector for Traffic

In this case, the controller resolves a conflict after receiving a conflict alert.

Use Case Steps

Present Day Procedures and Automation

1. URET conflict probe alerts of pending separation issue between AAL262 & AAL1516, 12 minutes before loss of separation.
2. The controller completes several trial plans. The first is to climb AAL262 to FL350; however, that reveals a conflict with AAL700 (DFW-EWR).
3. The next trial plan shows that FL310 has no conflicts.
4. The controller issues a vector for a 15-degree right turn.
5. The pilot turns, and the open trajectory begins (i.e., neither the flight crew nor the automation knows when the controller will turn the AC back).
6. Once clear of traffic, 6 minutes later, the controller re-clears the aircraft direct RMG and updates the route in ERAM. The pilot executes the reroute.

Managed in an MBT Environment

1. Strategic[1] conflict probe alerts of pending separation issue between AAL262 & AAL1516, 20 minutes before loss of separation. Conflict probe provides an automated resolution advisory with the reroute solution.
2. Controller evaluates and approves the resolution advisory and provides the reroute to the flight deck.

---

[1] "Strategic conflict probe" here is used to distinguish this conflict alerting capability from the current ERAM conflict probe, which acts on a very limited look ahead (6-8 minutes). This strategic conflict probe could be URET or similar future capability.

3. Flight deck reviews, accepts, and executes the reroute.
4. Assigned trajectory is amended and shared.

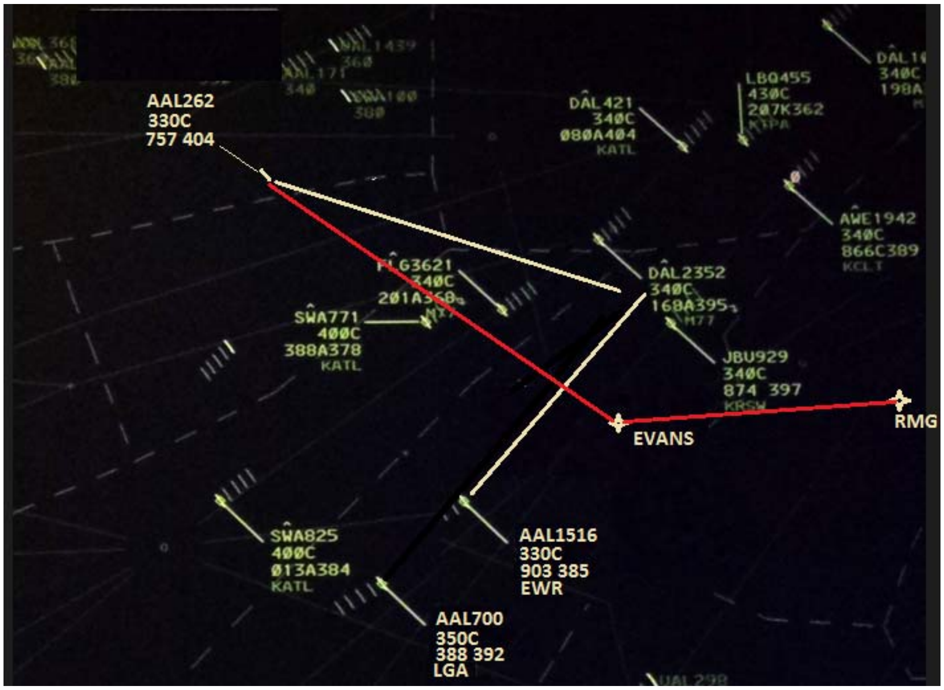


Figure A-1: Lateral path conflict resolution solution

Note that there are several use case variations associated with this use case in an MBT environment that are discussed below.

Variations on the Conflict Detection Horizon

Improved trajectory predictability in the MBT environment will support an even longer conflict detection horizon than indicated in the use case, on the order of 30 minutes or more. At this horizon, it is likely that adding a time constraint to one or more of the aircraft trajectories would resolve the conflict without requiring them to otherwise change their trajectories. The controller uplinks an RTA to either or both aircraft. The pilot evaluates, accepts, and executes the RTA, and the aircraft automation adjusts the aircraft speed accordingly. This case requires the controller automation to know both aircrafts' time performance capabilities to identify time constraints that provide sufficient separation and minimize the speed adjustments required.

On the other hand, some unforeseen trajectory change limiting trajectory predictability could delay conflict detection until the resolution requires immediate execution (e.g., an aircraft encountered turbulence or some malfunction that required it to change altitude). Immediate execution of the conflict resolution would prohibit the use of CPDLC to coordinate the trajectory amendment. In this case, the controller provides the clearance by voice and ensures that the clearance is captured in the automation such as by accepting the automated resolution advisory or entering the clearance provided to the aircraft.

Similarly, a lateral route change may require more time to execute than a speed or altitude change, and so a shorter conflict detection horizon may preclude the lateral route change illustrated in this use case.

"Equipped" and "Unequipped" Aircraft Capabilities

In this use case, an "equipped" aircraft is capable of both receiving a clearance via CPDLC and auto-loading it into the FMS. Such aircraft are able to receive complex clearances because there is minimal opportunity for human error in the process of entering the new route into the FMS.

An “unequipped” aircraft is not CPDLC-equipped and must receive clearances via voice. Such clearances must be simple enough to deliver that the flight crew can quickly write it down, read it back, and manually enter it into the FMS for evaluation.

Note that even in the near term many aircraft are expected to be equipped to receive clearances via CPDLC, but will not support auto-loading clearances into the FMS. It be easier to keep these aircraft on closed trajectories than voice-only aircraft because there can always be a digital copy of a clearance provided by CPDLC. However, aircraft that do not support FMS auto-load will not be able to receive complex clearances or clearances involving latitude/longitude because they still must be entered into the FMS manually. Thus, the clearance provided to the aircraft will not be significantly different from that provided to a voice-only aircraft.

Use Case Assumptions

The proposed approach to managing the conflict in an MBT environment incorporates several assumptions about the operational environment. These are presented here with some discussion as to their effect on the use case in an MBT environment.

Earlier Conflict Detection

Improved trajectory prediction supported by MBT and other TBO concepts allows conflicts to be detected sooner than in the present day. In the use case, the example of a 20-minute look ahead was used, but the look ahead time for conflict detection will depend on several factors, including just how good the system is at predicting trajectories.

The 20-minute look ahead was selected for this use case because that is currently the typical look ahead used for URET.[2] Since the use case was presented to retired controllers and traffic managers at the cognitive walkthrough who would be familiar with URET, the research team wanted the look ahead time to seem plausible to them.

However, the cognitive walkthrough participants stressed that they do not use URET to detect conflicts for several reasons. First and foremost, they strive to perform conflict detection and resolution manually specifically to avoid dependence on automation. They indicated that depending on automation to alert them to conflicts would indicate that they were not capable of managing the traffic scenario efficiently enough to consistently provide conflict solutions that would not introduce a second conflict.

Secondly, the current conflict detection and alerting tools provided to controllers – URET and ERAM conflict probe – use different data and algorithms and therefore produce different results. URET provides longer look ahead times than ERAM conflict probe, but it does not have all the necessary data to accurately predict trajectories at those look ahead times. In large part, this is due to the use of open trajectories. Cognitive walkthrough participants gave examples such as departures having their climbs stopped to avoid conflicts with crossing traffic. The controllers working those flows of traffic know that the aircraft will have their climbs resumed to meet the agreed handoff altitude, but the automation does not have access to that information.

On the other hand, ERAM conflict probe uses track data to make assumptions about aircraft behavior in the next 6-8 minutes. When aircraft are in “free track”, i.e., when the automation has detected that the aircraft is operating on an open trajectory, ERAM makes assumptions about when the aircraft will rejoin its flight plan route and the trajectory it will use to get there.

---

[2] The look ahead time is a facility assigned parameter (20-60 minutes), but most facilities set it at 20 (the minimum) because it becomes less accurate the further out in time it probes.

A key goal of the MBT concept is to keep aircraft operating on closed trajectories as much as possible. This will increase predictability, which is required to support earlier conflict detection. As the conflict detection horizon (and traffic volume) increases, controllers will need to increase their use of automation to support conflict detection and resolution. Increasing the conflict detection horizon such that conflicts are managed by amending trajectory constraints before the conflicting aircraft enter the ATC sector where the conflict occurs has implications for the distribution of responsibility among controllers. The D-side controller that today assists the R-side controller is more likely to have the information needed to reliably detect conflicts and can take action to coordinate resolving such conflicts before the aircraft enter the sector. This requires inter-sector coordination, as discussed below.

Controller Automation Provides Conflict Resolution Advisories

Automated conflict resolution advisories are expected to be available in ERAM starting in 2019.[3] Thus, it is expected that in the end state MBT operational environment, these will be not only available but routinely used by controllers.

The routine use of automated conflict resolution advisories would drastically reduce the number of aircraft operating on open trajectories due to vectors for traffic. However, the MBT concept does not depend on this capability to maintain closed trajectories. During the cognitive walkthrough, the discussion of this use case started with the premise that the controller automation would suggest a conflict resolution, but the discussion quickly moved to ideas for approaches to supporting controllers in providing conflict resolutions in a way that was easy and would maintain a closed clearance.

However, even if the controller developed his/her own conflict resolution, the controller automation would prepare the clearance for the controller to deliver to the aircraft. This would allow a single controller action to resolve the conflict using a closed trajectory.

Use Case Functions, Allocation, and Automation Requirements

The functions identified in the use case are summarized in Table A-1. Table A-1 also provides the allocation of the function in the current environment and in the MBT environment. Where multiple participants are indicated for a given function, the primary participant is listed first. For example, in the current environment, controllers are primarily responsible for conflict detection with automation support. However, in the MBT environment, it is expected that controller automation will have a more significant role in conflict detection and resolution.

Also, where only the human participant is noted as responsible for a function, the human participant likely has automation to support performing that function. However, the automation is not listed because it is intended as an aid to the human participant that is responsible for carrying out the function.

Table A-1: Vectors for Traffic Use Case Functions and Allocation

Function	Current Allocation	MBT Allocation
Detect conflict	Controller	Controller
Plan conflict resolution clearance	Controller Pilot	Controller (Aircraft Sector) *Pilot*
Deliver conflict resolution clearance	Controller	Controller (Aircraft Sector)

---

[3] FAA, "NAS Target Top Level Systems Requirement Document (Target RD), Version 4.0," Federal Aviation Administration, Washington, DC, 2014.

Function	Current Allocation	MBT Allocation
Evaluate conflict resolution clearance	Pilot	Controller Pilot
Execute conflict resolution clearance	Pilot	Pilot
Amend flight plan	N/A	Controller

Notes on Proposed MBT Allocation and Automation Requirements

The following paragraphs provide reasoning behind the proposed MBT allocation of some of the functions in Table A-1. This explanation focuses on the aspects of those items that differ between the current environment and the MBT environment.

Detect Conflict

Controllers will retain responsibility for conflict detection in the MBT environment, but MBT will allow the automation they use to be much more reliable than it is today. Cognitive walkthrough controller participants stressed that in the current environment they are not likely to use their strategic conflict detection capability for several reasons. Critically, the strategic tool does not have access to all of the data it needs to produce an accurate trajectory prediction. For example, if a climbing aircraft has been leveled off by the controller in the previous sector, the controller receiving the strategic conflict alert knows that the previous sector controller will continue the aircraft's climb before handing it off. However, the strategic conflict probe does not know the aircraft will continue its climb. MBT conflict detection automation will require access to the updated assigned trajectory and the ability to share trajectory changes across sectors. The core of the MBT concept, i.e., applying constraints to the assigned trajectory to effect change in the trajectory, will support the controller automation in meeting these requirements.

The controller participants also noted that if controller automation is to effectively detect conflicts based on a trajectory prediction, it must be able to very quickly detect when an aircraft deviates from the predicted trajectory. Note that the introduction of ADS-B Out for surveillance data will provide much more frequent track updates than the current radar surveillance, and will enable must faster detection of trajectory nonconformance. Further, trajectory nonconformance will be detected as early as possible using downlinked aircraft intent.

Plan Conflict Resolution Clearance

Note that the function "Plan conflict resolution clearance" is allocated primarily to the controller, but also to the pilot, in the current environment. This is because when time permits, many controllers will provide pilots two alternative conflict resolutions from which to choose. It is noted that this is a desirable feature of the current environment to retain in the MBT environment. However, the current development arc of advanced conflict resolution and data exchange tools, including CPDLC and automated conflict resolution advisories, does not seem to consider this alternative. In order to support this feature, the CPDLC message set must be expanded.

There was a consensus among the controller and pilot participants that providing the option is a desirable goal for MBT. The pilot has access to information about the aircraft capabilities that is not available to the controller. For example, the controller may instruct the aircraft to climb due to traffic but the aircraft may not be able to climb. In other cases, the pilot may prefer the climb over a lateral path solution to a conflict. Providing the option was considered more efficient than the controller providing a clearance, the pilot rejecting it because the aircraft is unable to execute it, and the controller providing an updated clearance.

In the MBT environment, the controller will retain primary responsibility for planning the conflict resolution advisory. But the controller will have significantly more automation support, with the automation providing resolution advisories as discussed elsewhere.

An important aspect of the earlier detection of conflicts expected in MBT is that conflicts are likely to be detected before the conflict aircraft are operating within the sector where the conflict occurs (unless sectors are expanded from their current design). Thus, it is important to determine not only that the controller is responsible for planning the conflict resolution clearance, but *which* controller. Figure A-2 illustrates the situation where two aircraft are predicted to conflict in a sector that is downstream for both aircraft.[4]

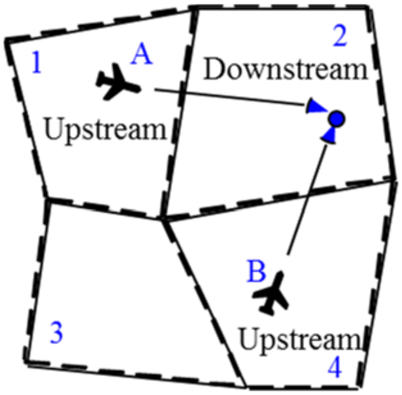


Figure A-2: Inter-sector Conflict[5]

Previous research into this question has provided different recommendations depending on the purpose of the research. Green and Leiden[6] suggested that the upstream controller team, i.e., the controller team responsible for the sector where the aircraft is operating at the time the conflict is detected, should be responsible for resolving the conflict and delivering that resolution to the aircraft. This was chiefly to minimize coordination requirements and relieve workload in the downstream sector, which was expected to be busier.

Other work has suggested that the conflict be resolved by a new role, the Multi-Sector Planner (MSP).[7] The MSP would not be a controller, and therefore would not have direct communication with the aircraft, and so the MSP would create a conflict resolution plan and provide the clearance to the controller currently responsible for the aircraft to deliver.

These previous results beg the question: What should the controller of, for example, Sector 1 in Figure A-2 be responsible for? Should that controller be monitoring the predicted (downstream) trajectories of the aircraft currently operating in Sector 1 to identify and resolve conflicts between those aircraft and other aircraft currently operating in yet other sectors (e.g., Sector 4 in Figure A-2)? If this is the case, coordination and/or procedures would be required between the Sector 1 and Sector 4 controllers to ensure that the conflict between Aircraft A and Aircraft B is resolved.

---

[4] Figure from S. Green and K. Leiden, "A Trajectory Orientation Approach to En Route Strategic Planning," in *3rd USA/Europe Air Traffic Management R&D Seminar*, 2000.

[5] Ibid.

[6] Ibid.

[7] N. Smith, T. Prevot, A. Kessell, J. Homola, H. Lee, J. Mercer, C. Brasil, M. Mainini and P. Lee, "A human-in-the-loop evaluation of multi-sector planning in mixed equipage airspace (MSP III)," NASA Ames Research Center, Moffett Field, CA, 2011.

Green and Leiden[8] suggested that automation determine which controller should be notified of the conflict, with the other controller notified only after a period of time with inaction. On the other hand, the MSP would be responsible for adjusting both aircraft trajectories as needed to resolve the conflict and providing the clearances for both aircraft to the respective sector controllers to deliver to the aircraft.[9]

Alternatively, the MSP, a traffic manager, or some other position could use Data Comm to uplink the clearance directly to the aircraft if certain conditions are met.[10] The chief consideration in these conditions is that the change in either aircraft's trajectory is sufficiently downstream from its current position that it is outside any tactical controller's planning horizon.

However, MBT cognitive walkthrough participants preferred an approach by which the Sector 2 controller be responsible for identifying and resolving the conflict, and then providing the clearances for Aircraft A and B to the Sector 1 and 4 controllers, respectively, to deliver to the aircraft. Note that Green and Leiden[11] rejected this approach because of the coordination required among the sector controllers and the potential that the downstream sector's clearance (e.g., Sector 2) would be made obsolete by an action taken by the upstream controller (e.g., Sector 1). The latter concern would be lessened by the MBT approach to resolving conflicts by modifying the assigned trajectory, in which the amended assigned trajectory is provided to all relevant stakeholders, and automation supports participants in avoiding trajectory amendments that introduce new problems.

It must be noted, however, that the cognitive walkthrough participants' preferred approach, in which the downstream controller is responsible for resolving the conflict, aligns best with the current environment in which conflicts are detected and resolved within a single sector (i.e., the conflict shown in Figure A-2 would not be acted upon until one or both aircraft had entered the control of Sector 2). The cognitive walkthrough participants may have been biased by their experience with the current environment, characterized by poor trajectory predictability such that it is not effective to act early on a detected conflict.

MBT allocates this responsibility to the upstream controller. The controller is responsible for solving problems related to the trajectories of the aircraft under his/her control. It is desirable to resolve conflicts as early as practical, and with improved trajectory predictability they can be resolved much earlier than today. If the controller responsible for the aircraft at the time the conflict is detected is responsible for resolving the conflict, then the downstream controller will take responsibility for an aircraft *after the conflict has been resolved* and likely will never know the aircraft had been involved in a conflict. The conflict resolution clearance must conform to all existing constraints on the assigned trajectory if at all possible, minimizing the chance that the conflict resolution will introduce any new problems.

Further research is required to determine which upstream controller should be responsible for resolving the conflict in all cases, including situations like that illustrated in Figure A-2 in which the conflicting aircraft are currently operating in two separate upstream sectors. This is a key requirement for the conflict detection automation. Automation might use a prioritization scheme to identify the controller to notify of the conflict that includes factors such as controller workload and whether the conflict resolution advisory modifies the trajectory of one or both aircraft. The prioritization scheme also should consider the goals of MBT, including:

---

[8] Green and Leiden, 2000.

[9] Smith, et al., 2011.

[10] FAA, "NextGen Trajectory Negotiation Concept of Operations," Federal Aviation Administration, Washington, DC, 2014.

[11] Green and Leiden, 2000.

- Resolve problems as early as practical to minimize the magnitude of trajectory changes and allow time for negotiation
- Allow fully equipped aircraft to remain on their trajectories without controller intervention to the extent possible (best equipped, best served)
- Keep aircraft on closed trajectories to the extent possible
- Evaluate the downstream effects of a proposed trajectory amendment to avoid introducing new conflicts
- Manage controller workload

ANSP ground automation already has aircraft performance information, but these detailed models do not support controllers in identifying conflict resolution clearances. In an MBT environment, the assigned trajectory object will contain more detailed information about aircraft capabilities, and advanced data exchange capabilities could update this information for the controller automation in real-time that would be used in constructing and/or trial planning a conflict resolution.

A key aspect of planning the conflict resolution clearance is determining the best way to "translate" the controller's plan into a clearance that is appropriate for a given aircraft's capabilities. The expected mixture of aircraft equipage associated with receiving clearances (via Data Link or voice), auto-loading a Data Link clearance into the FMS, executing clearances (e.g., RTA, interval management, Dynamic RNP, execution of 4DT clearances), etc., will require more knowledge about specific aircraft capabilities than what is available to the ATC system today. Further, this level of knowledge about specific aircraft is likely too much for controllers to process in developing a conflict resolution plan. Thus, it is important that controller automation utilize information about aircraft capabilities to support controllers in constructing a conflict resolution plan and associated clearance.

Some additional automation capabilities would support the controller in effectively and efficiently resolving conflicts. For example, the controller automation should automatically update the proposed clearance if the controller amends the resolution advisory.

Also, there was consensus among controllers participating in the cognitive walkthrough that a coordination countdown timer should ensure that all controllers know how much time is available to approve the amendment before the solution is no longer valid. One controller noted, however, that a long lead time on the coordination countdown timer will require that the automation keep up with any changes made to other aircraft trajectories that might affect the validity of the solution. Note that this latter requirement is valid for all of the functions related to selecting, negotiating, and implementing a trajectory amendment.

Deliver Conflict Resolution Clearance

The controller is expected to be responsible for delivering the clearance to the aircraft in conflict avoidance situations. However, a key difference in the MBT environment is the expectation that the controller will deliver a closed clearance as much as possible. To support this, it is desirable to make the process as consistent as possible for the controller, regardless of aircraft capabilities. As noted above, the automation is expected to automatically build a clearance appropriate for the aircraft based on the automated conflict resolution advisory and controller modifications of the advisory. For clearances that must be delivered by voice, the controller automation needs to make it as easy as possible for the controller to provide the clearance to the ground automation.

Evaluate Conflict Resolution Clearance

In the current environment, the pilot evaluates a clearance, including a conflict resolution clearance, before executing it to ensure it is safe for the aircraft. This will also be required in an MBT environment.

In addition, in the MBT environment the controller automation is expected to provide conflict resolution advisories. The controller is expected to evaluate such an advisory before providing it to the pilot. The controller is listed first in Table A-1 only because the controller will be the first person to evaluate the clearance and not because the controller's responsibility is considered greater than that of the pilot's.

Amend Flight Plan/Assigned Trajectory

In the current environment, the aircraft's flight plan would not be amended to account for the conflict resolution clearance. In the MBT environment, the assigned trajectory will be amended to account for all clearances provided to the aircraft. In this use case, the controller is responsible for ensuring that the assigned trajectory is amended. There are some important considerations for automation support for this function.

It is important to note that adding responsibility to the controller for entering all clearances provided by voice into the automation has consequences. First, controllers may be more likely to accept the automated solution to avoid manually entering information into the automation, which requires that the automation provides adequate solutions (and makes it desirable for automation to consistently provide solutions that are as good as or better than those the controller would propose). More consistent use of automated conflict resolution advisories may decrease controllers' skill at detecting and resolving conflicts manually, which could present a safety issue if controllers are expected to be the safety net in the case of automation failure.

If a controller has to enter a clearance manually into the automation, it is important that not only is the automation designed to make that easy, but having the information in the automation also must provide a benefit to controllers. Research has shown that when people are expected to enter data into automation to support others with no benefit to themselves, it is not likely that they will do so.[12] Thus, to support closed clearances, the controller automation should be designed with the following goals in mind:

- Amend assigned trajectory without explicit controller action to the extent possible
- Facilitate easy assigned trajectory amendment in cases where controller must enter information manually.

Controller Issues Interim Altitude for Traffic

This is a variation of the use case in which the controller issues an interim altitude rather than a lateral path solution to resolve the conflict.

Use Case Steps

Present Day Procedures and Automation

1. URET conflict probe alerts of pending separation issue between AAL262 & AAL1516, 12 minutes before loss of separation.
2. The controller completes several trial plans; the first is to climb AAL262 to FL350, however that reveals a conflict with AAL700 (DFW-EWR). The next trial plan shows FL310 has no conflicts.
3. The controller verbally clears AAL262 to descend to FL310.
4. Pilot descends to FL310.

---

[12] J. Grudin, "Why CSCW applications fail: Problems in the design and evaluation of organizational interfaces," in *Proceedings of the 1988 ACM Conference on Computer-Supported Cooperative Work*, New York, 1988.

5. Once clear of traffic the controller clears aircraft to FL330 and removes the interim altitude.
6. The pilot climbs to FL330.

Note that trajectory probing in ERAM remained at FL330 during the entire event.

Managed in an MBT Environment

1. Strategic conflict probe alerts of pending separation issue between AAL262 & AAL1516, 20 minutes before loss of separation. Conflict probe provides an automated resolution advisory with an interim altitude solution.
2. Controller evaluates the resolution advisory and provides the interim altitude to the flight deck.
3. Flight deck reviews, accepts, and executes the interim altitude.
4. Assigned trajectory is amended and shared.

Updating the assigned 4D trajectory for the flight allows ERAM to probe along the interim altitude.

Similar to the previous use case, there are several variations associated with this use case in an MBT environment:

- Variations on the conflict detection horizon affecting available resolution options and ability to deliver the clearance via CPDLC
- Aircraft data exchange equipage

Use Case Assumptions

The proposed approach to managing the conflict in an MBT environment incorporates the same assumptions as the previous use case (Controller Issues a Vector for Traffic). They are listed here for convenience; refer to the discussion associated with the previous use case for more information.

- Earlier conflict detection
- Controller automation provides conflict resolution advisories and prepares the clearance
- Equipped aircraft can receive clearances via CPDLC and auto-load them into the FMS. Non-equipped aircraft receive clearances via voice.

Use Case Functions and Allocation

The functions identified in the use case are summarized in Table A-2. Table A-2 also provides the allocation of the function in the current environment and in the MBT environment.

Table A-2: Interim Altitude Use Case Functions and Allocation

Function	Current Allocation	MBT Allocation
Detect conflict	Controller	Controller
Plan conflict resolution clearance	Controller	Controller Pilot
Deliver conflict resolution clearance	Controller	Controller
Evaluate conflict resolution clearance	Pilot	Controller Pilot
Amend flight plan	N/A	Controller
Execute step climb	Controller	Pilot Controller

Notes on Proposed MBT Allocation

The following paragraphs provide reasoning behind the proposed MBT allocation of some of the functions in Table A-2. Functions discussed previously are not repeated here unless the consideration of responsibility assignment was expanded through evaluation of this use case.

Executing Step Climb

A key part of the interim altitude solution is the aircraft executing the climb after leveling off or descending to avoid traffic. In the current environment, the controller tells the aircraft to descend (or stop its climb), and then when it is time for the aircraft to climb again the controller instructs the aircraft to climb. However, a closed 4DT should include the step climb. An important question is who is responsible for ensuring that the aircraft executes the step climb. In the current environment, the responsibility is clearly the controller's. But in the MBT environment, it is not clear whether the controller or the pilot should be responsible for prompting execution of the step climb.

No FMS currently is designed to execute the vertical profile automatically the way they execute the lateral profile (except in specific phases of flight), and the standards for future FMS do not envision such behavior either. Cognitive walkthrough participants expressed that expecting the aircraft to execute the vertical profile in the same way it executes the lateral profile would entail "quite a learning curve" for pilots and "a big change" for controllers. One pilot who participated in the cognitive walkthrough cautioned that he would prefer that ATC tell him to climb "when I need to do it." Unless there is an upfront reminder, he said it is "probable" that he won't remember to do it. In fact, this is in line with anecdotal evidence that controllers are discouraged from providing conditional clearances because pilots frequently forget to execute them. It may be true that responsibility for the step climb should remain with the controller except for aircraft that can automatically execute the vertical profile.

The cognitive walkthrough participants did provide suggestions for useful ways to construct the clearance such that the aircraft could execute it. Namely, they suggested the use of clearances such as:

- "REACH [altitude] BY [time]" or "REACH [altitude] BY [fix]"
- "CROSS [fix] AT [altitude]"
- "AT [fix] CLIMB TO FL [altitude]"
- "CROSS [fix]/[distance] AT [altitude]/S"

These are clearances that can be used today, although the first two are the only ones that are typically used. The third is rarely used, and the fourth cannot currently be loaded in an FMS.

It would be a philosophy shift for aviation, but part of the vision of MBT is that aircraft operate along their assigned trajectories without intervention from controllers. Of course, the premise of this use case is that controller intervention was required to maintain separation. However, controllers typically prefer to provide one clearance to resolve a conflict and move on to their next task. Once the capability is available for the controller to resolve the conflict by amending the aircraft's assigned trajectory, this capability should support minimizing controller intervention and workload to the extent possible. Thus, the automation should support the controller providing the interim altitude clearance in one step using any of the clearances discussed above. Similarly, it should support the pilot in executing that clearance in minimal steps; the pilot should be able to auto-load the clearance and the aircraft follow the vertical profile indicated in the clearance.

Controller Issues Vectors for MIT Sequencing

In this use case, due to a low AAR and excessive demand at EWR, ZNY has passed back a 20 MIT restriction to ZOB for all EWR arrivals. ZOB passes the entire 20 MIT back to ZID. The ZID controller issues reduced speed and a turn/path stretch to achieve the required spacing.

Note that in the far term, time-based metering is expected to be used for this scenario in place of MIT. However, it will likely take some time to phase out use of MIT.

Use Case Steps

Present Day Procedures and Automation

1. ZID TMU posts the 20 MIT RSTN on their ESIS board and coordinates with their sectors/areas
2. The ZID62 controller identifies two EWR arrivals (AAL1516 & AAL1700) that need to be sequenced. Taking upper level winds into account, the controller turns AAL1700 30 degrees left to a heading of 360 (an open clearance). AAL1700 is also asked to reduce speed to Mach .76.
3. The pilot reduces speed and turns to a 360 heading (open trajectory begins)
4. After 5 minutes on that heading, the controller clears AAL1700 direct ROD at Mach .77 (its original speed)
5. The pilot turns back on course to ROD and resumes normal speed
6. The controller enters the reroute in ERAM, closing the trajectory, and hands the two EWR arrivals off to the next sector perfectly spaced at 20 MIT

Managed in an MBT Environment

1. ZID TMU provides the 20 MIT RSTN to the affected sectors/areas
2. The ZID62 controller identifies two EWR arrivals (AAL1516 & AAL1700) that need to be sequenced. The controller identifies a path stretch for AAL1700. AAL1700 is also provided a Required Time of Arrival (RTA) at ROD that achieves the spacing goal.
3. The pilot evaluates, accepts, and executes the reroute and the RTA. The trajectory is updated in ERAM.
4. When AAL1700 crosses ROD the controller provides the aircraft an interval management clearance to maintain 20 miles of spacing behind AAL1516
5. The controller hands the two EWR arrivals off to the next sector such that they are using interval management to maintain 20 MIT

Use Case Assumptions

The use case relies on one of the same assumptions as the previous use cases; namely, it uses the same definitions of equipped and unequipped aircraft.

In addition, the use case assumes that controller automation provides a function allowing the controller to draw a path stretch that “snaps” to geographical locations appropriate for the aircraft. The geographical location might be lat/lon if the aircraft is equipped (i.e., the flight crew can auto-load the clearance). Otherwise, some FMS can accept named fixes not already in flight plan and others require heading/range from flight plan fixes (see Figure A-3). Still other FMS can take a more sophisticated S-turn defined as 2 fix radius transitions.[13]

Figure A-3: Example path stretch using automatically selected, named waypoints

Use Case Functions and Allocation

The functions identified in the use case are summarized in Table A-3. Table A-3 also provides the allocation of the function in the current environment and in the MBT environment.

Table A-3: Vectors for Sequencing Use Case Functions and Allocation

Function	Current Allocation	MBT Allocation
Apply MIT restriction to flow	ARTCC/TRACON Traffic Management Specialist	ARTCC/TRACON Traffic Management Specialist
Identify aircraft subject to MIT	Controller	ARTCC/TRACON Traffic Management Specialist
Communicate MIT restriction to controllers	ARTCC/TRACON Traffic Management Specialist Area Supervisor	ARTCC/TRACON Traffic Management Specialist Area Supervisor
Add constraint to achieve MIT to affected aircraft	Controller	ARTCC/TRACON Traffic Management Specialist

---

[13] FAA, "Dynamic Required Navigation Performance Preliminary Concept of Operations," Federal Aviation Administration, Washington, DC, 2014.

Function	Current Allocation	MBT Allocation
		Controller
Identify aircraft to be sequenced	Controller	ARTCC/TRACON Traffic Management Specialist Controller
Plan speed reduction	Controller	Pilot Controller
Plan path stretch	Controller	ARTCC/TRACON Traffic Management Specialist Controller
Deliver clearance	Controller	Controller ARTCC Traffic Management Specialist
Evaluate clearance	Pilot	Controller Pilot
Execute clearance	Pilot	Pilot
Amend flight plan	N/A	Controller

Notes on Proposed MBT Allocation

The following paragraphs provide reasoning behind the proposed MBT allocation of some of the functions in Table A-3. Functions discussed in previous sections are not repeated here unless the consideration of responsibility assignment was expanded through evaluation of this use case. Note that the use case specified ARTCC traffic management, but TRACON traffic management also makes use of MIT and MBT should account for that.

Apply MIT Restriction to Flow

The decision by traffic management to apply an MIT restriction to the EWR traffic is outside the scope of MBT. In fact, in the long-term MBT environment, it is expected that spacing will be created using time-based metering and not MIT. However, given the present-day prevalence of MIT, MBT must be able to support a near term environment in which MIT is used to manage spacing for traffic flows. The role of MBT is to provide a mechanism for “translating” the MIT restriction into constraints on individual aircraft trajectories, and the act of applying constraints to individual aircraft assigned trajectories associated with the MIT restriction is the responsibility of traffic management. In particular, traffic management specialists must select appropriate parameters for the traffic management automation to use to identify the affected aircraft, compute the appropriate trajectory constraints, and propose the assigned trajectory amendment to the trajectory negotiation mechanism. Note that traffic management automation already supports these functions for Collaborative Decision Making (CDM) programs and time-based metering (except for supporting negotiation). However, current automation provides limited support for these functions when MIT is used.

Identify Aircraft Subject to MIT Constraint

This function is the act of identifying the aircraft affected by the MIT NAS constraint. In the current environment, the traffic management specialist posts the MIT constraint to displays available to the controllers, and the controllers must identify the specific aircraft under their responsibility that are subject to the constraint.

In the MBT environment, a reference to the MIT constraint will be automatically applied to the affected aircraft assigned trajectories when the traffic management specialist implements the MIT constraint. Thus, the traffic management specialist is responsible for ensuring that the traffic management automation appropriately identifies the affected aircraft. Traffic management automation should support this just as today’s traffic management automation identifies aircraft subject to a GDP or AFP.

Communicate MIT Restriction to Controllers

This function is expected to be fully automated in the MBT environment. Currently, traffic managers manually enter information to be displayed in control Areas, and controllers are required to remain aware of the set of flow requirements affecting the aircraft they work.

Further, controllers are currently responsible for manually identifying affected aircraft and achieving the required spacing between them. In the MBT environment, this can be accomplished through trajectory modifications. While controllers may prefer to know about the restriction for their situation awareness regarding traffic flows, the critical function is for controller automation to notify controllers (and/or traffic managers) of aircraft whose assigned trajectories need to be amended to achieve the spacing requirement.

Add Constraint to Achieve MIT to Affected Aircraft

This function is the act of applying the trajectory constraints to the specific aircraft trajectories to achieve the MIT requirement.

There are multiple different individual aircraft trajectory constraints that can be applied to achieve the desired spacing. For example, aircraft can be provided crossing time constraints that would provide 20 MIT between pairs of aircraft on the same flow, or appropriately equipped aircraft could maintain the necessary spacing using interval management. In this use case a third alternative was proposed, in which automation recommended a speed reduction and/or path stretch; this was specifically in order to support a near term environment and capabilities already expected for controller automation.

The selection of which constraint(s) to apply is outside the scope of MBT, but the role primarily responsible for applying the constraint(s) depends on this choice. To promote strategic trajectory management to the extent possible, MBT encourages the traffic management specialist to select an approach to achieving the traffic management goals that provides flight operators the greatest flexibility in selecting a 4DT that meets the constraints while also providing traffic management sufficient predictability to ensure that the traffic management goals will be met. This involves applying the constraints as early as practical.

However, the controller will still be required to achieve spacing requirements where they have not already been achieved by traffic management functions. MBT will provide the controller the ability to select the appropriate constraints to apply to aircraft trajectories to meet the spacing requirements without introducing new downstream conflicts.

Identify Aircraft to be Sequenced

Ideally, the traffic management automation already has planned a sequence for the aircraft and identifies pairs of aircraft that require trajectory amendments in order to achieve the sequence before the controller takes responsibility for the aircraft. In such cases, the traffic management specialist could apply trajectory amendments to one or more aircraft to achieve the sequence and is thus given primary responsibility for identifying the aircraft. This may allow aircraft to execute the amended trajectory sooner and therefore more efficiently and/or with greater flexibility to negotiate the desired approach to meeting the constraints.

Although applying the necessary constraints more strategically such as by the traffic management specialist is desirable, this use case specifically addresses the situation in which the aircraft are handed off to the controller without the necessary spacing. In such cases, the controller must take responsibility for identifying the pairs of aircraft to be sequenced and achieving the needed spacing.

Both traffic management and controller automation need to identify pairs of aircraft that require trajectory amendments to achieve the spacing requirement. A key open question is a precise definition of the handoff of responsibility for this function from the traffic management specialist to the controller such that both do not simultaneously attempt to solve the same problem.

Whether it is the controller or the traffic management specialist identifying the affected aircraft, automation should support precise calculation of the spacing that will be achieved without trajectory amendments, immediate identification of aircraft that require trajectory amendments to achieve the required spacing, as well as support for planning the trajectory amendments.

Plan Speed Reduction

If time constraints are applied to the aircraft trajectories to achieve a speed reduction, the preferred approach is to uplink an RTA to the aircraft. Thus, the pilot will be primarily responsible for executing the RTA such that aircraft automation can implement the necessary speed reduction to meet the spacing goal. The pilot also is responsible for using aircraft automation for managing speed if interval management were used to meet the spacing goal. However, if an aircraft is not equipped to perform these functions with sufficient precision, the controller would provide a speed advisory and could use automation to identify the appropriate speed (note that GIM-S is capable of this today in support of metering constraints).

Plan Path Stretch

If a path stretch is required to achieve the spacing goal (i.e., speed reduction is insufficient), it is desirable for the traffic management specialist to use automation to identify this and apply the path stretch as early as practical. Performing this function at the traffic management level has multiple benefits, including: 1) the path stretch can more easily cross sectors; 2) the path stretch crossing multiple sectors can involve a less severe turn off of course, allowing the aircraft to stay closer to its preferred trajectory; and 3) controller workload is reduced, allowing the controller to focus on those aircraft that for some reason were unable to achieve spacing before the controller takes responsibility for the aircraft.

If the aircraft enter the controller’s responsibility without trajectories that will achieve the necessary spacing, the controller is responsible for further amending their trajectories as needed. Controller automation is expected to support controllers in planning a path stretch to achieve the goal. However, the controller will be required to be in the loop in planning the path stretch, especially in the near term.

Traffic management and controller automation need to support the traffic management specialist and controller, respectively, in devising a path stretch to achieve the spacing goal when required. The ground automation could provide a path stretch advisory, which would suggest a path stretch that would achieve the spacing goal.

Cognitive walkthrough participants noted that in order to be helpful in designing the path stretch, the automation must have accurate wind models and good predictions of the effect of wind on the aircraft’s capabilities.

Note that in the near term, controllers may not be comfortable with automation-proposed path stretch solutions. This is an expected near- or mid-term TBFM controller tools capability. One controller participant in the cognitive walkthrough said, “I would rather tell the automation what to do than have it suggest something,” and suggested tools to support controllers in easily defining a path stretch instead. Such capabilities might include allowing the controller to click on a point on the surveillance display to indicate the point the controller wants the aircraft to “aim for” on the path stretch, and automatically generate a clearance that uses the latitude/longitude of that point or a reference to a nearby named waypoint.

Deliver Clearance

In the current environment, only the controller can deliver a clearance to an aircraft. However, Data Link and other forms of advanced data exchange create the possibility for other approaches to delivering clearances. The primary approach to delivering clearances in an MBT environment will be delivery from the controller via controller automation (i.e., Data Link). But when constraints are applied to trajectories due to traffic management programs, the trajectory amendment could be delivered by the traffic management specialist via traffic management automation. Previous research has proposed the following requirements for traffic management delivery of a clearance:[14]

- The reroute does not affect the aircraft route or speed in the sector of the controller currently responsible for the aircraft.
- The trajectory change point is at least 2 sectors away and 1 hour of flight time away.
- The controller currently responsible for the flight needs to have access to information about the downstream trajectory change in case the flight crew asks about the new clearance.
- If the ARTCC TMU does not issue the clearance early enough, the clearance is sent to the controller to deliver.
- The aircraft must be within the geographical boundary of the ARTCC TMU delivering the clearance and under direct control of one of its sectors.
- The automation should prevent situations in which both the TMU and the controller in charge of the aircraft simultaneously issue a clearance.
- The flight crew acknowledgment of the amended clearance should only be received by the TMU that issued the clearance.

Further research is needed to quantify performance associated with traffic management delivery of clearances in various scenarios, including application of constraints to aircraft trajectories to meet traffic management program goals.

Evaluate Clearance

As in the current environment, the pilot has primary responsibility for ensuring that the clearance provided to the aircraft is safe and achievable before accepting and executing it. However, the controller also is given responsibility for this function, in particular to reflect the use of advisories provided by controller automation.

In the current environment, the controller mentally conceives almost all clearances as part of the separation management plan. However, if controller automation provides an advisory, it is important that the controller evaluates the recommended clearance before accepting and uplinking it to ensure that it achieves separation management and flow management requirements.

In the current environment in which open trajectories are used to provide the speed reduction and/or path stretch clearance to the flight deck, pilots typically implement the changes in the auto-pilot/MCP rather than in the FMS. As a result, the FMS does not recalculate the trajectory and does not provide planning guidance to help the pilot determine whether the clearance is within the aircraft's performance envelope. Pilots rely on their knowledge and on other aircraft monitoring systems to determine if the clearance is achievable. In the MBT environment, the closed clearances provided to the flight deck are expected to be more readily loaded into the FMS; thus, aircraft automation will better support pilots in evaluating the clearance.

Controller Issues Vectors for Metering

In this use case, due to a low AAR and excessive demand causing delays into EWR, ZNY initiates adjacent center metering with ZOB, ZID, ZDC, and ZBW.

---

[14] FAA, "NextGen Trajectory Negotiation Concept of Operations," 2014.

Use Case Steps

Present Day Procedures and Automation

1. TBFM builds the schedule at each meter fix and computes a Scheduled Time of Arrival (STA) for each flight once it crosses the freeze horizon for that fix. This STA is based on the TBFM-computed ETA at the meter fix, which may be off by several minutes. ZID TMU coordinates with each area and displays the EWR meter lists on the controller radar screens.
2. The ZID62 controller's meter list shows a 1-minute delay for AAL1516 and a 5-minute delay for AAL1700.
3. The controller reduces AAL1516 from Mach .79 (current speed) to Mach .77. This is an open clearance. As part of the controller's metering plan, he/she enters the reduced speed in the data block as a memory jogger, but it does not modify the flight plan assigned speed.
4. For AAL1700 speed control alone will be not be enough to reduce the delay in his sector, so the controller turns AAL1700 30 degrees left to a heading of 360 and issues a speed reduction to .76 mach.
5. The pilots reduce speed and AAL1700 turns to a 360 heading (open trajectory begins for AAL1700)
6. After the delay countdown timer in the data block reaches one minute, the controller clears AAL1700 direct ROD. The pilot turns back on course to ROD
7. The controller enters the reroute in ERAM and uses data block coordination on the handoff to coordinate both AAL1516 & AAL1700's speeds.

Managed in an MBT Environment

1. Traffic management automation (e.g., TBFM) uses each affected aircraft's ETA at the meter fix to build the schedule at each fix, computing an STA for each flight. Winds are uplinked to each equipped aircraft's FMS and the traffic management automation requests an ETA min-max report (or similar) from all appropriately equipped aircraft and uses improved trajectory predictions to compute a more accurate ETA than is available in the current environment. The traffic management automation adds the STA to each flight's assigned 4DT as a time constraint and the assigned trajectory is published. ZID TMU coordinates with each area and displays the EWR meter lists on the controller radar screens.
2. The STAs will be implemented by RTA. The ZID62 controller provides the RTA to AAL1516.
3. AAL1516 reviews and accepts the RTA. The aircraft slows to Mach .77. The new speed is provided to the controller automation.
4. Controller automation notifies the ZID62 controller that AAL1700 will require a path stretch to meet its STA and recommends a path stretch that will absorb the necessary delay.
5. The ZID62 controller evaluates and accepts the recommended path stretch, and provides the path stretch and RTA to the flight deck of AAL1700.
6. The flight crew of AAL1700 evaluates, accepts, and executes the path stretch with RTA. The aircraft slows to Mach .76 and executes the path stretch.

A variation on this use case is one in which the traffic management automation and traffic management specialist develop the path stretch and provide it to the controller for delivery to the aircraft.

4. Traffic management automation notifies the traffic management specialist that AAL1700 will require a path stretch to meet its STA and recommends a path stretch to absorb the necessary delay that crosses sector boundaries. The traffic management specialist evaluates the path stretch and provides it to the affected sectors for evaluation.
5. Each of the affected controllers evaluates and accepts the path stretch solution, and the ZID62 controller provides the path stretch and updated RTA to the flight deck of AAL1700.
6. The flight crew of AAL1700 evaluates, accepts, and executes the path stretch with RTA. The aircraft slows to Mach .76.

Use Case Assumptions

In addition to the assumptions associated with the previously discussed use cases, this use case assumes that in an MBT environment any aircraft can receive and control to a Required Time of Arrival (RTA). The level of aircraft equipage determines the tolerance associated with the RTA; a well-equipped aircraft can meet an RTA within +/- 10 seconds (consistent with the RTCA standard), whereas a lesser-equipped aircraft will have a wider tolerance.

The use case also assumes that in order to support use of RTA to meet the schedule at the meter fix, the RTAs are assigned at merge fixes and not necessarily at the meter fixes. For example, aircraft that merge into the flow at the Merge Fix shown in Figure A-4 would be provided RTAs at the Merge Fix and not at the Meter Fix. Aircraft that do not merge into the flow until the Meter Fix would be provided RTAs at the Meter Fix.

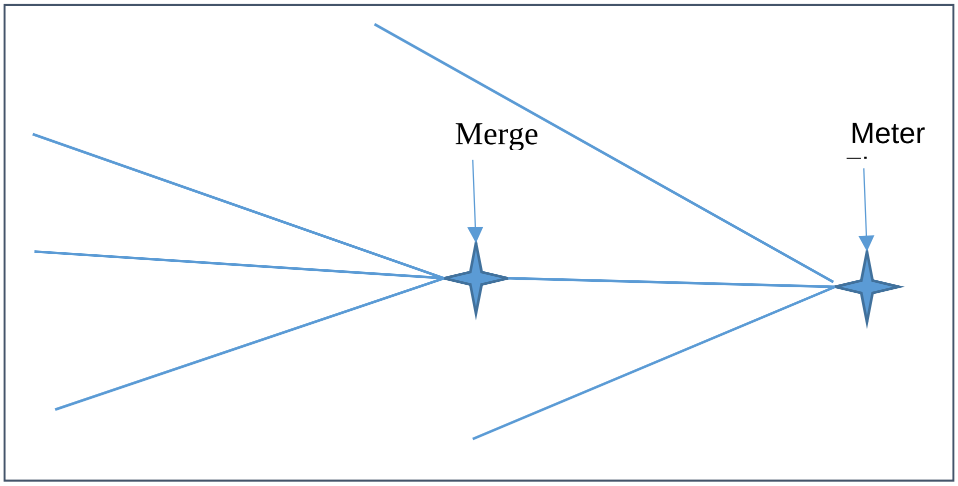


Figure A-4: Some Flows Merge Before the Meter Fix

In addition, the use case assumes that in an MBT environment there is automation support for a traffic management specialist building a path stretch, similar to the controller automation supporting conflict resolution.

Use Case Functions and Allocation

The functions identified in the use case are summarized in Table A-4. Table A-4 also provides the allocation of the function in the current environment and in the MBT environment.

Table A-4: Vectors for Metering Use Case Functions and Allocation

Function	Current Allocation	MBT Allocation
Apply adjacent center metering to flow	ARTCC Traffic Management Specialist	ARTCC Traffic Management Specialist
Coordinate metering program with affected Areas	ARTCC Traffic Management Specialist	ARTCC Traffic Management Specialist
Plan speed reduction	Controller	Pilot Controller
Plan path stretch	Controller	Controller ARTCC Traffic Management Specialist
Deliver clearance	Controller	Controller ARTCC Traffic Management Specialist
Evaluate clearance	Pilot	Pilot Controller
Execute clearance	Pilot	Pilot
Amend flight plan	N/A	Controller

Notes on Proposed MBT Allocation

The following paragraphs provide reasoning behind the proposed MBT allocation of some of the functions in Table A-4. Functions discussed in previous sections are not repeated here unless the consideration of responsibility assignment was expanded through evaluation of this use case.

Plan Speed Reduction

In the current environment, traffic management automation identifies aircraft that are subject to metering based on the parameters set by the traffic management specialist and sets an STA for the aircraft at the meter fix. This is not expected to change in the MBT environment, except that the STAs will be more achievable since they will be based on more accurate trajectory predictions.

The traffic management automation computes the delay the aircraft should absorb in each sector to meet the STA. Controller automation notifies the controller by displaying a delay countdown timer to the controller for affected flights. The controller is responsible for ensuring that the aircraft absorbs the indicated delay before handing it off to the next sector. The STA is never applied directly to the aircraft.

In the MBT environment, the STA will be applied directly to the assigned trajectory and available to all stakeholders. Rather than displaying a delay countdown timer to controllers, in an MBT environment the traffic management automation will provide the controller the RTA at the meter fix to uplink to the aircraft. Alternatively, the traffic management specialist could uplink the RTA to the aircraft.

Since RTA is the method of choice for ensuring the aircraft meets its STA, the pilot is primarily responsible for engaging the aircraft automation to plan the speed reduction (i.e., selecting appropriate speed(s) to meet the RTA).

For an aircraft that is not equipped to meet the RTA with sufficient precision, the controller can provide a speed advisory. Note GIM-S can support the controller in selecting the reduced speed in today’s environment.

Plan Path Stretch

In today’s environment, the controller manually determines whether a path stretch is needed and plans the path stretch based on knowledge of the effects of winds aloft on earlier aircraft ground speeds. In an MBT environment, controller or traffic management automation could provide a path stretch advisory to the user. Whether the path stretch should be a controller or traffic management responsibility would depend on the amount of delay that needed to be absorbed. If the path stretch spans multiple sectors, it may be a traffic management responsibility to support cross-sector coordination. This is a potential subject for future research – namely, the situations in which it is more appropriate for such a plan to be a traffic management versus controller responsibility and the performance characteristics of each approach.

Pilot Requests Deviation for Weather

In this use case, a pilot requests a deviation around weather. A key point to this use case is that the pilot sees weather out the window that is not visible on the ground automation radar, or that looks worse out the window than indicated by the radar display. Otherwise, traffic management, ATC, and the dispatcher likely would have already taken action to provide the flight a reroute around the weather. Thus, the pilot in this case has the most information about the weather and the desired proximity to it.

Use Case Steps

Present Day Procedures and Automation

1. Pilot of AAL262 observes weather ahead and requests deviation left of course
2. Controller: “Deviation left of course approved, proceed DRCT FERDY when able”
3. Pilot begins deviating left of course. Once clear of the weather, the pilot advises ATC “DRCT FERDY”
4. Controller acknowledges and updates route line in ERAM

A variation on this use case is one in which after several minutes off course, AAL262’s data block has gone into free track. Prior to handoff to the next sector, the controller needs to update the trajectory, done by approximating a point in space (guessing) based on where previous aircraft deviated or based on depicted weather. In the current environment, this guess is associated with the “worst case” such that the aircraft is very unlikely to pass that point before returning to course, but the aircraft is likely to return to course before that point.

Managed in an MBT Environment

1. Pilot of AAL262 observes weather ahead and requests a weather deviation. Controller advises pilot he/she is cleared to deviate up to 10 miles left of current route (see Figure A-5).
2. Controller increases tolerance on lateral trajectory between the aircraft’s current position and FERDY, giving the pilot discretion to deviate around the weather.
3. Increased tolerance on AAL262’s trajectory affects ability to predict downstream conformance and conflicts.

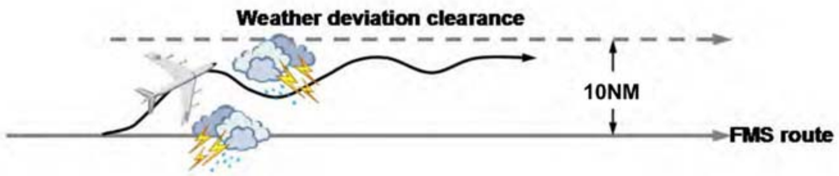


Figure A-5: Weather Deviation Offset Clearance[15]

Note that the system does not have more information than it has today about the aircraft's trajectory while it is deviating. However, it is known that the controller's and pilot's intent is for the aircraft to return to its route by time it crosses FERDY. Adding a time constraint at FERDY would seem to close the loop on the deviation clearance, but the aircraft will be unable to accurately predict its crossing time at FERDY since it does not know its precise path around the weather. Thus, ETAs provided by the aircraft as part of the aircraft intent are not likely to be accurate or stable until the aircraft crosses FERDY. In order for downstream trajectory predictions to be somewhat accurate, ground automation will need to estimate downstream delays, possibly using information about delays experienced by other aircraft that deviated around the same weather system.

In a variation on this use case, the aircraft is equipped with advanced automation that supports identifying a weather avoidance path. In this variation, the use case steps are:

1. Pilot observes weather ahead and uses advanced flight deck automation to generate a lateral path around the weather. The automation combines aircraft radar with uplinked weather information. The pilot uses the automation generated route and his interpretation of the weather situation to evaluate the route.
2. Pilot downlinks reroute request to ATC.
3. Controller evaluates and approves the weather deviation reroute, and uplinks a clearance to the aircraft.
4. Flight crew loads, evaluates, accepts, and executes the deviation reroute

The process is repeated, or the conformance bound is increased, if the pilot needs further deviation. A key feature of this variation is that the aircraft remains on a closed trajectory throughout the weather deviation. However, the predicted trajectory may be unstable as the flight crew requests additional deviations. After some number of new trajectory requests, the controller or the flight crew may choose to revert to the approach of increasing the tolerance on the current trajectory in an attempt to avoid further requests. Note that this approach may be required in some regions of airspace, such as those that have not yet had demand reduced to account for the weather system.

Use Case Assumptions

In addition to the assumptions associated with previous use cases, this use cases introduces a "fully equipped" aircraft that has flight deck automation that supports the flight crew in identifying a weather deviation route as well as an appropriate data link connection to downlink the route request. The fully equipped aircraft also has CPDLC and FMS auto-load.

New technologies make it possible to provide more information than ever to an EFB. For example:

---

[15] Figure modified from: ICAO, "Global Operational Data Link Document (GOLD), 2nd Edition," International Civil Aviation Organization, Montreal, 2013.

- ADS-B In provides traffic data
- New connections make more data available from the ground (SWIM, weather, etc.)
- Aircraft interface devices (AIDs) extract data from the FMS
- Increased computing power

Emerging concepts take advantage of these technologies. For example, NASA's Traffic Aware Planner (TAP) implements the Traffic Aware System Aircrew Request (TASAR) concept, which supports en route re-optimization that considers aircraft capabilities, traffic data, wind, weather, etc.[16,17]. The flight deck automation variation of this use case leverages the TASAR/TAP concept. Importantly, TAP generates an optimized flight path that is deconflicted for traffic, weather, etc., while focusing on calculating a fuel, time, or combination benefit for the flight.

Use Case Functions and Allocation

The functions identified in the use case are summarized in Table A-5. Table A-5 also provides the allocation of the function in the current environment and in the MBT environment.

Table A-5: Weather Deviation Use Case Functions and Allocation

Function	Current Allocation	MBT Allocation
Identify need to deviate	Pilot	Pilot
Plan weather deviation	Pilot Controller	Pilot Controller
Deliver clearance	Controller	Controller
Evaluate clearance	Pilot	Pilot Controller
Execute clearance	Pilot	Pilot
Amend flight plan	Controller	Controller

Notes on Proposed MBT Allocation

The following paragraphs provide reasoning behind the proposed MBT allocation of some of the functions in Table A-5. Functions discussed in previous sections are not repeated here unless the consideration of responsibility assignment was expanded through evaluation of this use case.

Identify Need to Deviate

In an MBT environment, it is still expected that there will be times when the pilot will have better information than any automation – air or ground – about weather in the vicinity of the aircraft and decide to deviate. In such situations, the pilot will have the primary responsibility for identifying the need to deviate. However, in the MBT environment it is expected that many aircraft will have advanced automation that can identify a weather avoidance route. A recommended weather avoidance route may prompt the pilot to consider deviating.

---

[16] J. Henderson, "Traffic Aware Strategic Aircrew Requests (TASAR) Concept of Operations," NASA Langley Research Center, Hampton, VA, 2013.

[17] J. M. Maris, M. A. Haynes, D. J. Wing, K. A. Burke, J. Henderson and S. E. Woods, "Traffic Aware Planner (TAP) Flight Evaluation," NASA Langley Research Center, Hampton, VA, 2014.

Plan Weather Deviation

In the current environment, pilots request deviation parameters from the controller (e.g., 20 degrees left of course), and the controller will provide the pilot as much discretion as possible to safely operate the aircraft. Anecdotally, controllers often note that their displays only show radar returns, and so they only see weather systems on their displays if there is precipitation. However, pilots can see weather systems out the window of the aircraft and can identify cloud formations (e.g., the “anvil” of a thunderstorm) that indicate treacherous airspace. However, controllers (and pilots) also note that the flight deck radar displays are limited in scope, and so pilots requesting a deviation may not see a system behind the one they are trying to avoid.

Thus, in addition to maintaining safe separation between aircraft, controllers support pilots to the extent that they can in planning safe and efficient weather deviation routes. This is not expected to change in the MBT environment. While it is expected that both pilots and controllers will have access to better weather information in the future, including advanced aircraft automation that supports identifying a weather avoidance path, it is likely that the pilot and controller will still need to collaborate to identify the best weather deviation route.

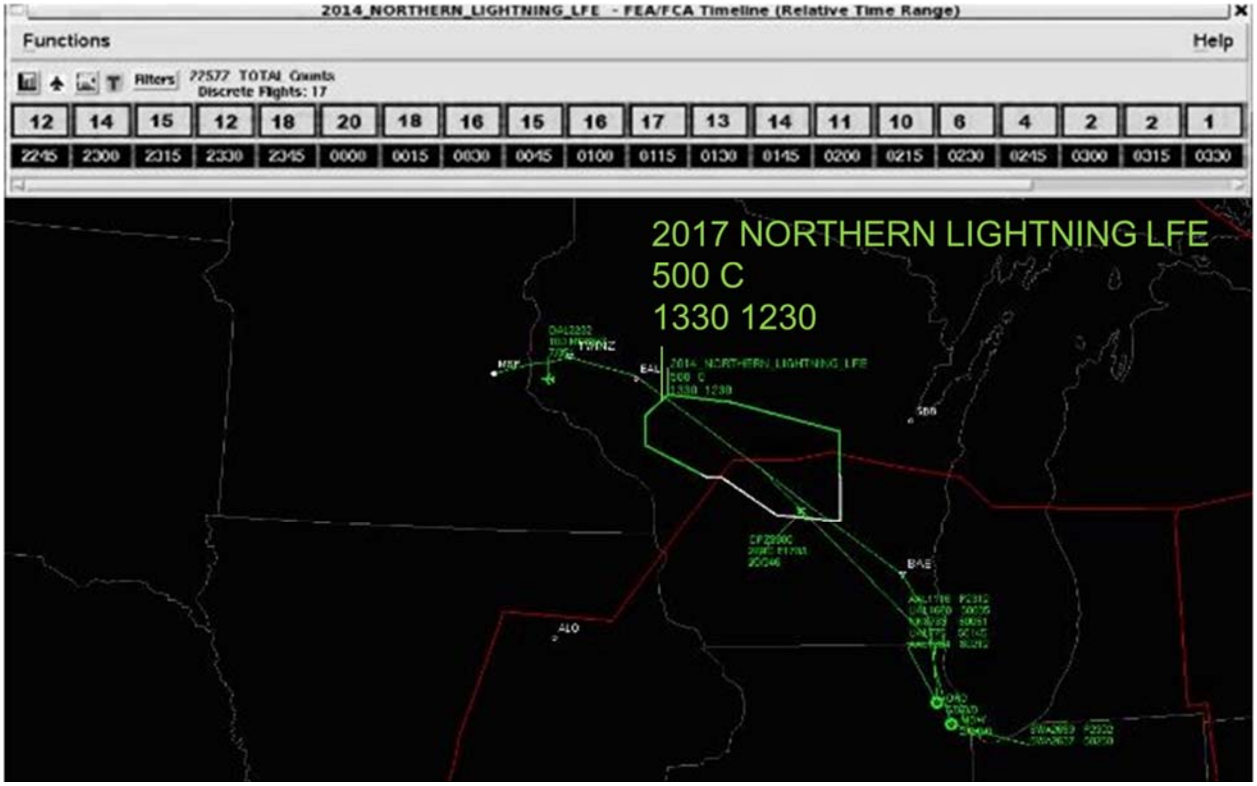
Two of the pilot cognitive walkthrough participants noted that it may be difficult for pilots to identify the lateral distance offset shown in Figure A-5, although this is already the procedure in oceanic airspace (and one of the two pilots routinely operated in oceanic airspace). The two pilots said that they are reasonably confident that their initially requested heading will allow them to “skirt” the weather they see out the window, but they hesitated to commit to an offset until they were able to see what might be behind the weather they could see on the radar.

All of the cognitive walkthrough participants expressed enthusiasm for the variation in which the pilot requested a specific weather deviation route using advanced aircraft automation. Participant statements included:

- Pilot: “Seems like the pilot would have more certainty than today.”
- Controller: “At least there is structure there so now I know and may be able to run aircraft closer to him… Uncertainty is bad for controllers.”

Dispatcher Requests Reroute for Special Activity Airspace Restriction

In this use case, a dispatcher requests a more efficient route for a flight when a Special Activity Airspace (SAA) is made available. A large exercise at Volk Field in WI, called Northern Lightning, is coordinated between the military and the FAA. This exercise requires the fighter training airspace to extend up to FL500 during several busy periods during the day. The event affects a busy aviation corridor causing hundreds of reroutes, particularly MSP and ORD arrivals/departures.



12	14	15	12	18	20	18	16	15	16	17	13	14	11	10	6	4	2	2	1
2245	2300	2315	2330	2345	0000	0015	0030	0045	0100	0115	0130	0145	0200	0215	0230	0245	0300	0315	0330

Figure A-6: Example FCA for Northern Lightning Exercise

Use Case Steps

Present Day Procedures and Automation

1. The Air Traffic Control System Command Center (ATCSCC) and local Traffic Management Units (TMUs) build Flow Constrained Areas (FCAs) and brief the flight operators on all the planning teleconferences (see Figure A-6). Dispatchers file flight plans around the airspace for all flights captured in the FCAs.
2. During the middle of the military exercise the flight operator ATC desk receives an ATCSCC advisory notifying that the Northern Lightning airspace has been cancelled for the remainder of the day. The ATCSCC opens the Tactical Customer Advocate (TCA) position to support flight operators in rerouting flights.
3. The ATC coordinator disseminates the cancellation notice to the FOC floor and all dispatchers begin sending ACARS messages to all affected flights including route guidance.
4. DAL610, en route from SEA to DTW, receives the ACARS message and requests a shortcut from the controller working ZLC32. Since the reroute request involves fixes far

beyond the next fix in ZMP, the controller instructs the pilot to forward the request on the next frequency.

5. 30 minutes later DAL610 requests the reroute on ZMP's frequency, which is approved and entered into ERAM.
6. For some aircraft, the flight operator sends a group of reroute requests to the TCA position at the ATCSCC. The TCA is able to amend flight plans, but there is a delay as the traffic management specialists working the TCA position manually process each flight.
7. This same coordination between dispatchers and pilots, then pilots and controllers is taking place in dozens of sectors throughout the NAS, as each flight operator tries to improve efficiency, reduce delay and save fuel.

Managed in an MBT Environment

1. The ATCSCC and local TMUs build FCAs and brief the flight operators on all the planning teleconferences. The dispatchers file flight plans around the airspace for all flights captured in the FCAs.
2. During the exercise the flight operator ATC desk receives an ATCSCC advisory that the Northern Lightning airspace has been cancelled for the remainder of the day. ANSP automation removes that constraint from the assigned trajectory of any flight that referenced it.
3. Relevant dispatchers receive notifications that identify the flights whose assigned trajectories have had the reference to the constraint removed. They begin coordinating reroutes for affected flights:
    a. Submit trajectory amendments to the ANSP for flights that are "far enough away" for ground-ground negotiation
    b. Uplink proposed trajectory amendments to the flight deck (e.g., via ACARS) to request from the controller
4. DAL610, en route from SEA to DTW, is "far enough away" (currently in ZLC32). The dispatcher submits an amendment request to the ANSP automation with the trajectory change point in ZMP. ZMP TMU reviews and approves the amendment request. ZMP TMU sends the amendment to ZLC. It passes automated screening to be sent to ZLC32. The controller provides the amended clearance to DAL610.
5. DAL611, en route from MSP to BOS, is not "far enough away" (e.g., already in ZMP). The dispatcher uplinks an amendment to the flight deck (e.g., via ACARS). The flight crew evaluates the amendment and requests it from the controller. The controller evaluates and approves the amendment and provides the amended clearance to DAL611, executing the reroute in ERAM.
6. This same coordination between dispatchers and ANSP automation, dispatchers and pilots, then pilots and controllers is taking place in dozens of sectors throughout the NAS, as each flight operator tries to improve efficiency, reduce delay and save fuel.

Note that the approach to managing the constraints, and advanced automation support, reduces the need for the TCA position unless there is an issue in the process of negotiating a trajectory amendment for a given flight.

In a variation on this use case, the ZMP TMU sends the amendment to ZLC. ZLC TMU personnel and/or automation review the amendment and uplink it directly to the flight deck without controller intervention.

In a second variation, the ZMP TMU uplinks the amendment directly to the flight deck without coordination with ZLC or controller intervention.

In a third variation, the flight operator maintains an updated Trajectory Options Set (TOS) on file with the traffic management automation that includes an optimized trajectory through the FCA/SAA. When the SAA is reopened and the FCA is canceled, the traffic management automation automatically and immediately identifies the flight operator's trajectory option as its preferred trajectory and offers it to the flight operator.

Use Case Assumptions

A key assumption associated with this use case is the use of a capability that allows the flight operator to reference the constraint (FCA) being avoided by the assigned 4DT. Since the assigned 4DT avoids the constrained area, the FCA constraint will not be directly included in the 4DT in the same way that a time constraint would be. This is an important part of the constraint sharing and constraint management that are fundamental to MBT.

In addition, it is expected that in an MBT environment, military SAA is integrated into traffic management automation such that opening and closing of SAA is immediately and automatically communicated to the FAA. Similarly, effective trajectory management requires an agile communication/coordination network that has the ability to quickly respond to the opening and closing of available airspace.

Use Case Functions and Allocation

The functions identified in the use case are summarized in Table A-6. Table A-6 also provides the allocation of the function in the current environment and in the MBT environment.

Table A-6: Use Case SAA Reroute Functions and Allocation

Function	Current Allocation	MBT Allocation
Coordinate use of airspace	ATCSCC ARTCC Traffic Management Specialists	ATCSCC ARTCC Traffic Management Specialists
Publish airspace constraints	ATCSCC	ATCSCC
Apply constraints to aircraft trajectories	ATCSCC	ATCSCC
File flight plan	Dispatcher	Dispatcher
Request flight plan amendment	Pilot Dispatcher	Dispatcher Pilot
Evaluate amendment requests	Controller ARTCC Traffic Management Specialists	ARTCC/ATCSCC Traffic Management Specialists
Amend the flight plan	Controller ARTCC Traffic Management Specialist	ARTCC Traffic Management Specialist Controller
Deliver amended clearance	Controller	Controller ARTCC/TRACON Traffic Management Specialist

Notes on Proposed MBT Allocation

The following paragraphs provide reasoning behind the proposed MBT allocation of some of the functions in Table A-6. Functions discussed in previous sections are not repeated here unless the consideration of responsibility assignment was expanded through evaluation of this use case.

Publish Airspace Constraints

In the current environment, the ATCSCC and traffic management automation publish the FCAs and associated advisories. This process will be similar in the MBT environment. Each airspace constraint must be identified in a way that is machine- and human-readable so that traffic management and flight operator automation can ingest the airspace constraints and associate them with trajectory constraints.

Importantly, when the SAA is reopened, the same process is used to publish the change in airspace constraints (in this case, the removal of a constraint).

Apply Constraints to Aircraft Trajectories

In the current environment, traffic management automation uses the FCAs identifying the airspace constraint associated with the military exercise to indicate closed airspace. Any flight plan that penetrates that airspace during the active times should be rejected. This would also be true in an MBT environment, but the rejection notification would include a reference to the violated airspace constraint (i.e., the FCA).

FCAs are not always used to identify closed airspace as is done in this use case. Rather, FCAs are often used to moderate demand for a given region of airspace when demand is predicted to exceed capacity. In such cases, the traffic management automation uses the FCA along with demand predictions to apply Controlled Times of Arrival (CTAs) to aircraft predicted to use the airspace. These CTAs, in turn, are used to calculate Expect Departure Clearance Times (EDCTs) to which flight operators are expected to adhere.

In an MBT environment, the traffic management automation would apply the CTA directly to the assigned trajectories and flight operators would then choose the departure time that would best allow them to meet the CTA.

When the airspace is reopened and the FCA is canceled, the traffic management automation does not automatically act on any aircraft trajectories in the current environment, and it would not do so in the MBT environment. Rather, flight operators will be able to monitor changes in airspace constraints and may request an amendment to the assigned trajectory at any time.

Request Flight Plan Amendment

In the current environment, flight plan amendment requests for en route flights typically come from the pilot, although the dispatcher may coordinate reroutes in cases such as dynamic weather that is significantly downstream from the aircraft’s current location. In the MBT environment it is expected that there will be some distance from the Trajectory Change Point (TCP) at which the aircraft will be considered too close to the TCP for the trajectory amendment to be coordinated by the dispatcher (e.g., an aircraft already operating within the controller’s planning horizon). In such cases, the pilot will continue to request the trajectory amendment and not the dispatcher. Such requests will be downlinked to the controller.

However, for flights that are farther from the TCP, the dispatcher will be able to request the trajectory amendment directly from the traffic management automation, which is expected to be capable of evaluating most requests and agreeing to the requested change, rejecting the request, and/or negotiating with the flight operator until an amended assigned trajectory is agreed upon. In fact, it is expected that Flight Operations Center (FOC) automation will be capable of requesting an amended trajectory and even negotiating with the traffic management automation on the flight operator’s behalf.

Note that the Trajectory Options Set (TOS) associated with Collaborative Trajectory Options Program (CTOP) and flight operator and traffic management automation to manage TOS submission and evaluation are current-day examples of such capabilities. In the near- to mid-term MBT environment, it is expected that flight operators will be capable of maintaining an up to date TOS. Even when no CTOP is in place, the traffic management automation would evaluate the TOS to determine whether the current set of airspace and trajectory constraints render a different trajectory on file to be preferred by the flight operator.

Evaluate Amendment Requests

One reason that reroutes are so time-consuming and difficult in the current environment is that there are several manual steps involved in receiving and evaluating flight operator reroute requests. In a scenario like the one described in this use case, each reroute request (for en route flights) must be received by a controller via voice, manually entered into the controller automation, and evaluated by the automation and the controller. Only a controller working in the affected ARTCC can process the reroute. This concentrates the workload associated with processing requests on a few controllers, creating a bottleneck that can lead to the controllers not accepting any reroute requests at all because they do not have time to process them.

In an MBT environment, the flight operator can request the reroute at any time, allowing many of the reroute requests to be processed before the aircraft enters the affected ARTCC. The dispatcher sends these requests directly to the traffic management automation, which can evaluate the requested trajectory against known constraints. In many cases, the traffic management automation will be able to approve the requested route. Where necessary, the traffic management automation will request review by a traffic management specialist. The automation will need to have parameters indicating when to request traffic management evaluation, and which facility or facilities – e.g., which ARTCC or the ATCSCC – should do the evaluation.

Note that use of the TOS as discussed above would imply that the traffic management automation periodically evaluates the TOS for each flight – even in the absence of a CTOP – to determine if a different trajectory in the TOS is acceptable and preferred.

Amend the Assigned Trajectory

In the current environment, the flight plan amendments for scenarios like that described in this case must be entered manually into the controller or traffic management automation by a controller or traffic management specialist. In an MBT environment, it is expected that traffic management automation can engage in trajectory negotiation with flight operators and can thus amend the assigned trajectory at the conclusion of the negotiation according to parameters set by the traffic management specialist.

However, controller automation will not be expected to negotiate this kind of assigned trajectory amendment and therefore the controller would need to take a separate action to use the controller automation to evaluate and amend the assigned trajectory. Note that this is similar to the conflict avoidance maneuvers discussed above, in which the explicit action taken by the controller was to uplink a clearance to the aircraft and this action also triggered amendment of the assigned trajectory.

Traffic management specialists will have equal authority to amend the assigned trajectory to what they have today, but it is expected that in the MBT environment they will be primarily responsible for managing the process by which the traffic management automation negotiates trajectories and amends the assigned trajectories.

Dispatcher Requests Delayed Arrival for Gate Management

In this use case, a dispatcher requests that a flight crew reduce in flight speed in order to delay their arrival time for gate management. However, the aircraft encounters higher than expected headwind and therefore absorbs more delay than expected. Furthermore, the extra delay pushes the aircraft into a heavy arrival bank that is exacerbated by weather.

Use Case Steps

Present Day Procedures and Automation

1. After an on-time departure from TPA, DAL610 receives an ACARS message from dispatch instructing the pilot to reduce speed to lose 15 minutes over the course of the flight due to a gate management issue upon arrival at MSP. The speed reduction is less than 10kts and does not require coordination with ATC.
2. DAL610 encounters stronger than forecast upper level winds. 90 minutes into the flight, the pilot checks with dispatch. They've lost more than the desired 15 minutes, and so they resume normal speed.
3. MSP weather transitions from M-VFR to an IFR AAR of 52, and ZMP has extensive metering delays. ZMP passes back a 30 MIT restriction to ZAU.
4. Due to the reduced speed plus strong headwind, DAL610 has slipped from a period of low arrival demand into the busiest arrival spike of the day at MSP – the 2230 bank.
5. DAL610 gets slowed and turned to meet the 30 MIT pass-back restriction in ZAU airspace.
6. Once inside ZMP airspace DAL610 receives two turns in the hold due to a 15 minute TBFM metering delay.
7. DAL610 arrives at MSP 45 minutes late.

Managed in an MBT Environment

1. After DAL610 departs, the dispatcher is notified of a gate management issue at MSP, and submits a trajectory amendment request reflecting a reduced cruise speed (and hence a later ETA at the destination airport). The new trajectory is accepted by the traffic management automation and is sent to the controller for uplink to the aircraft.
2. While en route, the ANSP ground automation detects that the aircraft is out of conformance with its assigned trajectory, operating slower than expected.[18] The ground automation notifies the dispatcher and the controller, who in turn notifies the pilot that the flight is out of conformance with its assigned trajectory.
3. Alternatively, an onboard conformance monitoring capability detects that the aircraft is out of conformance and notifies the pilot that the aircraft is operating slower than expected. The pilot (or the aircraft automation) notifies the dispatcher.
4. There are no time constraints associated with the assigned trajectory, and so the flight operator can choose whether to request an update to the assigned trajectory that maintains the current speed or to modify the aircraft behavior in order to maintain the current destination ETA. The dispatcher remodels the flight and advises the flight crew to increase the cruise speed to try to maintain the current destination ETA.
5. Alternatively, the pilot could downlink a request for updated winds to FOC automation, which provides the uplink. The pilot loads the winds and remodels the assigned trajectory, identifying an appropriate speed to meet the desired arrival time, and

---

[18] Ground-based conformance monitoring could be done in a variety of ways, including monitoring ground speed relative to assigned trajectory speed, comparing downstream ETAs between the aircraft intent and the ground automation predicted trajectory, and monitoring vertical and lateral position relative to the assigned trajectory.

downlinks a request for that cruise speed to coordinate the amendment to the assigned trajectory.

6. The pilot implements the new cruise speed and the next downlinked EPP report shows improved conformance with the assigned trajectory.
7. MSP weather transitions from M-VFR to an IFR AAR of 52, and ZMP has extensive metering delays. The traffic management automation amends the assigned trajectory of DAL610 to include an STA that involves 10 minutes of metering delay. The traffic management automation uplinks the amended trajectory with a Required Time of Arrival (RTA) at the last merge fix before the meter fix directly to the aircraft.
8. The traffic management automation notifies the dispatcher of the changes. The dispatcher coordinates with ramp control at MSP to ensure a gate will be available for this flight at its new arrival time.
9. DAL610 complies with the RTA and arrives to MSP at 2250Z, 25 minutes later than the original ETA, with a gate available.

A variation on this use case is one in which the aircraft is not equipped to downlink the predicted trajectory, which will make it more difficult for the ground automation to detect nonconformance.

Use Case Assumptions

This use case assumes that the flight operator is required to coordinate the reduced speed and/or desire to arrive to the airport later with the ANSP. Although the aircraft in this case is not subject to any time constraints at the time the flight operator chooses to reduce speed, managing aircraft on a 4DT will require time and/or speed conformance.

In addition, this use case assumes that the ANSP ground automation and/or aircraft automation has a conformance monitoring capability that compares the aircraft/flight operator predicted trajectory with the assigned trajectory. The ground-based conformance monitoring capability would also compare the aircraft/flight operator predicted trajectory with one or more ground automation predicted trajectories.

In this case, the assigned trajectory does not have any time constraints that will be violated by the reduced ground speed. Thus, in response to the nonconformance, the flight operator can choose whether to update the assigned trajectory to meet the current aircraft performance or to modify the aircraft’s behavior to meet the assigned trajectory.

Also, time based metering is used to manage the delays associated with the reduced AAR and not MIT. Although choice of TMI is out of scope of MBT, it is expected that improved trajectory predictions associated with MBT will make time based metering more accurate and therefore more likely to be used to manage dynamic airspace constraints.

Use Case Functions and Allocation

The functions identified in the use case are summarized in Table A-7. Table A-7 also provides the allocation of the function in the current environment and in the MBT environment.

Table A-7: Trajectory Conformance Use Case Functions and Allocation

Function	Current Allocation	MBT Allocation
Plan aircraft trajectory	Dispatcher Pilot	Dispatcher Pilot
Monitor conformance with the flight plan/assigned trajectory	Pilot Controller	Pilot Controller

Function	Current Allocation	MBT Allocation
Resolve nonconformance	Controller Pilot	Pilot Dispatcher Controller
Publish airspace constraints	ARTCC/ATCSCC Traffic Management Specialist	ARTCC/ATCSCC Traffic Management Specialist
Apply constraints to aircraft	Controller	ARTCC/ATCSCC Traffic Management Specialist
Amend the assigned trajectory	N/A	ARTCC/ATCSCC Traffic Management Specialist
Deliver clearance	Controller	Controller ARTCC/ATCSCC Traffic Management Specialist

Notes on Proposed MBT Allocation

The following paragraphs provide reasoning behind the proposed MBT allocation of some of the functions in Table A-7. Functions discussed in previous sections are not repeated here unless the consideration of responsibility assignment was expanded through evaluation of this use case.

Monitor Conformance with the Assigned Trajectory

In the current environment, pilots are primarily responsible for operating the aircraft in conformance with the clearances provided by the controller, including the flight plan, and notifying the controller of the intent to deviate from this shared plan. Some operations already require aircraft to be equipped to monitor conformance with various aspects of a trajectory. For example, Required Navigation Performance (RNP) requires conformance monitoring with a lateral path, and time of arrival control (TOAC) requires monitoring conformance with an arrival time at a waypoint. In both cases, the pilot is notified when the aircraft is UNABLE. Similarly, vertical navigation (VNAV) provides the pilot information consistent with the spirit of conformance monitoring. In such cases, the pilot is responsible for either adjusting operation of the aircraft to return to conformance, or coordinating an alternative with the controller.

Controller automation also monitors the aircraft trajectory for conformance with the flight plan in order to support sector controllers in coordinating the handoff. It is not concerned with downstream ETAs. In this use case, the downstream ETAs are not constraints on the assigned trajectory; rather, they are estimates used by the various automation systems for planning purposes. In a previous focus group with pilots, the concept of onboard versus ground responsibility for conformance monitoring was explored.[19] Participants in that activity stated that they would prefer to be notified first of nonconformance, before the controller, allowing them the opportunity to correct the nonconformance and coordinate with the dispatcher as needed. They noted that downlinked aircraft intent would include the nonconforming trajectory, and so there would not be much time between the pilot notification and the controller and dispatcher notification.

This (limited) feedback from pilots is consistent with TBO concepts in which the 4DT is considered a contract between the ANSP and the flight operator, and consistent with a goal of MBT that aircraft follow the assigned trajectory without controller intervention. Thus, the pilot is

---

[19] A. Fernandes, S. Vail, J. Rebollo and J. Brown, "Oceanic Flights and Airspace: Improving Efficiency by 4-Dimensional Trajectory-Based Operations Year End Report," Mosaic ATM, Inc., Leesburg, VA, 2015.

given primary responsibility for trajectory conformance, including conformance monitoring. This also gives the pilot primary responsibility for resolving trajectory nonconformance, as discussed in the next section.

However, a key aspect of this use case is the stronger than predicted headwind. In such a case, not only does the aircraft have a low-resolution wind forecast, but that forecast is incorrect. Ground automation, on the other hand, uses surveillance data to monitor the aircraft ground speed and has higher resolution winds than the aircraft. In this case, the ground automation may more quickly detect the trajectory nonconformance, particularly as it uses trajectory predictions to monitor demand at the downstream constrained resource. Further, the controller is ultimately responsible for separation management, which requires close monitoring of trajectory conformance.

Thus, it is clear that a ground automation conformance monitoring capability is required, in addition to onboard automation, to support controllers and traffic managers in achieving MBT. However, additional research is necessary to determine whether this should be a standalone capability or if it should be incorporated into one or more other automation systems (e.g., traffic management and/or controller automation).

Resolve Trajectory Nonconformance

In the current environment, detecting and resolving trajectory nonconformance is not as important as it is expected to be in an MBT environment, particularly in the time dimension. To the extent that a controller identifies trajectory nonconformance as an issue, the controller will provide instructions to the aircraft that will return it to its flight plan route. In the process, the controller may ask the pilot to explain the situation.

Managing aircraft by trajectories requires that there is a consistent view across all participants and automation systems of the aircraft’s planned trajectory. When nonconformance is detected, the pilot will have the most information about the reason for the nonconformance in most cases. A significant delay due to a poor wind forecast such as in this use case is an exception. In such a case, the dispatcher and controller will likely have access to better information about the winds.

Since the pilot is expected to have the most information about the reason for the nonconformance, as well as the most information about what the aircraft can do to resolve the nonconformance, the pilot is allocated primary responsibility for this function in the MBT environment. However, the dispatcher in many cases has access to relevant information such as all of the published NAS data reflecting the ground system trajectory predictions, the aircraft data, and the flight operator preferences to determine how to resolve the nonconformance. Thus, the dispatcher is allocated secondary responsibility. Note that flight operators typically have procedures in place for pilot-dispatcher coordination when route amendments are needed, and it is expected that each flight operator organization will identify situations in which the pilot or the dispatcher has primary responsibility for this function. The key for MBT is that automation to support trajectory conformance monitoring, trajectory amendment, and negotiation must be able to accommodate either pilot or dispatcher participation in this function.

However, not all aircraft are supported by a dispatcher. In such cases, the pilot will need to resolve the nonconformance, possibly by explaining the situation to ATC. If the pilot is unable to resolve the nonconformance, the controller may need to intervene to ensure that the aircraft and ground automation have all of the appropriate data to ensure consistent trajectory predictions.

Use of CTOP to Manage Multiple Dynamic Airspace Constraints

In this use case, a CTOP is used to manage a large, dynamic weather event that significantly disrupts NAS operations.

Use Case Steps

The long-range CCFP forecast indicates that a large area of thunderstorms will develop in the middle of ZKC within the next 24 hours. The ATCSCC PERTI Advanced Planning Team plans a CTOP TMI to manage the east/west flow of traffic for the following day. Flight operators participate on all planning teleconferences and begin planning their TOS options.

The following morning, the ATCSCC Traffic Managers work with the field TMUs and flight operators to determine the best FCA location and start/stop times, including both impact FCAs and adjacent (monitoring) FCAs. The CTOP TMI advisory is published and discussed on subsequent planning teleconferences.

Present Day Procedures and Automation

1. Flight operators submit a TOS for each flight affected by the CTOP. They continually revise and re-submit their TOS options, including substitutions, right up until 45 minutes prior to p-time. In the current environment, all TOS options are delivered pre-departure.
2. The FCA rates and start/end times are finalized and the TMI begins. The CTOP algorithm (in TFMS) distributes EDCTs and reroutes to meet the FCA throughput rates.
3. The FOCs file their “awarded flight plans”, but they continue to revise and resubmit, and the CTOP algorithm continues to re-evaluate the TOS, until 45 minutes prior to p-time.
4. The ABC Airlines FOC files the awarded flight plan for flight ABC123 from EWR to LAX, a route around the northern side of the FCA that was given less delay than the preferred route through the FCA.
5. Up until departure, the flight crew and FOC exchange flight plan information according to company SOP
6. ATCSCC and ARTCC traffic management specialists monitor the weather impact on traffic flows and sector volumes as the thunderstorms develop and conditions change. The ATCSCC continually dials capacity levels up and down based on comparing the forecast weather with the actual thunderstorm development.
7. The increased capacity for the FCA causes the route/delay for ABC123 to be modified, causing the preferred route through the FCA to be the top ranked route in the TOS.
8. After a 12-minute ground delay to meet its EDCT, ABC123 departs on the preferred route, which traverses the FCA.
9. While flight ABC123 is en route over PIT (in ZOB) the weather cells in ZKC develop more intensely and further north than forecast. This means that the FCA rates were set too aggressively and they are dialed down. This causes dozens of unplanned, last-minute airborne reroutes. In the adjacent regions on either side of the primary FCAs, there is a cascading effect of unplanned traffic volume, and additional flights (previously not impacted by weather) need to be moved further north and south, away from sectors that have now gone “red”.
10. ABC123 requires a reroute around the FCA. An ARTCC traffic management specialist manually enters a reroute for the flight into the controller automation. The reroute is delivered to the controller workstation for the sector where the aircraft is currently operating.
11. As the CTOP event concludes, the ARTCC and ATCSCC traffic management specialists continue to monitor the weather impact on all sector monitor alert parameter (MAP) values and begin to dial demand back up to match available capacity (i.e., create an exit strategy for the CTOP), and eventually traffic is returned to normal.

12. Numerous large-scale tactical reroutes and several close-in, short-haul ground stops were required in addition to the CTOP to manage the event, which is a very challenging day in the NAS. The FOCs have cancelled dozens of flights and now work diligently to recover their operations.

Note: This is a realistic depiction of how NAS-altering weather events occur today and how they are expected to occur during early deployment of CTOP TMIs, prior to the introduction of PDRR/ABRR. The alternative version of this Use Case would be to use an overly aggressive approach where the FCA rates are set too high and the over-restrictions slow the NAS to a snail's pace. The NAS then experiences a large amount of unrecoverable delay.

Managed in an MBT Environment

1. Flight operators submit a TOS for each flight affected by the CTOP. They continually revise and re-submit their TOS options, including substitutions, until a more desirable route is no longer an option (e.g., the flight has passed the affected airspace). In the future environment, TOS options are delivered pre-departure (via PDRR) as well as while flights are airborne (via ABRR).
2. The FCA rates and start/end times are finalized and the TMI begins. The CTOP algorithm (traffic management automation) distributes CTAs at the FCA boundary and reroutes to meet the FCA throughput rates.
3. Each time a flight's CTA at the FCA boundary changes or the preferred route in its TOS changes, the traffic management automation notifies the FOC and negotiation begins to amend the assigned trajectory. Each flight operator will determine the appropriate level of automation to support this negotiation on their behalf, but it is expected that most FOCs will have automation support for evaluating the ANSP-proposed amendment and agreeing to or rejecting the amendment (or notifying a dispatcher and/or ATC coordinator that a review is required).
4. The ABC Airlines FOC agrees to an assigned trajectory for flight ABC123 from EWR to LAX involving a TOS option around the north side the FCA that has less delay than the preferred route through the FCA.
5. Up until departure, the flight crew and FOC exchange flight plan information according to company SOP.
6. ATCSCC and ARTCC traffic management specialists monitor the weather impact on traffic flows and sector volumes as the thunderstorms develop and conditions change. The ATCSCC continually dials capacity levels up and down based on comparisons between the forecast weather with the actual thunderstorm development.
7. The increased capacity for the FCA causes the route/delay for ABC123 to be modified, causing the preferred route through the FCA to be the top ranked route in the TOS. The assigned trajectory for ABC123 is modified to include the preferred route as well as the CTA at the FCA boundary.
8. ABC Airlines determines that the best way to meet the CTA at the FCA boundary is to absorb 12-minutes of delay on the ground. After this 12-minute delay, ABC123 departs on the preferred route, which traverses the FCA.
9. While flight ABC123 is en route over PIT (in ZOB) the weather cells in ZKC develop more intensely and further north than forecast. This means that the FCA rates were set too aggressively and they are dialed down. This causes dozens of unplanned, last-minute airborne reroutes. In the adjacent regions on either side of the primary FCAs, there is a cascading effect of unplanned traffic volume, and additional flights (previously

not impacted by weather) need to be moved further north and south, away from sectors that have now gone “red”.

10. ABC123 requires a reroute around the FCA. The traffic management automation evaluates its TOS (which the ABC FOC has kept up to date with its preferences for airborne reroutes and delay) and identifies a route that satisfies the updated NAS constraints. The traffic management automation notifies the FOC of the reroute and also distributes the amendment to the controller workstation where the aircraft is currently located. The controller delivers the clearance to the aircraft, the flight crew evaluates and accepts the route, and the assigned trajectory is amended.
11. As the CTOP event concludes, the ARTCC and ATCSCC traffic management specialists continue to monitor the weather impact on all sector monitor alert parameter (MAP) values and begin to dial demand back up to match available capacity (i.e., create an exit strategy for the CTOP), and eventually traffic is returned to normal.
12. To the extent that amending the assigned trajectories for flights that are airborne and pre-departure does not sufficiently manage demand, traffic management retains the flexibility to make use of ground stops and other tactical traffic management initiatives. However, the ability to accurately predict traffic demand and efficiently negotiate assigned trajectory amendments for airborne flights reduces the need to employ these measures. Note that there still must be a recovery process for flight operators, but it is not expected to be as severe in an MBT environment.

In one variation to this use case, the FOC evaluates the amendment to the assigned trajectory in Step 10 and decides to negotiate an alternative. ANSP trajectory negotiation automation makes this possible; in the current environment the manual workload associated with such requests would make it infeasible in a scenario like this.

Use Case Assumptions

This use case assumes that PDRR and ABRR are available in the future environment. Note that these concepts are separate from the MBT concept but are part of the MBT operational environment. MBT leverages them to support efficient amendment of assigned trajectories.

Also note that the use of CTOP as a TMI and the selection of rates, etc., is outside the scope of MBT. MBT provides the mechanism to apply the constraints associated with the TMI to the assigned trajectories as conditions change.

The use case also assumes that trajectory constraints associated with a TMI can be applied directly to the assigned trajectory. In the use case, the CTOP TMI assigns CTAs at the FCA and then translates them into EDCTs to ensure that the aircraft incur as much of the delay as possible on the ground. MBT envisions assigning the CTA at the constraint point directly to the assigned trajectory, and allowing flight operators to choose the appropriate amount of ground delay to allow them to fly a closer to optimal trajectory to the constraint point. Note that mechanisms must be put in place to prevent flight operators gaming the system by assuming they can take all necessary delay in the air.

Use Case Functions and Allocation

The functions identified in the use case are summarized in Table A-8. Table A-8 also provides the allocation of the function in the current environment and in the MBT environment.

Table A-8: CTOP TMI Use Case Functions and Allocation

Function	Current Allocation	MBT Allocation
Manage CTOP TMI	ATCSCC/ARTCC Traffic Management Specialist	ATCSCC/ARTCC Traffic Management Specialists

Function	Current Allocation	MBT Allocation
Publish airspace constraints	ATCSCC Traffic Management Specialist	ATCSCC Traffic Management Specialist
Apply constraints to aircraft trajectories	ATCSCC Traffic Management Specialist	ATCSCC Traffic Management Specialist
Submit TOS	Dispatcher	Dispatcher
Maintain and update TOS	Dispatcher Pilot	Dispatcher Pilot
File "awarded flight plan"	Dispatcher	N/A
Negotiate assigned trajectory amendments	ATCSCC/ARTCC Traffic Management Specialist (Pre-departure) Dispatcher/ATC Coordinator (Pre-departure)	ATCSCC/ARTCC Traffic Management Specialist Dispatcher/ATC Coordinator
Plan reroute	ARTCC Traffic Management Specialist	ARTCC Traffic Management Specialist Dispatcher

Notes on Proposed MBT Allocations

Note that there are few differences in the allocation of roles and responsibilities between the current environment and the MBT environment in this use case. Improvements in the MBT environment are largely driven by enhanced automation capabilities, including some that are outside the scope of the MBT concept.

Maintain and Update TOS

In the current (or near-future) environment, flight operators have automation to support dispatchers in maintaining and resubmitting the TOS as conditions and preferences change. This automation is primarily responsible for this function. The dispatcher (and/or ATC coordinator) is the responsible participant.

While the pilot does not submit TOS options, the pilot does coordinate preferences and options with the dispatcher. The pilot should be in the decision-making loop and therefore is included as a participant with responsibility for this function.

The allocation of responsibility ostensibly does not change in the MBT environment. However, the expanded access to information and automation capabilities on the flight deck may increase the role of the pilot. It is conceivable that advanced aircraft automation can support TOS maintenance.

File Awarded Flight Plan

In an MBT environment, once the flight operator submits the TOS, the top-ranked trajectory can automatically be set as the assigned trajectory for a flight. This eliminates the need for the dispatcher to take the extra step of filing a flight plan based on the TOS. Flight plan filing and negotiation can be managed as continual evaluation and management of the TOS.

Negotiate Assigned Trajectory Amendments

The allocation of roles and responsibilities is not expected to change significantly between the current environment and the MBT environment, but the negotiation will be handled differently. In the current environment, the CTOP algorithm (traffic management automation) selects the preferred TOS option and offers it to the FOC, which evaluates and then re-files the newly awarded trajectory. In the future environment, more of the negotiation is expected to be handled by automation, and it is not expected that the dispatcher/ATC coordinator will need to re-file the awarded TOS option.

One cognitive walkthrough participant suggested considering the use of a TOS at all times, even in the absence of a CTOP program. Negotiation via the TOS would work the same way whether there was an active CTOP or not. This implies that the allocation of responsibility for trajectory negotiation would be consistent with that proposed for this use case in many other use cases as well.

Plan Reroute

In the current environment, airborne reroutes require a traffic management specialist to manually enter the reroute. In addition to other efforts to increase automation support for managing airborne reroutes, this use case takes advantage of the TOS and traffic management automation that is already designed to manage changes to the preferred trajectory option after departure. A key part of this is FOC automation that keeps the TOS up to date throughout the life of the flight, adding responsibility to the dispatcher for ensuring that the TOS is appropriately maintained.

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. REPORT DATE *(DD-MM-YYYY)*
01/10/2017

2. REPORT TYPE
Contractor Report

3. DATES COVERED *(From - To)*

4. TITLE AND SUBTITLE
Management by Trajectory Trade Study of Roles and Responsibilities between Participants and Automation Report

5a. CONTRACT NUMBER
NNL16AA17C

5b. GRANT NUMBER

5c. PROGRAM ELEMENT NUMBER

5d. PROJECT NUMBER

5e. TASK NUMBER

5f. WORK UNIT NUMBER
999182.02.65.07.01

6. AUTHOR(S)
Fernandes, Alicia B.; Kaler, Curt; Leiden, Kenneth; Atkins, Steve;
Bell, Alan; Kilbourne, Todd; Evans, Mark

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
NASA Langley Research Center
Hampton, Virginia 23681-2199

8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
National Aeronautics and Space Administration
Washington, DC 20546-0001

10. SPONSOR/MONITOR'S ACRONYM(S)
NASA

11. SPONSOR/MONITOR'S REPORT NUMBER(S)
NASA-CR-2017-219676

12. DISTRIBUTION/AVAILABILITY STATEMENT
Unclassified
Subject Category 03
Availability: NASA STI Program (757) 864-9658

13. SUPPLEMENTARY NOTES

14. ABSTRACT

This report describes a trade study of roles and responsibilities associated with the Management by Trajectory (MBT) concept. The MBT concept describes roles, responsibilities, and information and automation requirements for providing air traffic controllers and managers the ability to quickly generate, evaluate and implement changes to an aircraft’s trajectory. In addition, the MBT concept describes mechanisms for imposing constraints on flight operator preferred trajectories only to the extent necessary to maintain safe and efficient traffic flows, and the concept provides a method for the exchange of trajectory information between ground automation systems and the aircraft that allows for trajectory synchronization and trajectory negotiation.

15. SUBJECT TERMS
Management by Trajectory; Roles and Responsibilities; Trajectory Based Operations (TBO)

16. SECURITY CLASSIFICATION OF:			**17. LIMITATION OF ABSTRACT**	**18. NUMBER OF PAGES**	**19a. NAME OF RESPONSIBLE PERSON**
a. REPORT	**b. ABSTRACT**	**c. THIS PAGE**			STI Help Desk(email help@sti.nasa.gov
					19b. TELEPHONE NUMBER *(Include area code)*
U	U	U	UU	72	(757) 864-9658