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Capacity-Enhancing Air Traffic Management Concept

Alvin L. Sipe,* Robert W. Schwab,† Áslaug Haraldsdóttir,‡ Ewald G. Schoemig,§ Marissa K. Singleton,¶
Paul A. van Tulder,** Monica S. Alcabin,†† Steven H. Glickman,‡‡ and Arek Shakarian§§
The Boeing Company, Seattle, Washington 98124-2207

A capacity-enhancing, gate-to-gate air traffic management (ATM) operational concept for the U.S. National Airspace System in 2020 is presented. The concept defines five core services for ATM: airspace, flow, traffic, separation, and information management. Flow, traffic, and separation management are the services that directly influence air traffic movement, whereas airspace management determines the physical resources available to accommodate traffic demand. Information management is a new service that provides the collection, storage, and dissemination of air traffic information throughout the system. The planning and control authority of flow, traffic, and separation management is determined using a partitioning of planning time horizons to each service. A method for assessing the benefits of these and other operational concepts is also outlined.

Introduction

THE current U.S. air traffic management (ATM) system is built on an operational concept that relies on displays of past aircraft location and a set of predefined procedures. This system is very safe but is reaching its capacity limit as evidenced by recent frequent levels of unacceptable delay. In addition, today's system is very labor intensive for pilots, controllers, and other system agents. The system fails to take advantage of enormous technological advances available today, having become so complex that substantive operational change is difficult or impossible.

This paper presents a further definition of a capacity-enhancing, gate-to-gate ATM operational concept for the U.S. National Airspace System (NAS) in 2020.[1–3] This concept would transform air traffic operations from a tactical control with controllers issuing vectors and short-term commands, based on radar displays of past aircraft position, to computer-based estimation of the future traffic state of the system based on aircraft-derived trajectory information. This concept would transform the pilot's role from following vectors in busy airspace to flying a preplanned trajectory. It would transform the locus of command from setting capacity constraints to managing trajectories.

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*Program Manager, P.O. Box 3707, Engineering and Programs, Air Traffic Management, MC 7X-40; alvin.l.sipe@boeing.com.

†Consultant, P.O. Box 3707, Engineering and Programs, Air Traffic Management, MC 7X-40; robertschwab2@boeing.com.

‡Technical Fellow, P.O. Box 3707, Engineering and Programs, Air Traffic Management, MC 7X-40. Member AIAA.

§Associate Technical Fellow, P.O. Box 3707, Engineering and Programs, Air Traffic Management, MC 7X-40. Member AIAA.

¶Lead Engineer, P.O. Box 3707, Engineering and Programs, Air Traffic Management, MC 7X-40.

**Associate Technical Fellow, P.O. Box 3707, Engineering and Programs, Air Traffic Management, MC 7X-40.

††Associate Technical Fellow, P.O. Box 3707, Engineering and Programs, Air Traffic Management, MC 7X-40. Senior Member AIAA.

‡‡Senior Strategy Analyst, P.O. Box 3707, Engineering and Programs, Air Traffic Management, MC 7X-40.

§§Critical Deconstructionist, P.O. Box 3703, Engineering and Programs, Air Traffic Management, MC 7X-40.

Objectives, Assumptions, Process, and Standards

The focus of this gate-to-gate operating concept is the provision of instrument flight rule (IFR) services for the 2020 system operation. The driving objective of the concept is capacity to meet the predicted demand. The concept addresses the primary objectives of system users and the service provider in real time. For the user, the primary operational objective is flight schedule integrity. The schedule is the user's statement of operational objective. For the service provider, the operational objective is safety, expressed as preventing the overloading of system resources or the close proximity of flights.

This operational concept is based on the following assumptions:

Airport development will keep pace with the traffic demand across all user types. This concept addresses the airspace problem that remains.

Airspace definitions and operating rules will change to support implementation of the concept.

An information system exists that is capable of handling the required data exchange between system agents.

This description of the concept is not constrained by political considerations.

The following initial set of standards is proposed for evaluating the merits of an operational concept:

An operational concept is a central element of the early phase of system configuration development and interacts with other system engineering products: requirements,[4,¶¶] architecture, and assessment.

In addition, an operational concept must be responsive to strategic system needs and defined as an integrated set of services. The concept defines the assignment of services and functions to system agents and resources. The concept needs to be validated (to ensure that the strategic needs are met under future operational scenarios) and needs to define a transition path from the current system to the future vision.

An operational concept must be defined in the context of the system engineering process. The entire process is driven by the strategic objectives, here identified as measures of mission (MOM) and measures of effectiveness (MOE). These parameters represent performance at the system level. The operational concept definition is based on allocating measures of performance to the system agents and resources in support of the system operation.

Operational Concept Overview

This concept is built on four core ideas: trajectory-derived integrated services, required total system performance (RTSP) based airspace control, precision procedural control, and human-centered design. These ideas are explained in this section and amplified in the rest of this paper.

¶¶Data available online at http://www.boeing.com/atm/pdf/sprd.pdf [cited xxx].

Trajectory-Derived Integrated Services

All Services Working Toward the Same Objectives

The 2020 system must be designed with feedback control for the integration of services. The system will be measured in near real time against explicit operating performance objectives.

Control Coordinated by Time Horizon

Air traffic services are partitioned with operationally determined time partitioning to establish prediction, detection, and resolution time horizons. The airspace management service determines the time horizons based on an estimate of quality of prediction.

Core Services Time Horizons for Prediction, Detection, and Control

Prediction accuracy for the basic flight plan is estimated for flow, traffic, and separation. The basis of each of these predictions is consistent across the services. Current and future flight phases for each aircraft will change the prediction uncertainty estimate. Prediction uncertainty will vary with operating domains.

Detection Accuracy and Criticality for Air Traffic Services

All flow, traffic, and separation services make decisions on detection of unsafe conditions. For flow, these are thresholds for safe operating traffic use for airports, gates, sectors, and other air traffic resources. For the traffic service, complexity in smaller regions of airspace is the resource to be assessed. For separation, the proximity of aircraft pairs is the detection criteria. Going from flow to traffic to separation, prediction detection fidelity increases along with service quality criticality. Each detection decision has a threshold for acceptable miss detection and false alert rate.

Future Projection of Traffic/Weather/Resource Picture Based on Flight Paths

Many trajectory-based tools are found in ground automation, from Center-TRACON Automation System to user request evaluation tools to enhanced traffic management systems. The proposal is to integrate these diverse trajectory-based applications and flight management trajectory applications with standardized input data sets to provide an integrated operational planning base for a range of air traffic services and for system users.

Shared Future Projection

This concept considers the four core management services of the ATM system: airspace, flow, traffic, and separation. The concept has all four services working simultaneously to protect system safety while minimizing the impact on user flight plan preferences.

Comprehensive Performance-Based Framework

This framework spans from top-level system performance metrics, through ATM functional performance, to subfunction performance requirements connecting the concept functions to elements of the architecture. Each function in the hierarchy is given a set of operational goals derived from predicted environmental conditions and system state. Real-time measurement and feedback of core services performance is provided.

Coordinated Flight Replanning

Change control of the flight plan needs to be unambiguous. When an aircraft is under active management, the separation manager has the authority to issue a trajectory change. Other services may identify flight plan changes for a particular flight and coordinate these changes through the appropriate separation manager. Prior to pushback, trajectory replans are coordinated between traffic, flow, and the user based on time horizon partitioning.

RTSP-Based Airspace Control

Dynamic Airspace Rules According to Infrastructure, Weather, and Traffic Constraints

The airspace management service will integrate configuration management of airports and runways, surrounding airspace, and the dynamic definition of routes and sectors. Dynamic reconfiguration of sectors will also be accommodated.

RTSP-Based Flight Planning

Users will plan using the communication, navigation, and surveillance (CNS) system performance capabilities of their fleet. The system performance capabilities will be based on the prediction performance level determined by airspace management. Access to all airspace and airport resources will be prioritized based on airplane RTSP level when required.

Precision Procedural Control

Trajectory-Based Flight Planning

The system operation will be founded on more precise, trajectory-based flight planning that enhances the current basis of system operation. Trajectory-based flight planning is already a core flight management functionality on all modern airplanes. Today, the flight management trajectories are the basis of an airplane's flight path when aircraft are operating in lateral navigation and vertical navigation flight modes. In the 2020 concept, the flight plan will reflect the user-desired flight trajectory.

Enriched Flight Planning, Objectives, and Path

Today, the user files a flight plan for full IFR services. In this concept, this will be supplemented with flight objectives and priorities and flight performance capabilities for use by air traffic services when flight plan modification is needed.

Human-Centered Design

Similar to the way airspace, flow, traffic, and separation services are integrated, within each of the services human operators and automation are integrated to share a specific set of objectives. Under "normal" conditions, higher levels of automation exist to support the operator. For example, trajectory prediction is an automated task. The human is involved both as a planner and as a monitor (with machine input) of system health. However, the human operator also selects (in the way a supervisor of an all-human team would) which human/automation team member will perform which tasks. Selection allows for the leveraging of the strengths of both types of team members as is most appropriate for whatever the given condition.

Flow

Information on scheduled flights is gathered and converted into predicted airport and airspace demand. These data are available to users for consideration in combination with their business objectives when planning future activities. Humans, both users and service providers, use the information to collaborate on future and daily plans.

Traffic

The computation of planned trajectories is automated both on the ground and in the aircraft. The automation provides assessment of planned trajectories and resolutions for simple complexity issues. Humans, with support automation, resolve the more difficult complexity issues as well as off-nominal problems.

Separation

Trajectories are planned to be conflict-free 20 min into the future by the traffic automation. Separation violations are generally resolved prior to issuance of a clearance. Humans monitor for off-nominal situations to which the automation is not programmed to identify or respond. The central separation plan is executed with high integrity. Both ground and aircraft monitor conformance to the plan. The aircraft role in short-term replanning, where infrequently required, is the subject of a proposed trade study.

Airspace

Automation allows tracking and visualization of the airspace and associated rules. Humans use the information to make changes to address unexpected conditions.

Functional Analysis

A representation of the 2020 concept functional structure is shown in Fig. 1. The concept includes five core ATM services: airspace, flow, traffic, separation, and information management. A fundamental attribute of the concept is the allocation of the core ATM services to time horizons and geographical domains. Another key aspect of the concept is that the functions base their problem detection on different levels of fidelity, starting with flow (considering airport arrival and departure rates and sector loads), traffic (considering groups of aircraft inside sectors across multiple sector areas), and separation (detecting conflicts between pairs of aircraft).

All services rely on assessment of current operating state, prediction of that state based on the current set of four-dimensional trajectories, and a projection of the traffic load onto key system resources such as runways or sectors for flow, routes and airspace segments for traffic, and spatial proximity for separation. The services produce an alert where overloading is detected and generate a new plan to remove the overload condition.

As distinguished from current NAS operations, in this concept each function operates directly on individual trajectories to solve detected problems in its time horizon. In the current U.S. and European systems, with the exception of flow management ground delay allocations, the services upstream from the sector act only indirectly on flight plans. This coordination is currently performed by taking actions such as miles-in-trail spacing rules, airport ground stops, reroute advisories, and so on. While often effective in reducing system overloads, these actions can work at cross purposes, cause underutilization of resources, and make the progress of individual flights through the system unpredictable. Therefore, an operational concept that allows each function to schedule and route individual flights, based on a hierarchy of operational goals, is expected to enable significantly higher system performance than that currently achieved, enabled by an integrated functional architecture and an extensive information and automation infrastructure.

A fundamental attribute of the operational concept is the allocation of the core services to planning time horizons. A presentation of the 2020 concept services and associated time horizons is shown in Fig. 2. The prediction time horizons (PHs) identify the overall temporal scope of a service. For example, rerouting around large convective weather areas in flow management will require a PH on the order of hours to capture the effects of a new plan, whereas collision avoidance is considered to be on a very short time horizon. System uncertainty generally limits the usability of predictions for planning purposes and, thus, it is important to limit the accuracy of a planning objective to the quality of the data used for problem prediction.

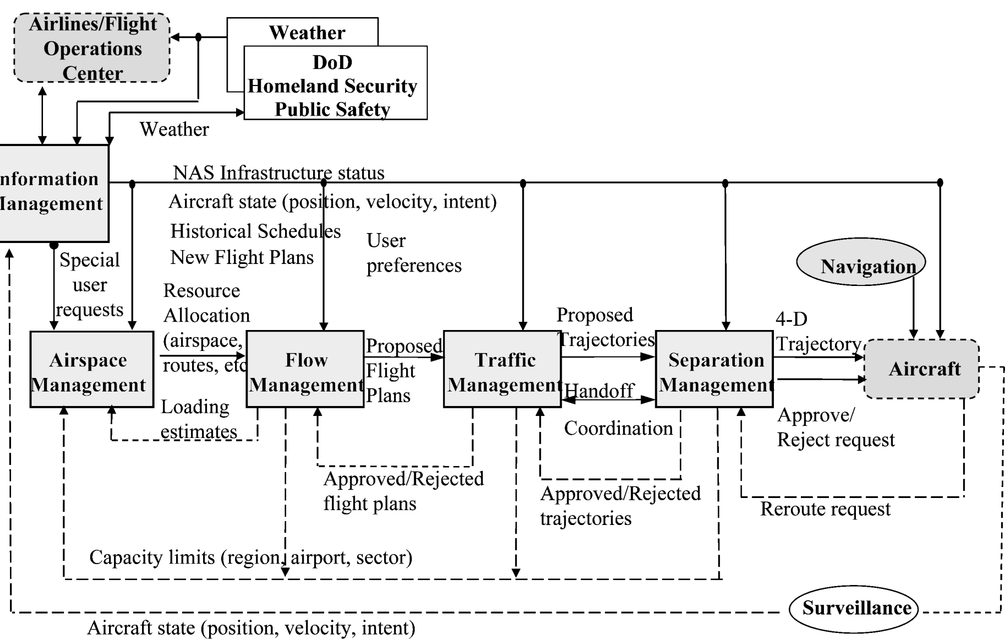

Fig. 1 Integrated set of core services: simplified block diagram.

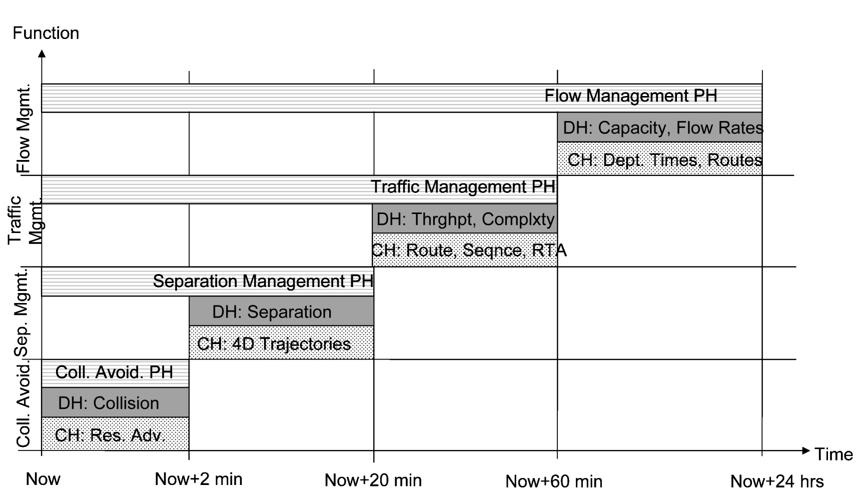

Fig. 2 Segregation of flight plan control authority by time.

The PH for the system functions may need to be adjusted dynamically, depending on system predictability for a given condition; thus, the boundaries between the services can vary with condition. Additionally, system predictability depends on the phase of flight and/or operational domain; for example, the differences between predeparture and in-flight state and, thus, the time horizons are adjusted to operational domain and location. The detection time horizon in Fig. 2 defines the future time period within which a service detects problems and determines a plan to achieve its objectives. For flow management, this implies that it looks at the time period beyond 60 min to detect airport and sector overloads and does not concern itself with problems prior to 60 min. The lower level service, traffic management, is at the same time actively examining situations prior to 60 min. The control time horizon (CH) in Fig. 2 specifies the time frame in which a service can modify its control variables. This implies that traffic management is allowed to modify the route and/or required time of arrival of a flight starting 20 min from now to solve a problem in its DH. Conversely, traffic management is not allowed to reach inside the separation management time horizon with a trajectory change.

The division of control based on time horizons illustrated in Fig. 2 is designed to avoid ambiguity in control authority. A scenario that follows the interactions of a flight with the associated ground agents can be envisioned. The scenario brings to light coordination requirements between the functions, which, for the sake of clarity, are not illustrated in Fig. 2. A structure such as this holds the key to the overall functional architecture of the future gate-to-gate system to ensure a logically coherent integration of services, procedures, and ATM automation aids.

Flow Management Service

The primary objective of the flow management service is the determination, communication, and monitoring of a flow plan that supports the user's flight operations center (FOC) by minimizing disruptions due weather and congestion and to protect traffic and separation management from overloads. The flow management service detects capacity and demand imbalances across the NAS over a 24-h time horizon and proposes resolutions that balance users' schedule integrity with the risk of overloading system resources while considering user preferences and equity. The resources of concern to flow management include airport arrival and departure rates, gate availability, and airspace sector capacities. The principle of collaborative decision making between the service provider and users is central to the flow management service. Figure 3 illustrates the functional structure of the flow management service. Collaboration between the service provider and the users in revising flight plans allow users the flexibility to manage their schedules to minimize delay propagation, cancellations, and repositioning of flights. The feedforward path in Fig. 3 performs flight-plan predictions and detection of resource overloads, and the feedback path illustrates the collaboration with the user in allocating resource capacities and revising flight plans. Inputs used by flow functions include the current state of aircraft, wind data for trajectory predictions, and resource capacity information.

The flow management service is continually executed with an update rate sufficient to safely support other downstream services. Flight-plan modifications in flow management are performed from 60 min in the future up to the flow management PH.

Collect Flight Plan Data

Accumulate flight plans for the planning horizon.

Allocate Flight Plans

This function predicts all aircraft positions and trajectories and maps flight plans onto resources for each time slice in the flow manager's planning horizon.

Detect Overloads

This function checks for resource capacity overloads over the flow planning horizon. If no capacity overload is detected, the user's flight plan is accepted by the flow manager and forwarded to the traffic manager for flight-plan clearance at departure. If capacity overloads are detected, a flow resolution action is initiated.

Allocate Capacity

This function first computes available capacities by predicting usage by committed flights for each resource and time slice. It then allocates the constrained resources to individual FOC planners using equity rules and provides this allocation information to the FOCs.

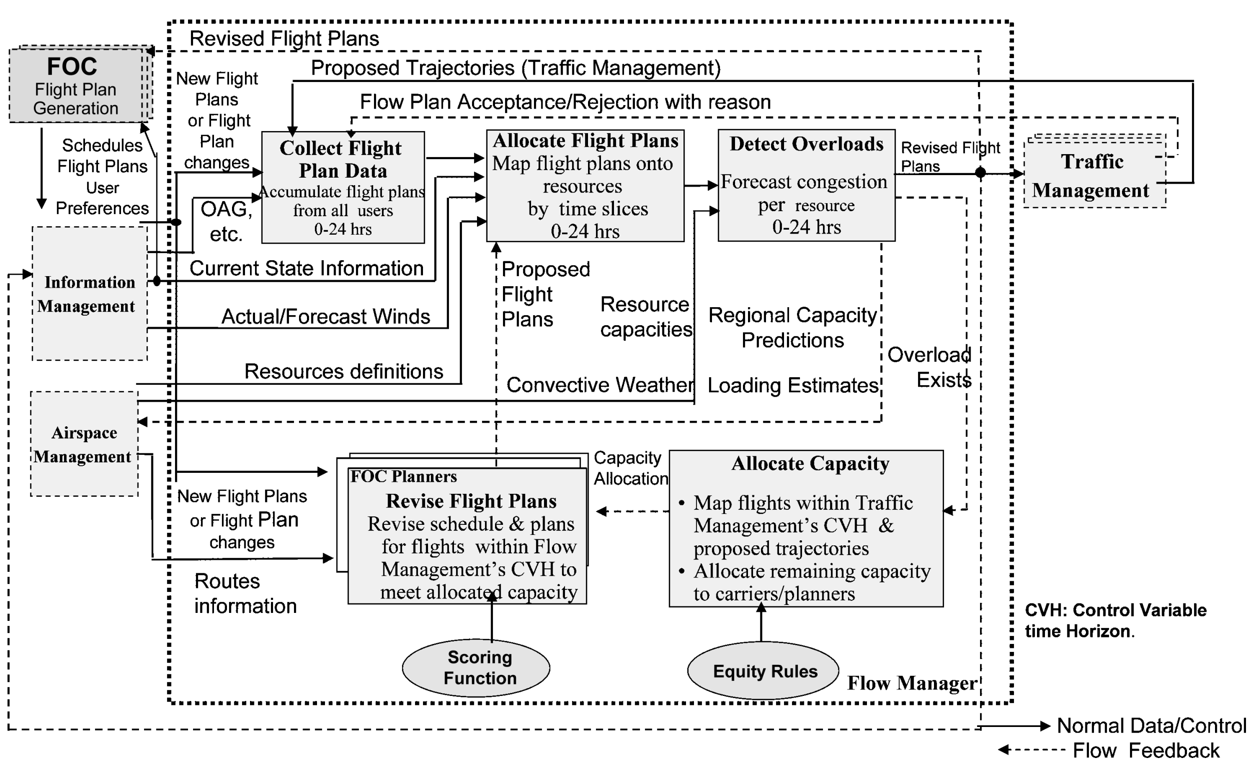

Fig. 3 Flow management.

Revise Flight Plans

In keeping with the principle of collaborative decision making, the revision of flight plans is the responsibility of the system users. Their flight operations functions use strategies and automation aids to examine their allocated capacities and revise their schedules and flight plans to meet the flow constraints. Each individual FOC planner uses its own objectives to balance reroutes with departure delays and cancellations and closely collaborates with the allocated capacity function to maximize capacity utilization and schedule integrity. For each flight, the user considers factors such as the number of seats or amount of cargo onboard, the distance flown, the amount of delay incurred during the day, and other cost- and revenue-related aspects of a flight that are known only by the individual user.

Once all flight plans have been allocated to system resources and no overloads exist, revised flight plans are submitted to the allocate flight plans function to ensure that constraints have been met.

The frequency of flow plan updates will be limited by the time needed to recompute a flow plan, the number of flights and airlines to be considered, and data communication performance. The ability to compute and execute the flow plan is subject to uncertainties such as the ability to predict and update aircraft intent, the ability to predict departure times, and the ability to determine flight-plan intent in the face of traffic and separation actions that deal with local congestion. Models for these uncertainties will be used to compute a prediction performance metric to guide flow management strategies. High levels of prediction uncertainty may require more frequent updating of flow predictions. Flow replans may be triggered at fixed time intervals and executed continuously to account for the latest convective weather forecasts. Other strategies may be needed to deal with sudden system events, such as runway closures, where the objective of the flow replan is to minimize downstream effects on traffic and separation services and to ensure flow plan stability. Alternatively, replans can be initiated reactively when a flow conformance deviation from the current plan has been detected.

Traffic Management Service

The primary objective of the traffic management service is the determination, execution, and monitoring of a traffic plan that reduces traffic complexity and maximizes throughput under spacing constraints across a regional area, based on a flow plan determined by flow management. The traffic management service fills the gap between strategically oriented flow management and tactical separation management.

This service consists of four functions, as illustrated in Fig. 4. Traffic assessment compares the current traffic situation with the traffic plan and evaluates the need for a replan. Four-dimensional trajectory predictions for each airplane form the basis for computing complexity measures and aircraft spacing, which permits the identification of complexity overloads or spacing goal violations. If a new traffic plan is required, the traffic replan function maximizes a throughput metric with traffic complexity and spacing constraints in the planning time horizon and the multisector region.

Assessment of Replan Need

Based on a composite view of the surface and air situation, traffic monitoring tracks compliance with the plan and evaluates whether a new plan needs to be generated. Traffic replans may be triggered proactively or executed continuously. Alternatively, replans can be initiated reactively when a traffic conformance deviation from the current plan has been detected. Proactive triggering aims at continuous efficiency improvement via a scoring function that compares benefits between a new or existing plan.

A threshold will determine whether to activate the new plan. Reactive triggering compares traffic deviations against a defined complexity tolerance to determine the need for a replan.

Trajectory/Traffic Prediction

Information for prediction includes planned trajectory, procedures, and the time horizon over which the path has to be calculated. Path prediction also requires predicted wind and temperature,

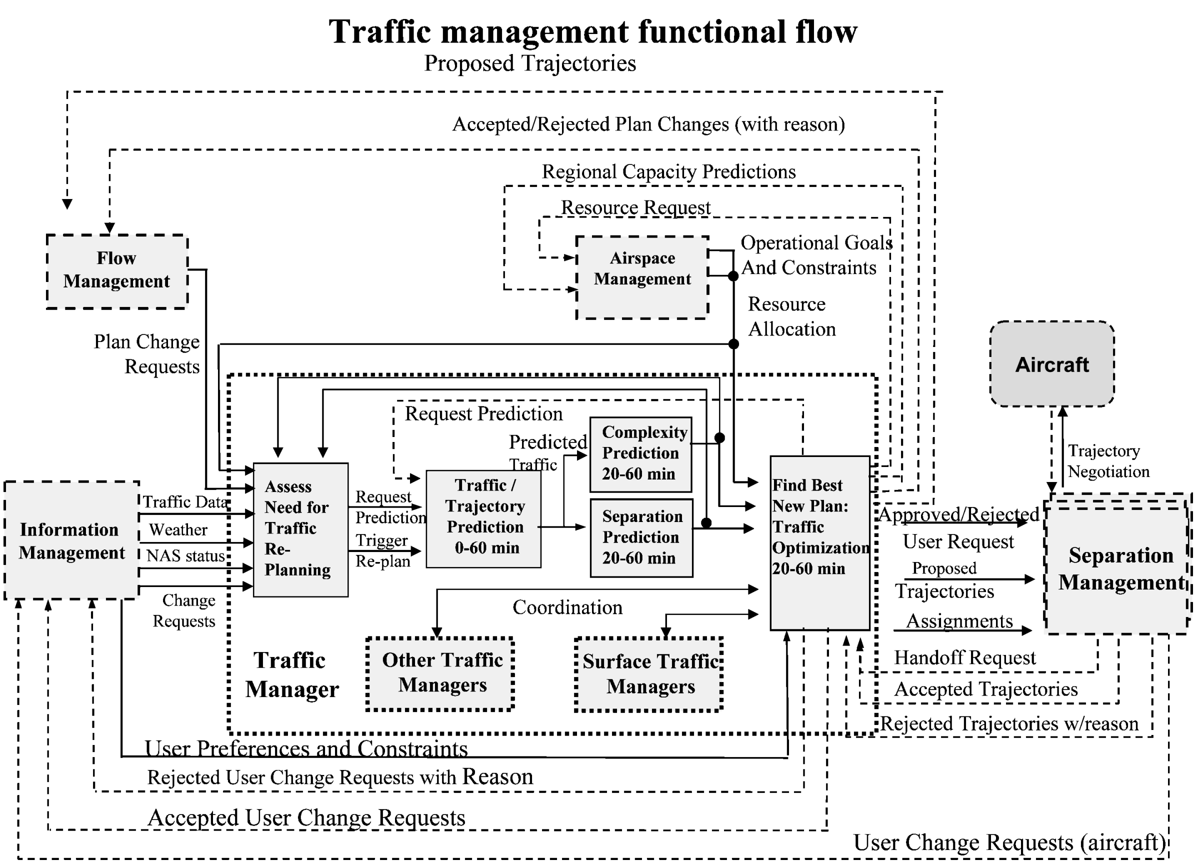

Fig. 4 Traffic management functional flow.

as well as a model of airplane performance. Prediction performance is a key aspect of reliable planning. Models for prediction uncertainties will be used to compute uncertainty bounds. This metric is essential for computing overall traffic plan stability and determining achievable PH.

Complexity and Spacing Detection

Based on predicted airplane paths, complexity and spacing predictions are computed. Complexity and spacing performance goals are inputs from airspace management. Comparison of these goals with the predicted metrics permits the determination of constraint violations. The computation of the spacing constraints may be based on pairwise distances between aircraft or represented in a combined complexity and spacing metric.

Traffic Optimization

A new plan is computed by maximizing an efficiency metric subjected to operational constraints expressed in terms of traffic complexity, spacing goals, and user preferences. Subfunctions of traffic optimization include 1) computation of the efficiency metric for traffic planning; 2) determination of constraint compliance; 3) definition of a new trial plan considering user preferences; and 4) integration of inputs from other planning functions, constraints, and performance goals.

The traffic management service integrates planning of arrival, departure, and en route traffic within the multisector region and is tightly coupled with surface traffic management to ensure efficient arrivals and departures and maximized airport throughput.

Traffic Management Control Mechanisms

Traffic management services modify four-dimensional trajectories in the CH from 20 to 60 min. Traffic management includes the following control: 1) departure times of aircraft and surface traffic trajectories at airports for the surface traffic manager, 2) route selection for aircraft within the multisector region, 3) dynamic four-dimensional trajectory allocation via waypoint designation and associated timing targets, and 4) sequencing of aircraft through merges and intersections.

Intersector Handoff and Coordination with Other Traffic Managers

The traffic manager is responsible for handoff coordination between sectors as well as across multisector boundaries. This task includes short- to medium-term conflict detection on airspace boundaries and the generation of resolution strategies. Conflicts on boundaries internal to the multisector region are handed over to separation management for resolution. Conflict resolution on boundaries with other multisector regions are negotiated and resolved in cooperation with other traffic managers.

Separation Management Service

This service plans, communicates, and monitors four-dimensional aircraft trajectories to ensure no violation of the minimum allowed separation between pairs of aircraft while contributing to full utilization of airspace and airport resources by operating as close to the minimum as feasible. This service is the sole point of trajectory change communication between the aircraft and the ground-based ATM functions after pushback from the gate. Separation management coordinates directly with traffic management and airspace management to achieve its operational goals.

The following assumptions are made regarding separation minima in 2020, driven by the goal of accommodating the predicted traffic demand: 1) en route distance is 5 nm; 2) terminal area is 3 nm, extending significantly farther from the airport than the current TRACON airspace; 3) in-trail final approach in VFR is determined by runway occupancy time; 4) in-trail final approach in IFR is limited only by low-visibility runway exit performance; 5) closely spaced parallel approaches are independent operations down to 750 ft centerline distance; and 6) vertical is 1000 ft at all altitudes.

Figure 5 illustrates the functions in the separation management service. The PH for separation management is 20 min and is continually executed with an update rate sufficient to safely support the separation standard in use. The detection and control time horizons for the separation management service are bounded below by 2 min. The service produces a conflict-free four-dimensional trajectory for every aircraft in the sector or airport surface, out to the 20-min prediction horizon, and communicates this four-dimensional trajectory as a clearance to the aircraft. The aircraft flight manager assesses the ability to execute the trajectory within the given tolerances for the procedures in use and, if able, transmits an acceptance message and flies the trajectory. If the trajectory is infeasible, the flight manager notifies the separation manager of rejection with a reason by stating the constraint or by proposing a modified trajectory for consideration.

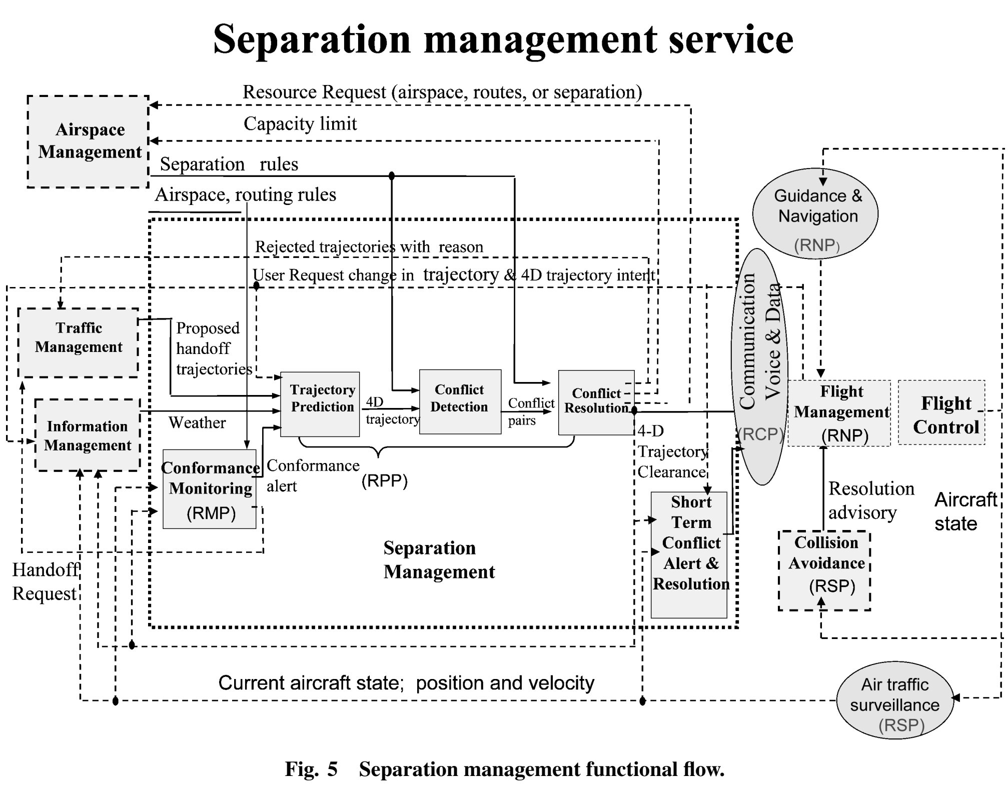

Fig. 5 Separation management functional flow.

The four-dimensional trajectory definition is a collection of three-dimensional (x, y, z) points in space, with associated estimated or required future time values. Associated with the trajectory definition is a four-dimensional conformance bound. The separation manager generates trajectories for each aircraft such that if they stay within their four-dimensional tolerance it is ensured that conflicts will not occur. The ability to execute such a plan is subject to a number of sources of uncertainty and, thus, there is a certain probability that a plan will require updates within the 20-min time horizon on which it was based. It is expected that the longitudinal intervention rate will be higher than the vertical and lateral rates, but all need to be sufficiently low to ensure stability and computational and communication feasibility.

Figure 5 illustrates that the separation manager continuously monitors each aircraft's conformance to the cleared four-dimensional trajectory through the conformance monitoring function. This function will detect and alert with the need for plan updates in cases when aircraft exceed the given conformance limit and in cases when an unexpected change in aircraft intent is communicated.

Due to the computational complexity of the 20-min four-dimensional trajectory planning process, and the likely stringent safety and certification requirements on the separation management service, it may be necessary to include an independent function for short-term conflict detection.

Four concept alternatives are proposed for short-term plan update functionality, one based on allocating it to the ground element, the other three allocating it to the airborne element, as described in more detail in Ref. 5. The separation management service accommodates user objectives and preferences, through trajectory change requests from the aircraft, that are approved subject to modifications to ensure a conflict-free plan. This concept is consistent with an increased role for the airborne element in short-term conflict detection and resolution and in maintaining relative spacing with other traffic.

Airspace Management Service

The airspace management service is responsible for long-term activities, such as defining and planning airspace resources, and short-term activities, including the dynamic allocation of airport and airspace resources. Long- to medium-term responsibilities include determining the physical definition and operating rules of the airspace, airways, and airport assets, including air traffic and flight procedures. Short-term responsibilities include dynamic allocation of these resources to the flow, traffic, and separation services based on predicted total system performance levels.

Airspace management will forecast required and available air traffic service levels for the day. Airspace management will decide the partitioning of prediction, detection, and control time horizons for the flow, traffic, and separation services based on an assessment of prediction uncertainty. Airspace management will adjust sector boundaries, establish routings and spacing targets, and allocate other key NAS resources to flow, traffic, and separation.

Collect NAS Status

Airspace management gathers information on the status of resources that will affect the day's operation. CNS equipment status and planned outages, runway repairs, weather forecasts, and so on are collected to form the basis for an assessment of actual total system performance levels (ATSPs). A grid of ATSP by time of day will be provided via the information management service for all NAS users.

Allocate Resources to Flow, Traffic, and Separation Services

Based on the traffic demand and weather picture for the day's operation, the function allocates resources to the other services. The airspace management service also establishes time horizons for flow, traffic, and separation services. Sector boundaries, routes, and spacing targets are determined in real time. All airspace is defined in terms of RTSP-based criteria consistent with operational needs.

Analyze Performance

The airspace management function will analyze overall system performance on an ongoing basis. A performance baseline of NAS operations will be developed and a dynamic process for statistical analysis of trends and causal factors will be established to provide performance feedback to management and users.

Information Management

This service is responsible for the orderly collection, storage, and dissemination of the information in the system. This includes weather, infrastructure, traffic, and other information. This service performs the duties of a librarian with latency, accuracy, staleness, and timeliness as performance characteristics. As librarian, this service sets the interface standards, archival processes, access limitations, and so on for the information that is exchanged throughout the system.

Trajectory information is the key information component. By having the flow, traffic, and separation services all working off the trajectory information, and by exchanging this information digitally, all agents will have the information needed to operate much more efficiently. The additional, more accurate information will make reductions in operational buffers, as well as regulatory buffers, possible.

Sharing information digitally via ground networks and rf data link both provides better access to information when needed and allows sharing of a common view for collaborative decision making.

Benefits Assessment

With the 2020 concept defined, an assessment methodology is being developed to determine if the operational concept meets the strategic objectives or measures of mission. This assessment methodology consists of three elements: benefits assessment, operational requirements assessment, and feasibility assessment. Operational requirements assessment investigates the range of operational choices and quantifies the performance required for each choice. Feasibility assessment investigates the feasibility of various technologies to meet the operational performance requirements. The remainder of this paper focuses on benefits assessment.

The MOMs and MOEs provide an overall report card for an operational concept that ideally addresses all pertinent stakeholder issues. They serve as the decision criteria by which to assess the operational concept. The MOMs for which this concept will be evaluated are capacity, safety, security, access, flight-path efficiency, environmental efficiency, global interoperability, and affordability. Some measures will be quantitative (capacity), whereas others will be more subjective or qualitative (access).

The first step in the benefits assessment is to develop a performance baseline for the current system. Because our concept focuses on capacity, the performance baseline will assess the average delay per flight throughout the NAS for the study reference year (2000). A model of operations of the NAS for 2000 will be developed that will provide a network-centric representation of NAS operations. The number and types of models required are based on the NAS resources that are related to the system metric under consideration and those required to adequately represent operation of the current system.

Three models of NAS operations in 2020 will be developed. One will represent the NAS in 2020 with the implementation of the Federal Aviation Administration's Operational Evolution Plan (OEP) and whatever additional enhancements are operational by 2020. The second will represent the NAS in 2020 with planned runway improvements without any airspace constraints. The third will represent the NAS in 2020 with the capabilities of the operational concept. The model without airspace constraints will be used to define the upper limit of possible capacity increase without runway additions beyond those planned.

An experiment will be developed for a systemwide capacity assessment as well as requirements development activities in the areas of operational trade studies. Scenarios will be developed to support the planned experiments. These scenarios will be required for

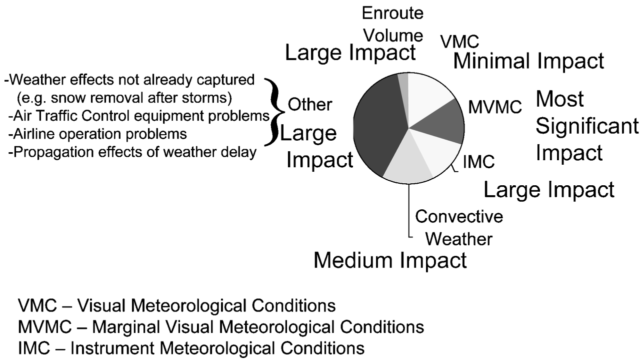

Fig. 6 Preliminary assessment of benefits.

normal and stressing conditions for future NAS operations. A baseline forecast for future daily operations for 2005, 2010, 2015, and 2020 will be developed as well as alternative traffic forecasts that may include a number of different assumptions from the baseline future traffic forecast. These alternative traffic forecasts will be used to test the robustness of the 2020 operational concept.

An analysis will determine the OEP's impact on the NAS model for 2020. A similar analysis will examine the impact of the Boeing 2020 concept of operations on the NAS model. Concept evaluations, also referred to as trade studies, will be conducted to determine the benefits and requirements associated with the elements of the 2020 operational concept. An example of such a combination of trade studies might consider operations at Chicago's O'Hare International Airport (ORD). Initially, models would be developed to represent the surface, gates, and the runways at ORD for 2000. The outputs of these models would be used as inputs to the airport and airspace model of ORD. The outputs of that model would in turn be used as inputs to a systemwide model. Next, these individual models would be revised to represent changes to each of the NAS resources for 2020. This would be repeated to represent the changes in operation for the 2020 concept elements.

A recent qualitative assessment of the 2020 concept is shown in Fig. 6. Benefits are expected in improved airport capacities for visual, marginal visual, and instrument conditions and for enhanced sector capacity. The integrated concept will also reduce capacity losses of the current system due to inadequate integration of flow, traffic, and separation initiatives. Subsequent work has been directed at the visual meteorological conditions (VMC) airport capacities and technical requirements to reduce runway occupancy time. Lateral and longitudinal spacing are both being evaluated.

Other concepts could be evaluated using the same methods. The primary purpose in evaluating these concepts is to determine the required performance associated with the concept elements that provide the most benefit for the lowest cost.

Conclusions

The operational concept summarized in this paper is the first step toward a significant rethinking of the operational paradigm for air traffic management, one focused on a shared definition of flight and traffic intent. This concept is built on four core ideas: trajectory-derived integrated services, RTSP-based airspace control, precision procedural control, and human-centered design. This vision must be supported by methods and tools to identify benefits and technical performance requirements that will measure the concept's promise and difficulty of implementation. Work to quantify these benefits is ongoing.

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References

[1]Boeing Air Traffic Management, "Revolutionary Concepts That Enable Air Traffic Growth While Cutting Delays," National Center of Excellence for Aviation Operations Research (NEXTOR) Rept. RR-97-3, Oct. 1997.

[2]Haraldsdottir, A., Schwab, R. W., and Alcabin, M. S., "Air Traffic Management Capacity-Driven Operational Concept Through 2015," *Air Transportation Systems Engineering*, edited by G. L. Donohue and A. G. Zellweger, Progress in Astronautics and Aeronautics, Vol. 193, AIAA, Reston, VA, 2001, pp. 9–26.

[3]Boeing Commercial Airplane Group, "Air Traffic Management Concept Baseline Definition," National Center of Excellence for Aviation Operations Research (NEXTOR) Rept. RR-97-3, Oct. 1997.

[4]Boeing Air Traffic Management, "System Performance Requirements Document," D780-10010-1, The Boeing Company, Seattle, WA, Jan. 2002.

[5]Haraldsdottir, A., Schoemig, E. G., Schwab, R. W., Singleton, M. K., Sipe, A. L., and van Tulder, P. A., "Boeing Capacity-Increasing ATM Concept for 2020," *5th USA/Europe Air Traffic Management Research and Development Seminar*, Budapest, June 2003.