NextGEN

Vision for Trajectory Based Operations

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Executive Summary

The Federal Aviation Administration's (FAA's) Next Generation Air Transportation System (NextGen) program is transitioning the National Airspace System (NAS) to Trajectory Based Operations (TBO) to make flight operations more efficient and predictable, while maintaining operational flexibility. TBO is an Air Traffic Management (ATM) method for strategically planning, managing, and optimizing flights throughout the operation by using time-based management, information exchange between air and ground systems, and the aircraft's ability to fly precise paths in time and space.

TBO leverages significant NextGen investments already made in Performance-Based Navigation (PBN), surveillance, communications, and automation systems for decision support, flight data management, and information sharing. The vision for TBO in 2025 will be accomplished through improved air traffic management strategic planning initiatives along with the predominant use of time-based management using precise and repeatable paths defined by PBN procedures and routings.

Together, time-based management and PBN comprise a four-dimensional (4D) trajectory (latitude, longitude, altitude, and time) that airspace users negotiate with the Air Navigation Service Providers to identify a solution that best accommodates both their needs. The trajectory includes a path between origin and destination with predicted crossing time estimates at key points along the path which are much more accurate than the estimates used today for strategic planning. The time parameter provides a common planning reference across all phases of flight, including pre-departure. The trajectory facilitates integration across Air Traffic Control (ATC) domains, enables the FAA to plan accounting for user objectives, and allows for more collaborative and flight-specific solutions in response to NAS constraints. This represents a great improvement over today's strategic planning initiatives and tactical flow management techniques and addresses many of today's operational shortfalls.

TBO in 2025 depends upon use of improved data sets and greater collaboration between the FAA and its customers to enable better traffic planning and scheduling decisions. Improved data sets reflect access to new data elements, more accurate and timely data, and data integrated into automation tools where appropriate. User provided inputs are considered in the generation of the ATC schedule given availability of NAS resources and constraints. TBO in 2025 also depends on providing controllers, traffic managers, and airspace users with the necessary decision support tools to provide efficient flows that meet that schedule and the ability to adapt to changing operational conditions. It also requires that aircraft be appropriately equipped with navigation and communication capabilities needed to achieve the full benefits of TBO. Altogether, this will maximize use of available system capacity, reduce fuel burn, and result in more reliable travel times.

Because levels of demand and traffic complexity vary across the NAS, the application of TBO will be scaled appropriately to satisfy operational conditions. In other words, TBO will be available NAS-wide and higher TBO performance levels, which can include higher level of PBN precision and greater use of time-based management decision support tools, will be applied where it is needed. The determination for how it is applied will be driven by the operational needs and goals targeted.

Operational transition to the 2025 TBO vision will be evolutionary, building upon PBN infrastructure and time-based management enabling technologies. The magnitude of benefits will gradually increase over time with experience and with national implementation. Successful implementation requires more than just sound technology and procedures. It will only be achieved through shared FAA and operator collaboration, actions,

and investments. While many investments and changes have already been accomplished, many are still forthcoming. Achieving the TBO vision requires a clear understanding and commitment by all stakeholders (from executives in the FAA and industry, to controllers, pilots, traffic managers, and flight operation centers), and a system-of-systems approach to change management to include the technology, people and culture, procedures, policies, and operator and workforce training. Executing on the TBO vision will deliver the benefits envisioned by NextGen and improve the flying experience for millions.

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Introduction

In June of 2016, the FAA updated the National Airspace System (NAS) Modernization plans in the *Future of the NAS*[1] report, which describes Trajectory Based Operations (TBO) as a major operational concept for providing improved services to users. TBO has been envisioned as an important element of NAS modernization since the original Next Generation Air Transportation System (NextGen) Concept of Operations was written. Additionally, building upon previous NextGen Navigation and Performance-Based Navigation (PBN) accomplishments, the FAA in collaboration with industry published in September 2016 its *PBN NAS Navigation Strategy*[2] which describes a compelling view of the future with PBN as the basis for daily operations across the NAS. The strategy emphasizes priorities on increasing PBN procedure usage, efficiently providing the right navigation services across the NAS, and enabling transition to time-based management operations for full benefits realization. It represents an agreed-to community vision and ensuing roadmap for achieving a PBN NAS. These two documents highlight the on-going path toward TBO that has already been initiated, and are central to the TBO vision described by this paper.

This TBO vision paper provides a lower level concept description aimed to improve the understanding of TBO across stakeholder groups and to provide a framework with which the FAA and the user community can work together to prioritize specific implementation plans for TBO.

The FAA has made tremendous progress in modernizing the NAS. NextGen accomplishments[3] have laid a firm foundation for the future with communications, navigation, surveillance, and automation infrastructure modernization and new information and data sharing mechanisms. For example, installation of the new automation platform in our en route facilities has been completed, and steady progress is being made in upgrading the terminal automation systems. Enhancements have been made in strategic planning through new tools that facilitate collaboration and system-wide information sharing. Flight operations have been made more efficient through the introduction of time-based metering controller spacing tools. Departure delays have decreased for equipped aircraft through the deployment of tower Data Communications services. Airspace redesign and revised arrival/departure procedures are improving flight efficiency and capacity. The establishment of a network of thousands of precisely defined PBN procedures and routes is making the flow of air traffic more efficient.

While great progress has been made in deploying the foundational infrastructure of the future NAS, there is still much work to do to achieve the full realization of NextGen operational benefits. Additional ground-based tools and aircraft software and avionics capabilities are needed by controllers, traffic managers, dispatchers, and pilots to make the NAS more predictable and efficient across tower, terminal, and en route domains. This vision of predictable operations continues to allow for operators to optimize their flight paths given their preferred trade-offs among fuel use and travel time between origin and destination pairs. TBO predictability benefits come from improved confidence that operators will be able to largely fly the flight path they desire within the timing parameters they desire.

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[1] The Future of the NAS, Federal Aviation Administration, June 2016, http://www.faa.gov/nextgen/media/futureOfTheNAS.pdf

[2] PBN NAS Navigation Strategy, Federal Aviation Administration, September 2016, https://www.faa.gov/nextgen/media/PBN_NAS_NAV.pdf

[3] See the Introduction (pages 6-9) to the Future of the NAS for a more detailed description of NextGen accomplishments.

As collaboration between the FAA and Industry is a major part of TBO, the implementation plan that is derived to meet the TBO vision must be a joint plan that documents and prioritizes the TBO capabilities needed to deliver more efficient and predictable NAS operations. The activities we pursue together to achieve TBO must encompass the full range of operational improvements, from applying change management principles in the way our pilots, controllers, dispatchers, and traffic managers are trained to completing the investments that the FAA and industry must make in order to give our workforces the tools they need to achieve the full set of operational benefits.

Description of Trajectory Based Operations and Vision

TBO is an Air Traffic Management (ATM) method for strategically planning, managing, and optimizing flights throughout the operation by using time-based management, information exchange between air and ground systems, and the aircraft's ability to fly precise paths in time and space. Key attributes of TBO are that 1) all Instrument Flight Rule (IFR) flights participate and are aware of the plan 2) aircraft and ground systems are aware of and operating to the same plan, and 3) that plan is expressed and shared with all to result in an 'agreed trajectory,' which is used as a reference for the flight. Specifically, the TBO concept allows for airspace users to negotiate trajectories with the Air Navigation Service Providers to identify a solution that best accommodates both their needs; the negotiated trajectory is known as the "agreed trajectory". The agreed trajectory includes a path between origin and destination with predicted crossing time estimates at key points along that path, which are much more accurate than the estimates used today for strategic planning.

The time parameter of the agreed trajectory provides a common planning reference across all phases of flight, including pre-departure. Time and any changes to it or the flight path can be propagated through the expected flight's trajectory and evaluated for impact by other automation systems to ensure a coordinated solution. In other words, predicted crossing times at different points along the flight's trajectory can be evaluated by automation systems to assess the impact of that flight upon system resources and constraints. The flight's trajectory can be modified to meet any constraints and the updated trajectory can be coordinated across automation systems (see Figure 1). Predicted crossing times at key points along the flight's trajectory become target values for controllers to meet once the flight crosses a designated horizon. The horizon is adapted in automation given a specified travel time/distance to the crossing point. In this way, the agreed trajectory facilitates integration across Air Traffic Control (ATC) domains and enables the FAA to develop a plan that accounts for user objectives such as a preferred reroute or a high value flight. This allows for more collaborative and flight-specific solutions in response to NAS constraints such as a major weather event or high airport or airspace traffic demand where aircraft need to be sequenced into congested flows or major flows converge. This represents a great improvement over today where the frequent use of static, distance-based spacing (e.g., miles-in-trail restrictions) results in individual aircraft assigned crossing times that are not known to or correlated by automation throughout the trajectory. These techniques can result in lost capacity and throughput given the variability in demand and capacity and provide limited opportunities for user collaboration.

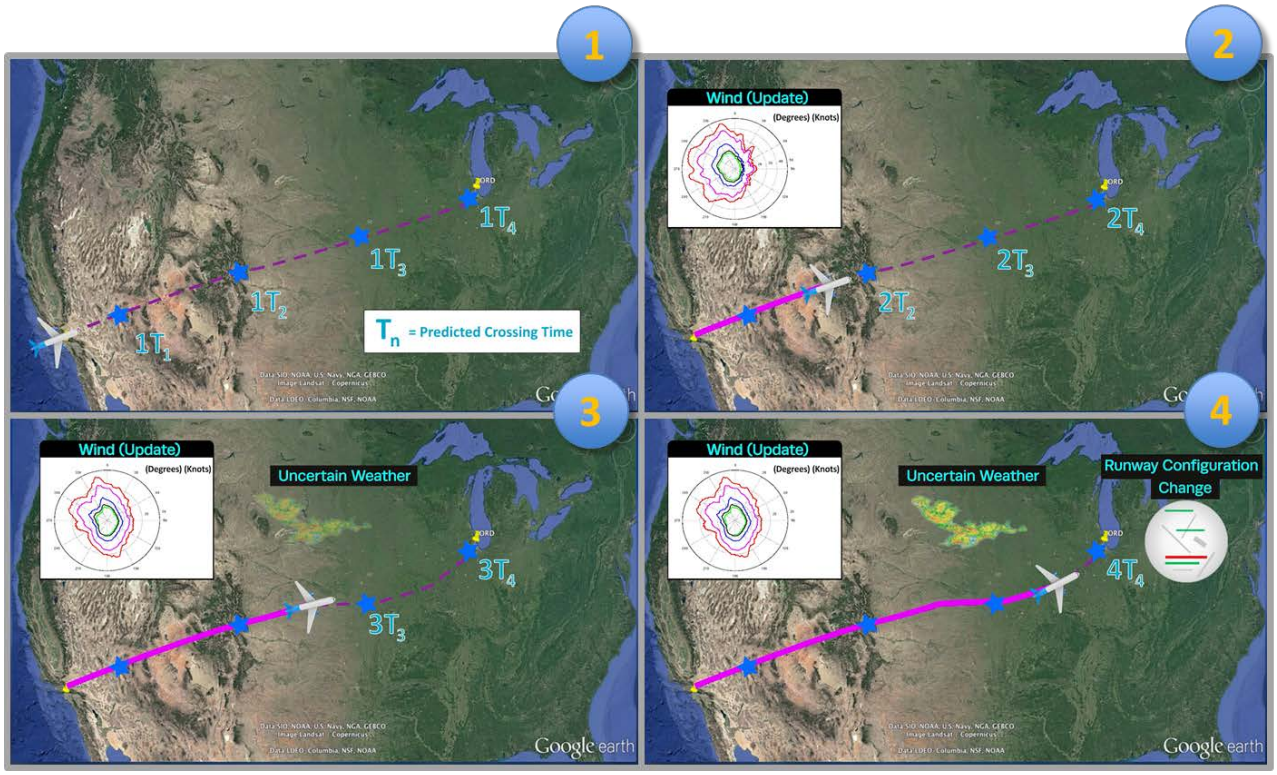

Figure 1. *The trajectory reflects a plan with predicted crossing times at key points along the flight. Future crossing times and/or the flight path can be updated to respond to operating environment uncertainties that may manifest in the gate to gate operation, such as winds aloft, convective weather, or a runway configuration change at the destination airport. Such updates can be propagated throughout the expected flight's trajectory to evaluate the impact upon NAS resources.*

With TBO, controllers continue to provide separation[4] assurance based on where a flight currently is and improved predictions of where and when the flight is expected to be at key points in the future. The flight's trajectory will be synchronized by automation, using improved and consistent information, to result in better aircraft sequencing and fewer tactical maneuvers at these key points. All flight trajectories competing for the same point in space at the same time will be sequenced to ensure appropriate spacing at those points. Any tactical decisions made after that synchronization will aim to respect the strategic plan.

Because levels of demand and traffic complexity vary across the NAS, the application of TBO will be scaled appropriately to satisfy operational conditions. In other words, TBO will be available NAS-wide and higher performance levels of TBO will be applied where it is needed. There is a basic level of participation required everywhere and at some places (e.g., airports, airspace, regions) a higher degree of TBO performance may be required. The determination for how it is applied will be driven by the operational goals targeted. While this is expected to result in differences for how air traffic management operations are impacted, it allows for versatility in serving a wide range of markets reflected by a diverse set of NAS users. Although all capabilities and procedures will not be used in all places, the use of the capabilities where applied will be consistent.

[4] Use of the term separation here refers to approved separation minima and appropriate procedures (e.g., divergence). Use of time-based longitudinal separation on final approach (i.e., time-based separation) is also compatible with TBO.

As part of NextGen, the vision for TBO is to make flight operations in the NAS more efficient and predictable, yet operationally flexible. This doesn't mean all flights are traveling the same flight paths between origin-destination pairs; rather, the vision continues to allow for operators to optimize their flight paths given their preferred trade-offs among fuel use and travel time. TBO preserves flexibility while simultaneously improving operational predictability. This results in improved confidence that operators are able to fly the flight paths and times they desire.

By 2025, the goal is to manage flights into/out of designated major airports and appropriate airspace feeding those major airports using NextGen's initial set of TBO enabling capabilities. The year 2025 is targeted for this goal because it accounts for the implementation timelines for required, key major program investments and the post-implementation timeline expected to achieve adoption and regular use in the field. Operations targeted by 2025, which will be described next, depend upon operator equipage of previously certified flight deck capabilities/avionics to enable higher levels of benefit both system-wide and for equipped flights, and operator investment in capabilities that allow for the increased sharing of information between users and the FAA (both air-to-ground and ground-to ground). In other words, the vision described depends on operators equipping, but not with any capabilities or performance criteria that has not yet been defined. Implementation of capabilities that meet improved standards yet to be defined will contribute to more easily or more effectively achieving the 2025 TBO vision, but are not considered dependencies.

The vision for TBO in 2025 will be accomplished through improved strategic planning initiatives and with the predominant use of time-based management. Time-based management means the planning and scheduling of operations based on expected airport departure and arrival times and other user-provided inputs. A four-dimensional trajectory of a flight is developed using the precise and repeatable paths defined by PBN procedures and routings with time-based management. TBO leverages available PBN routes/procedures and time-based management automation and decision support tools to make flight operations more efficient and ATM operations more predictable. Where airspace and airports are congested, time-based management (both pre-departure and airborne) will be applied to published PBN routes and procedures and flights will navigate using their on-board PBN capabilities. In less congested situations, airborne flights will have the option to request a modified flight path based on a series of selected waypoints/fixes allowing for even greater point-to-point navigation. Time-based management will be applied (as needed) to those flight paths to formulate the four-dimensional trajectory. In either situation, effective use of time-based management relies upon improved strategic planning and that is only enabled through improved FAA and operator data sharing and collaboration.

TBO allows us to utilize capacity more effectively than we can with standalone tools and procedures. It's a better way to manage traffic demand with increased flight efficiency. For example, instead of waiting in long physical departure queues to initiate their place in the queue, aircraft can reserve their place while still at the gate (while the flight is loading) via a virtual queue[5] and be assured that we are already planning for their integration via an arrival slot at an airspace fix and/or destination airport. Instead of using extended down-winds (beyond a standard base leg turn) or terminal holding, flights are appropriately spaced for the merge at more fuel-efficient altitudes so that only minor speed adjustments within terminal airspace are needed. Traffic Management Initiatives such as Ground Delay Programs (GDPs) can also be better planned, as demand estimates in traffic flow management automation become more accurate with the addition of updated

[5] While the wait starts earlier (at the gate) it may conclude elsewhere on the surface, as needed, in order to free up gates for incoming flights.

departure information from the users. In this way, individual flights will burn less fuel and cost less to operate, and the overall system will be more predictable.

Time-based management is based on expected airport departure and arrival times, while considering uncertainty. Specifically, the vision for 2025 targets reducing unnecessary NAS uncertainty through the provision of new and higher quality data and inputs, keeping flights' trajectories aligned with the strategic plan, and updating it when it changes. That said, uncertainty in the NAS will continue to exist, but it will be better bounded as compared with today's operations. Predominant use of time-based management will enable more efficient flows that maximize use of available capacity, reduce fuel burn, enable more efficient use of airport and operator resources, and generate more reliable travel times. These improvements will be accomplished through the use of existing and new time-based controller decision support tools and improved data on demand and capacity which is shared between ATC and user automation systems such as those used by flight operation centers. This sharing enables greater collaboration between the FAA and its customers to enable better strategic traffic planning and scheduling decisions. For some origin and destination pairs that are highly coupled, integrated time-based management will be applied by correlating the timing of the flight's trajectory in a gate-to-gate manner.

Achieving the TBO 2025 vision fully and effectively depends upon suitable levels[6] of aircraft PBN equipage and operator data provision and collaboration. Availability of other flight deck capabilities, such as emerging avionics and displays and electronic data communication exchange, both ground-to-ground and air-to-ground, will be leveraged to achieve even more efficient flow spacing and enable easier and more effective response to ATC initiatives such as rerouting.

Beyond 2025, the TBO vision emphasis is on the use of better and more sophisticated capabilities to reduce and improve management of remaining NAS uncertainty. This includes leveraging new and advanced flight-deck capabilities, such as baseline 2 data communications and advanced interval management enabling technologies. Also included in those new and advanced flight deck capabilities is greater use of air-to-ground trajectory and data exchange to enable <u>real-time</u> operator and ATC individual flight trajectory negotiation and <u>shared</u> decision-making. The four-dimensional trajectory post-2025 will incorporate a number of state and intent variables, and depending on the functional need, the trajectory may be exchanged between the various air-to-ground and ground-to-ground automation systems. Increased exchange of the trajectory between FAA ATM systems and with flight operations center automation systems and aircraft will allow for more coordinated and collaborative decisions, enabling development of more robust trajectory solutions. Advanced ground automation system needs to meet the post-2025 TBO vision include use of improved weather forecasting capabilities and the ability to incorporate information from the flight deck into trajectory predictions. Combined, these changes will result in more predictable and efficient flight paths and travel times between origins and destinations.

[6] As specified by the 2016 *PBN NAS Navigation Strategy*.

Key TBO Objectives for 2025

- **More efficient use of airspace and airport capacity** through more precise estimates of an aircraft's four-dimensional trajectory that enables improved strategic planning and more effective time-based management to maximize aircraft throughput.

- **Improve operational predictability and day-to-day schedule integrity** through more efficient gate-to-gate strategic planning and scheduling, supported by updated user status information of an aircraft's four-dimensional trajectory and use of time-based management techniques.

- **Increase operational flexibility** for the user through increased collaboration regarding user preferences for which and how flights are impacted to meet system constraints. This enables users to best meet their business objectives.

- **Improve flight efficiency** by enabling more efficient flows into and out of major metropolitan areas through integrated operations. This includes the continuous use of optimal PBN procedures using time-based management techniques to optimize descents and ascents by better timing the integration of departures into overhead streams.

Description of Today's Operation and Shortfalls

The following describes challenges with today's operations that culminate in shortfalls such as inefficient traffic management techniques for aircraft scheduling and spacing, and a general lack of predictability as to when and where flow adjustments will be made and which flights will be impacted.

ATC and operators are not using the available PBN procedures as often as was expected

The FAA has established PBN arrival and departure procedures across the NAS which continue to deliver increasing levels of flight efficiency. As an example, flight efficiency benefits have been realized by minimizing the number and duration of level-offs below top of descent for arrival procedures at busy terminal areas. During busy traffic periods, however, current controller tools are not always effective in sequencing the aircraft sufficiently at higher altitudes to enable the aircraft to remain on an optimized profile descent throughout the arrival. This causes the controller to revert to tactical maneuvering and altitude control. Thus, in busy locations, ATC and operators are not using the available PBN procedures as often as was expected. When traffic density is low, air traffic controllers may provide aircraft short-cuts to the airport that save time but degrade operational predictability and can also have adverse effects on aircraft arriving at the airport before a gate is available or the operator is ready to process the flight. Doing so may also result in foregoing fuel-saving benefits from an optimal profile descent.

Current tools and lack of up-to-date flight information precludes optimal flight planning and operations

Time-based management and controller decision support tools are used to varying degrees where they have been deployed. However, the integration of time-based management across all phases of flight from gate-to-gate through congested airspace is needed before operations will move away from being planned and managed by less efficient methods such as applying miles-in-trail restrictions and static capacity constraints (e.g., pre-determined arrival rates). Use of these methods in formulating the strategic plan do not always account well for actual traffic demand and can introduce system-wide inefficiencies and uncertainty. The lack of timely updates

to flight schedules and the inability to integrate more timely flight information in ATM systems decreases the effectiveness of strategic decision support tools to manage operational uncertainties. The lack of timely and integrated schedule information also makes it difficult for traffic managers to formulate and execute more optimal and achievable plans that account for user preferences, balance demand with capacity, and inform ATC sequencing, merging, and spacing to carry out those plans.

Use of static distance-based spacing goals is an inefficient traffic management technique

Traffic flows that are managed using static distance-based spacing goals do not efficiently account for flights arriving to the same location from different directions. Because aircraft on converging flows are not integrated (i.e., spaced as if on a single flow to the merge point), this can result in "ties" which require tactical vectors from en route and terminal controllers to sequence and space traffic on descent and onto final. While issuing vectors to final approach can achieve desired in-trail spacing, it often results in flight paths that exceed the standard base leg turn and in busy traffic periods those flight paths may extend so far that it borders final approach airspace boundaries. Operating this way is workload-intensive and especially inefficient and costly at low altitudes. In addition, distance-based spacing goals can over-constrain the flow and generate spacing gaps where they are not needed, making it difficult to efficiently and fully use available airspace and airport capacity. In the terminal, sometimes the downwind length is adjusted by controllers to fill those spacing gaps. This technique, however, results in reduced operational predictability and longer flight paths for some flights to the runway. In some terminals, those spacing gaps are not easily recovered due to environmental constraints and can result in adverse impacts to throughput. When used, distance-based spacing goals are static, typically set in 5-mile increments in addition to separation minima. This often results in larger spacing margins as compared with time-based scheduling which uses automation to set flight-specific spacing intervals for each aircraft based on actual demand and capacity.

Lack of integrated time-based management tools across domains limits their effectiveness

While some traffic flows in the NAS are managed today using time, time-based management tools are not available in all domains. This can result in a mismatch of traffic spacing with capacity, preventing both the efficient use of resources, such as airspace or runways, and efficient flight operations. This limited application can result in significant flight maneuvers, such as holding and delay vectoring, issued by en route controllers to achieve the adjustments needed to meet the schedule. Furthermore, effective use of time-based management may need to span across en route facilities. The lack of automation system coordination regarding schedule generation and controller/pilot actions applied to meet the schedule across en route facilities can limit the effective use of time-based management. Finally, use of time-based management today at many places is not presented at a level of detail for it to be fully effective. Often, the crossing time assignment provided by the system to controllers is rounded to the nearest minute, introducing additional spacing margin and timing error.

As flights transition from en route to terminal airspace, the scheduling information that controllers have available in the en route environment is not shared with terminal controllers. Terminal controllers are left to apply a local, tactical approach guided by their own interpretation of traffic merging, sequencing, and spacing needs across terminal flows. Terminal controllers also lack effective decision support capabilities to assist them with those tasks, so they generally rely on low altitude vectoring in an arrival traffic push.

Limited data sharing between FAA automation systems and the user's ground and aircraft automation systems leads to inefficiencies and can make operations very manually intensive and reactive

Another factor which limits today's operations is the limited degree of information sharing between ground automation systems and the lack of data sharing technology among the aircraft's flight management system and flight operations centers and ATM automation systems in domestic operations. This limited data sharing leads to inefficiencies and can make operations very manually intensive and reactive. For example, today there is limited information shared with facilities (beyond the tower) about surface constraints, such as taxiway and ramp congestion and departure queue build-up. These constraints have real impact upon scheduling operations, but are not adequately incorporated into traffic flow planning and decision-making. As a second example, the plans and reroutes generated by traffic flow management automation in the event of weather or some other capacity constraint is not automatically integrated with time-based scheduling automation. Moreover, there is limited operator involvement in how those decisions are made and applied to flights.

Summary of Today's Operational Shortfalls

Table 1 summarizes today's operational shortfalls by domain that TBO is targeted to mitigate.

Surface Shortfalls	En Route Shortfalls	Terminal Shortfalls
• Excessive taxi delays when Approval Request for airspace fix or arrival airport are initiated as aircraft enter the movement area (i.e., currently no link to the virtual departure queue) • Inefficient departure queues – wrong aircraft sequence in queue to provide maximum throughput and/or lack of effective runway load balancing • Inequitable delays for departing flights within a shorter horizon to destination versus already airborne aircraft • Lack of integration across automation systems leads to uncoupled use of traffic management initiatives (e.g., double delay)	• Local efficiencies can lead to downstream inefficiencies (e.g., need to vector for delay spacing or separation due to early arrival at resource) • Additional level-offs (beyond that defined by PBN procedure design) on descent and ascent to accomplish appropriate spacing for crossing or converging flows lead to flight inefficiencies • Tactical re-routing to alternative arrival fix late in the flight leading to excessive distance and time versus early strategic arrival fix rebalancing	• Additional level-offs (beyond that defined by PBN procedure design) on descent and ascent due to inability to remain on PBN procedures • Lack of spacing integration across converging arrival corner-posts results in vectoring arrivals in terminal airspace • Extended down-wind segments (beyond a standard base leg turn) due to lack of efficient spacing and sequencing to merge aircraft onto final approach
Strategic Planning Shortfalls		
• Inaccurate or incomplete information about operator and controller intent introduces unnecessary uncertainty into strategic traffic planning and scheduling initiatives • Limited ability to easily identify flights subject to constraints and flight-specific trajectory options to mitigate those constraints • Incomplete information and limited ability to share and collaborate with operators on proposed strategic plans prior to implementation		

• Limited ability to proactively identify emerging constraints as operational conditions degrade and limited ability to conduct what-if planning to evaluate strategic plans prior to implementation results in rigid and fragile operations (e.g., late and excessive responses made using ineffective trial-and-error approach) • Failure to quickly recover use of airspace when constraints dissipate

Table 1: Summary of Shortfalls Mitigated by TBO

Guiding Principles and Assumptions

The following reflects major guiding principles and assumptions for achieving the 2025 TBO vision.

a. TBO is practiced NAS-wide. Higher TBO performance levels, which can include higher level of PBN precision and greater use of time-based management decision support tools, will be applied when and where it is needed. All IFR operations in controlled airspace participate in TBO at all times at some level to assist with the management and control of the overall NAS. At the most basic level, participation is through a planned departure schedule and flight plan just as they do today. Beyond that, users may participate more fully by providing data and flight preferences. If their origin, destination, and route of flight are included in a TBO schedule, additional crossing times and altitudes at select points along the trajectory may need to be established. Mixed equipage is expected regarding flight deck avionics, navigation, communication, and surveillance performance, but ground automation will support ATC in a mixed equipage environment. Ground automation will use the data provided to generate appropriate crossing time and altitude estimates, as needed, along the planned route for managing a single trajectory in the context of several.

b. The determination for how TBO is achieved and where higher performance levels of TBO are applied will be driven by the operational goals targeted and depend upon airspace complexity, demand in a region of airspace or at a given location, and aircraft equipage. More specifically, locations where TBO is applied depends on origin-destination pair interactions and the airspace transited between those pairs, collaboration with the users, and the associated business case.

c. In high density airspace where time-based management techniques are needed, the tools will be used at all times even during periods when traffic demand does not exceed capacity and no controller or pilot action is needed to meet the plan's objectives. This is essential to sustain operational predictability and assure the regional/national strategic plan is maintained. Individual efficiencies can be evaluated and changes approved as part of the overall strategic plan in lieu of ad hoc actions taken within an individual sector.

d. Controllers remain responsible for separation assurance. TBO will improve strategic and near-tactical planning. While this should decrease the number of conflicts that controllers need to tactically resolve because expected flight trajectory interactions are better understood, planned trajectories will not necessarily always be conflict-free. That level of precision could over-constrain operations. Controllers will tactically resolve any conflicts and the planned trajectory will be updated, if needed, to account for the impact of the conflict resolution.

e. TBO concept solutions will be introduced regionally and incrementally across the NAS as part of an integrated plan driven by a NAS-wide implementation strategy. This is in lieu of the current approach of using multiple, independent implementation waterfalls for TBO-enabling capabilities. The plan will be informed by an implementation strategy that ensures all new ground automation capabilities, PBN routes/procedures, operating agreements, ATC procedures and training, and aircraft equipage levels are aligned to enable beneficial, logical, and manageable operational changes for a given geographic location. The magnitude of beneficial, operational change resulting from TBO will gradually increase over time with experience and with national implementation.

f. Collaboration with the user community, operational concept development and validation on more advanced concept elements, additional investments by the FAA and users, and the development of improved operational

integration methods are still needed to mature system requirements and ATC procedures to meet this vision. Key dependencies are described in the *Key Transformational Initiatives* section of this document.

Description of 2025 TBO

This section describes how investments made by both the FAA and Operators will improve NAS operations by 2025. Operational scenarios that describe how TBO works in different operational situations are in a supporting document, *Trajectory Based Operations Scenarios*.

Benefits of TBO expected by 2025 include:

- Maximizing use of available airport and airspace capacity
- Reduced environmental impact and fuel burn due to uninterrupted ascents and descents and reduced wait times in physical departure queues at major airports
- Greater use of advanced PBN procedures that provide shorter paths to/from the runway
- More effective use of airport and operator resources
- Consistent and reliable schedule and travel times provide operators more opportunities to make better business decisions concerning fleet management and fuel-loading

Operational Concept Overview

In 2025, TBO will require a new, combined and more collaborative approach to strategic planning and aircraft operations, where traffic management and air traffic control services become much more cohesive. New FAA and flight operator investments will make additional and more accurate information available. This information will improve strategic planning and tactical operations. Toward that end, the FAA has investment plans spanning multiple systems and programs that reflect the full range of capabilities needed to achieve the vision. These capabilities will continue to be introduced within the existing ATM operations model of ATC and Traffic Flow Management to deliver an integrated planning and operations approach that will transform the NAS. Successful transition to the TBO vision depends on the development of an implementation plan that provides a comprehensive strategy for integrating TBO capabilities with each other and collectively across facilities.

Achieving the 2025 TBO vision relies on the following four key concept elements: Data Gathering, Planning, Resource Scheduling, and Execution. The most significant changes will be experienced with planning and managing domestic operations. Although TBO is already practiced in most oceanic airspace today, additional TBO improvements such as better gate-to-gate strategic planning and the improved transition between domestic and oceanic airspace will enable additional operational benefits for oceanic flights. At some NAS locations, there will be a need to strategically plan for and apply a higher level of time-based management performance in oceanic airspace in order to integrate those operations with domestic operations.

Data Gathering includes improved understanding of flight operator intent, flight readiness, routing preferences, capabilities available onboard the flight deck, and data about current and forecast NAS constraints, such as weather and traffic. Much of the information infrastructure for the operator's and FAA's individual use is already in place or coming online. There is a need to remove barriers to information exchange among pilots,

dispatch, traffic management, and controllers to improve pre-departure planning and introduce new inflight planning capabilities. Expanded use of shared information is already contributing to the development of more strategic pre-departure operations plans. The FAA has asked aircraft operators to begin providing data elements that were not previously provided, and is investing in new capabilities to leverage this data to further improve the integrity of strategic plans.

Planning involves the strategic balancing of predicted traffic demand with predicted NAS capacity. Expanded and automated collaboration between the ATC System Command Center (ATCSCC), ATC facilities, and aircraft operators using improved traffic flow management automation, shared NAS status information, and weather forecast systems will enable the development of more accurate and reliable strategic operation plans. The plans will leverage FAA and user investments in new tools and real-time information links that improve the quality of the data. This will enable traffic managers and dispatchers to better plan operations given uncertainty. Investments also include better capabilities for anticipating and estimating the impact of weather on capacity and for enabling the incorporation of user preferences on flights and trajectories through user provided trajectory option set data. A more accurate and reliable plan improves operator fleet management by allowing operators to make key business decisions such as dispatch management for fleet use and substitutions. This concept element heavily relies on aircraft operators providing data and updating data in a timely manner to support joint decision-making. Thus, when demand is expected to exceed capacity, appropriate Traffic Management Initiatives, such as rerouting flights or delaying flights at departure with a GDP, will be included in the strategic plan to realign demand with available capacity.

Resource Scheduling is the vehicle for implementing and refining the strategic plan. Resource scheduling refers to the assignment of specific crossing times for specific flights at designated reference points. It will be appropriately applied and reflected by the trajectory throughout all phases of flight for those operating to/from critical NAS locations. The goal is efficient use of available NAS resources and scheduling is the mechanism for achieving it. The FAA is currently investing in new scheduling enhancements, improved constraint information sharing and management, and traffic manager decision support tools to achieve this goal. Integrated resource scheduling automation will organize and integrate airborne and pre-departure traffic while also accounting for surface movement constraints such as taxiway congestion. For example, scheduling will account for departures merging into overhead airborne flows, en route congestion, and on convergence to the destination airport, taking into account different aircraft types and equipage. Use of time-based management is segmented across the flight's operation through the use of multiple time-based schedules at designated points along the trajectory, as needed. The scheduling points will be incrementally updated to better manage trajectory uncertainty due to winds, evolving en route and airport constraints, and trajectory deconfliction needs. While trajectories will be deconflicted at those designated points through use of a time-based schedule, a flight's trajectory will not automatically be conflict-free throughout gate-to-gate operation. Therefore, incremental scheduling updates will be used to refine traffic flow spacing and improve manageability. The result is a traffic flow with the right spacing between flights to minimize flight inefficiency while maintaining the maximum use of available capacity (see Figure 2).

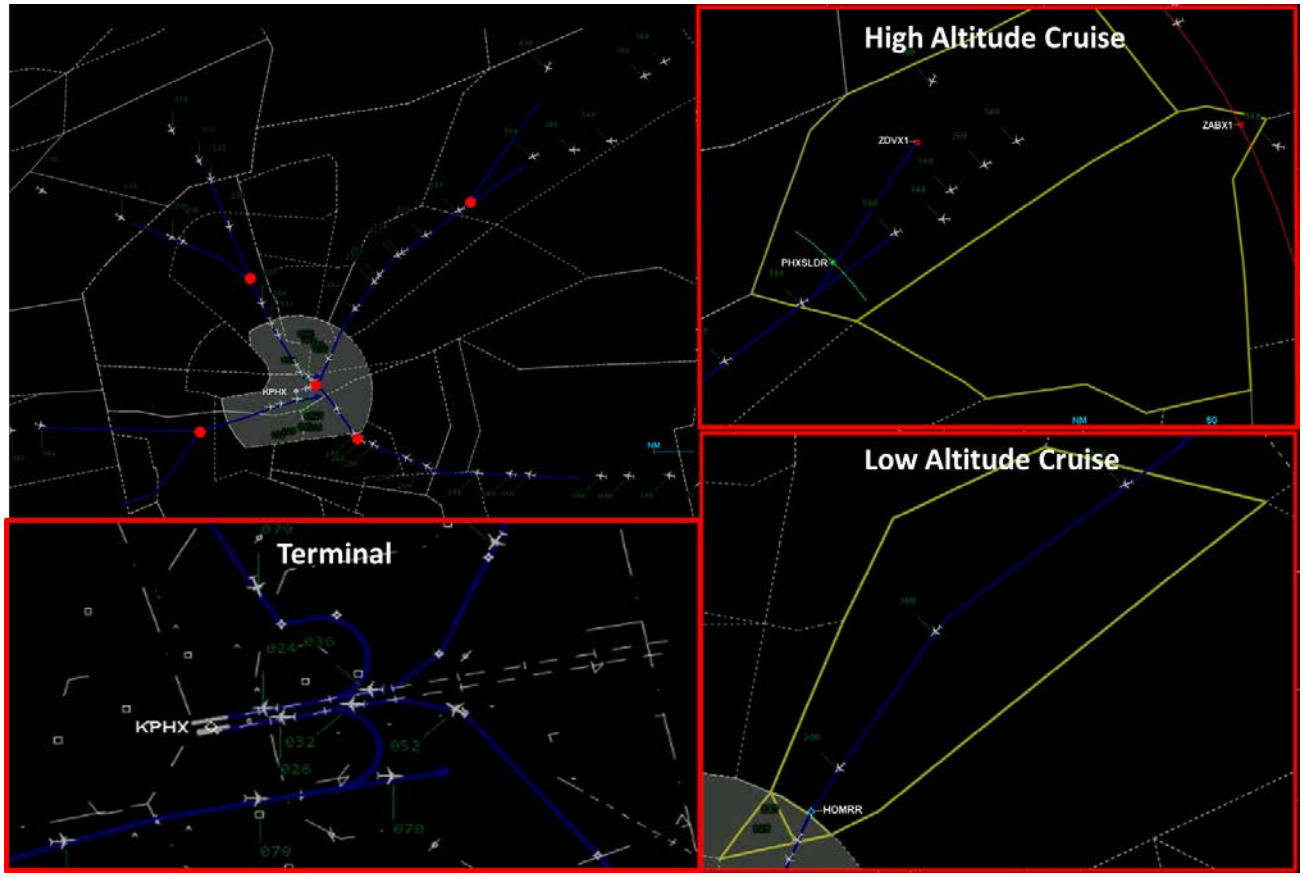

Figure 2. *Precise and repeatable PBN flight paths to the airport define specific merge and crossing points (noted by the red dots). This allows for time to be applied as a common planning reference to organize flows and integrate flights across ATC domains through use of conflict-free schedules at those points, which allow for flights to remain on their desired PBN procedure.*

As operational conditions evolve, the strategic plan and time-based schedule will be updated. This will be enabled by improved traffic manager tools that allow for effective coordination and improved, rapid assessment of schedule adjustments so that time-based management can be sustained during large scale disruptions and transient operational events such as convective weather or a cluster of go-arounds. These tools enable TBO robustness and flexibility.

Execution involves decision-making to realize the assigned schedule for specific aircraft and making adjustments to avoid schedule overlaps and/or to maintain separation. Separation adjustments will be needed for the controller to maintain required separation minima and are most likely to be needed for crossing streams of aircraft or vertical transitions within a stream for arriving and departing aircraft. Schedule overlaps may also be caused by changing environmental factors such as wind or weather. The goal is to make minor adjustments using primarily speed or time control to each flight to meet the schedule, along with any lateral and vertical path adjustments necessary to maintain separation that in total are more fuel-efficient relative to today's practices. Fuel efficiency is achieved in lieu of using large speed reductions, interim altitude assignments, and delay vectors such as S-turns and 360 degree holding patterns to meet the time-based schedule. The more fuel-efficient adjustments are enabled through use of decision support tools for controllers. The tools help to earlier identify precise actions needed to meet the schedule and with the execution of those actions. Other decision support

tools may also be available to pilots of equipped aircraft. In the future, the crossing time assignment will be presented on the controller display down to the second which is far more granular than the current 1 minute increments. This increased level of fidelity will assist controllers in meeting the exact crossing time target and to issue clearances based on efficient spacing solutions provided by decision support tools. These solutions result in a precise, common understanding among systems and people (i.e., closed-loop clearances).

In instances where required adjustments cannot be met using speed or time control alone, flight-specific efficient path changes will be issued by controllers to meet the schedule. In this way, significant schedule disruptions will be better managed with the use of existing and new decision support tools to maintain TBO by minimizing use of conventional vectoring, which does not result in an update to the trajectory. While the goal is to use less conventional vectoring, the controller is still actively controlling traffic largely through use of automation-captured speed and time control assignments to meet a variety of operational objectives, including providing separation. It should be noted that overcoming some transient operational events may require temporarily employing conventional vectoring or holding. Additionally, use of controller issued headings to turn some flights onto final approach or clear flights to their departure procedure may continue to be used as part of TBO where published PBN procedures are not defined all the way to/from the runways. With TBO, controllers will need to maintain a broad set of skills to manage various operational situations such as transitioning to/from high TBO performance to/from low TBO performance operations and for mixed equipage operating environments.

Execution decision-making will require controllers to determine what adjustments need to be made. This will be primarily conducted tactically by the controller using decision support tools, but may also be done in combination with the pilot/dispatch and traffic managers as operating conditions permit. For example, traffic managers can use their new tools to coordinate with flight operations centers and pilots to update schedules and collaborate on providing more effective reroutes to meet those schedules due to the presence of weather, a change of runway configuration, or arrival rate. Some rerouting decisions may also leverage availability of advanced flight deck reroute planning capabilities based on shared constraint information. Such capabilities are currently being researched. In these cases, trajectories will be used to collaborate among ATC, pilots, and flight operations centers on reroutes and resulting schedule updates. Some controllers will employ time-based management solutions to meet the ATC resource schedule by leveraging existing and emerging flight deck capabilities for equipped aircraft such as Flight Management System (FMS) Time of Arrival Control and flight deck awareness of the current traffic environment via Automatic Dependent Surveillance-Broadcast (ADS-B) IN. These flight deck capabilities will enable pilots to work with controllers in meeting the ATC resource schedule, further improving upon the accuracy and efficiency by which the strategic operations plan is met.

In an airspace environment with significant mixed equipage, there are different, complementary decision support tools that are envisioned as part of TBO to meet the time-based schedule. For example, when minor adjustments to the flight trajectory are required, flights that are equipped with time of arrival control capability will be assigned a crossing time clearance to capitalize on the opportunity to improve flight efficiency and accuracy in meeting that crossing time. As an alternative, unequipped flights will be issued speed clearances that are informed by ground automation system-provided advisories. Although these advisories are not as efficient as time of arrival control, they are still more efficient and accurate in meeting the crossing time assignment than today's conventional methods. Availability and use of the different decision support tools will be driven by operational need for a given airspace environment and the appropriate training.

FAA and Operator Investments

A shift to predominant use of time-based management, as a means for achieving TBO, requires new investments on behalf of the FAA and Operators. While many investments and changes have already been accomplished, many are still forthcoming.

Upgrades to FAA and user automation systems needed to facilitate time-based management and data sharing

Standard Terminal Automation Replacement System (STARS), En Route Automation Modernization (ERAM), Time-Based Flow Management (TBFM), Traffic Flow Management System (TFMS), and Terminal Flight Data Management (TFDM) systems are all foundational to achieve TBO envisioned by 2025. Combinations of enhancements planned for these systems, spanning multiple programs, enable key operational changes that allow for improved strategic planning, the sharing and maintaining of the flight's trajectory, and the predominant use of time-based management. Aeronautical Information Management Modernization (AIMM) will deliver integrated digital aeronautical information and Common Support Services – Weather (CSS-WX)/NextGen Weather Processor (NWP) will provide weather data, products, and imagery over information sharing systems like System Wide Information Management (SWIM) that facilitate data collection and data sharing, and enable user collaboration and improved NAS constraint management. Air-to-ground data communications will enable the exchange of more complex aircraft clearances and improved trajectory state information from the aircraft. To integrate the decisions that these tools support, new policy, governance, and applications which manage and link these current, nearly stand-alone, applications will be required. The FAA and flight operators must invest in the air and ground systems that allow for the continuous real-time exchange of flight state and preference information between ATM and operators both pre-departure and in-flight. This includes the ability of operators to share the 11 new data elements via TFMS Release 13, defined by the Surface Collaborative Decision-Making group, and the submission of user preferences via provision of trajectory option sets.

Flight Operator investments in avionics and flight planning systems needed to fulfill TBO vision

Flight operator equipage in PBN Area Navigation (RNAV) capability, and flight operator investments in flight planning systems and data provision are required to improve ATM strategic planning and resource scheduling needed to achieve TBO envisioned by 2025. Advanced navigation capabilities such as PBN Required Navigation Performance (RNP) enables further benefits to operators, and FAA system enhancements are targeted to allow operators to fly their desired PBN procedure. By 2025, all IFR aircraft are expected to have equipped with RNAV Lateral Navigation (LNAV) Global Positioning System (GPS) capability. Aircraft that have not equipped with additional navigation capabilities (e.g., RNAV (GPS) approach capability with LNAV/VNAV or Localizer Performance with Vertical guidance (LPV); RNP 1 capability; Distance Measuring Equipment (DME) navigation capability; and Radius to Fix (RF) capability) may not be able to efficiently access the largest airports.

Flight operator investments in advanced communications, such as airborne data communications and connections to airborne information sharing networks, will enable more effective and efficient operations. Users will be able to use the ground infrastructure investment to collaborate on pre-departure and airborne reroutes and data communication equipped aircraft will be able to receive more direct path changes or reroutes through the exchange of complex trajectory information.

Additional operator investments in certified flight deck capabilities that leverage ADS-B IN and ADS-B OUT technology and appropriate avionics, as well as Time of Arrival Control capability using a Required Time of Arrival (RTA) as an input, will further improve system-wide performance and resource schedule management as well as flight spacing efficiencies. An RTA refers to the time provided by ATC at which the airborne system is required to cross a designated point. An aircraft's FMS capability uses an RTA as the time constraint input and applies speed control to meet the time. Although aircraft with current Time of Arrival Control capability will be able to participate, those who meet the RTCA DO-236C Change 1 compliant standard which improves performance across different aircraft types may be able to more efficiently access airports.

Key Transformational Initiatives

Achieving operational transition to the 2025 TBO vision requires sound technology, and shared FAA and operator collaboration, actions, and investments. The vision is complex, requiring a system-of-systems perspective to ensure operational integration along with a clear understanding of and commitment by all stakeholders (such as controllers, pilots, traffic managers, and flight operations centers) to achieve the desired benefits. Without this commitment, transition to the operational change and associated benefits described in this paper will be delayed. Communicating a clear vision that describes the policy, impact on roles and responsibilities, as well as ATC and flight crew procedures is paramount. Additionally, revised approaches to implementation and training that foster new skillsets among the FAA workforce and aircraft operators will be crucial.

Implementation

As the successful realization of TBO improvements will require roles and responsibilities to evolve from ATC operations that are loosely integrated with strategic traffic management planning towards more tightly coupled strategic and tactical operations through predominant use of time-based management, the implementation of this evolution must be carefully and collaboratively developed. This vision for TBO will be used to develop these plans which need to be agreed upon and communicated early to the field and users so all stakeholders understand the direction and motivation of the change.

An integrated change management plan, that improves upon today's implementation processes to ensure consistent, effective, and sustained TBO, must to be developed to drive the change and must account for the workforce culture change required to achieve TBO. This plan needs to identify sets of TBO enabling capabilities targeted for implementation that are both logical and manageable, along with site and operator readiness criteria, and performance goals that constitute success. Incremental successes should be communicated early and often. The plan also needs to balance how much change is planned for a given facility over short periods to avoid 'change fatigue'. This will require accounting for initiatives that are external to achieving TBO or indirectly support TBO as part of producing an integrated plan. All initiatives and activities will need to be centrally coordinated to allow for proper implementation and training timelines.

The change management plan should also identify opportunities to mitigate implementation risk. Mitigations could include use of existing tools but with new procedures to bridge the interim, early initiation of site adaptation initiatives that account for a variety of operational needs such as seasonal changes and expected runway closures, and phasing of new technology that fosters familiarity and retention. The change management plan should consider new governance required to establish clear authority and accountability for making the

change, and processes to reinforce the change including use of performance agreements supported with incentive programs. The plan should also describe how progress will be measured and communicated to stakeholders, and the process for seeking help and/or quickly taking corrective actions where/when needed. The change management plan also needs to be communicated early to the field and users so all stakeholders understand and agree to how change will be incrementally delivered. Finally, successful implementation will rely upon ensuring that the FAA and operators have the appropriate resources in place to prepare and institutionalize the change in the operation. This may include use of pre-implementation support teams to ensure change readiness and on-site support for post-implementation needs.

Training

For training, a holistic, human-centric approach is needed to instill new skillsets needed for TBO. Emphasis on strategic planning, traffic flow management monitoring, and use of time-based management philosophies and techniques will be essential. These new skillsets will need to be acquired by the workforce in addition to maintaining proficiency in the use of conventional techniques. The training content needs to reflect integrated use of new and existing capabilities for achieving specific actions towards the broader common objective rather than focus on the technology itself. It needs to also ensure that the workforce understands the intended operational benefits of these capabilities and how reverting to conventional techniques erodes these benefits. The workforce needs to understand the desired performance goals associated with a capability, when the site has met those performance goals, or when additional training, adaptation, changes to adjacent facility interactions, or other initiatives are necessary. As TBO tools will vary across the NAS, there may be a need to develop training variants to adequately enable field transition.

Beyond training content, how training is provided is also very important. Since there are significant interdependencies expected between Airport Traffic Control Tower (ATCT), Terminal Radar Approach Control (TRACON), and Air Route Traffic Control Center (ARTCC) facilities for conducting TBO, the workforce will benefit from understanding those relationships. This can be communicated through use of team- and scenario-based training by flows or flow sets. This is also true for operators and their interaction with dispatch and flight operations centers. Infrastructure investments may be needed by both the FAA and operators to apply more effective training measures, such as enabling an integrated training simulation environment. In particular, greater focus upon providing traffic flow management training will be required.

Finally, improved training content and delivery mechanisms alone will not be sufficient to foster the shift to predominant use of time-based management techniques, improved strategic planning, and traffic flow management monitoring and decision-making. The FAA and operators will need to ensure the appropriate people resources are in place to execute the vision for TBO. Appropriately accounting for training impacts upon available workforce resources needs to be addressed, as services must continue to be provided while completion of training is delivered. Ensuring properly trained personnel are available across facilities before TBO implementation initiatives begin is key to achieving the 2025 vision.

Policy, Procedures, and Agreements

Policy, procedures, and agreements, including criteria for how time-based management is used, will need to be defined to achieve TBO across the NAS. For example, the use of time-based management all the time is required to manage the trajectory and maintain predictable operations versus using it only in periods of demand

and capacity imbalance. Effective use of time-based management techniques will certainly span facilities (ATCT, TRACON, and ARTCC) and in some cases operations may rely upon actions from adjacent ARTCCs. Letters of agreement will need to be developed to reflect those expectations and will rely upon field facility collaboration and Service Center(s) engagement. The time needed to develop agreements and achieve consensus needs to be accounted for in the implementation timeline.

Impact of Operating Business Decisions and Practices

Finally, achieving the 2025 TBO vision must involve clear expectation-setting regarding the level of benefits that will be observed. In some cases, the benefits that can be expected will be tempered by operator business decisions and practices. For example, if an airport (origin or destination) is overscheduled with more traffic in an hour than the airport can handle, there must be an understanding by all stakeholders that ATM actions are needed to correct the traffic demand-to-capacity imbalance. These actions will result in the assignment of flight times and flight path adjustments for delay purposes for some portion of the operating population. It should also be clear that further scheduling adjustments may be needed due to forecast uncertainty. If operational conditions worsen and operational capacity decreases due to events such as changing weather forecasts or decreased airport visibility, further ATM actions may be needed. It will be important to continue to communicate and emphasize, among the FAA and operators, the available system capacity. Should resources be overscheduled, the expectation by all must be that flights will need to be appropriately managed. TBO as envisioned may only allow for those flights to be more efficiently managed as compared with today.

When not all traffic demand can be accommodated at the desired times/places, operators often make trade-offs with respect to how they want to their operations to be impacted. These decisions are based on evolving business objectives and factors such as designating high value flights due to international connections, need for equipment, crew availability, cargo, and number of passengers served. There is limited external insight to the evolving prioritization of those factors. It will be important to highlight the impact of certain decision-making behavior that benefits the individual operator, but could result in an impediment to broader system benefits. For example, an operator may give gate preference to a high value flight at a surface-constrained airport as a trade-off to keeping another arrival flight waiting in the movement area. This type of trade can only be sustained in small amounts before it starts to impact the movement of ready flights and the broader, strategic plan established for many operators. Explicit stakeholder discussions and planning for how these types of situations will be managed needs to be addressed.

Conclusion

The operational change envisioned for achieving TBO in 2025 is significant but is motivated by the strong benefits potential. Even though the NAS is complex, strategic investments committed to by the FAA and Operators will incrementally improve NAS efficiency, predictability, and resilience. Ensuring that those investments are both operationally shaped for integration and that there is an agreed-to strategy involving change management principles will deliver the benefits promised and improve the flying experience for millions.