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CAPACITY ENHANCING AIR TRAFFIC MANAGEMENT CONCEPT

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Abstract

This paper presents a capacity enhancing, gate-to-gate air traffic management (ATM) operational concept for the US National Airspace System (NAS) in 2020. 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, while 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 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. This paper also outlines a method for assessing the benefits of these and other operational concepts.

1. Introduction

This work was performed in the context of the NASA Virtual Airspace Modeling and Simulation (VAMS) project[1] in collaboration with NASA Ames. This gate-to-gate, integrated air traffic management concept represents further development of the Boeing ATM operational concept first published in [1], built on foundations laid in [2-3]. The concept is driven by requirements collected by the Boeing ATM Working Together Team [4], with particular focus on the capacity-related objectives.

The authors have been active participants in the developments of a number of related ATM operational concepts [5-9]. Thus, this concept has a number of features in common with others, with an emphasis on the integration of a hierarchical set of services around a 4-D trajectory basis. This paper presents a summary of the Boeing ATM 2020 operational concept, which is described in detail in [10].

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2. Objectives, Assumptions, Process, and Standards

The focus of the Boeing gate-to-gate operating concept is the provision of instrument flight rules (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 provider, the operational objective is safety, expressed as preventing the overloading of system resources or the close proximity of flights.

The Boeing 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 concept is not constrained by political considerations.

We propose the following initial set of standards for evaluating the merit of an operational concept.

We believe that an operational concept is a central element of the early phase of system configuration development, and interacts with other system engineering products: requirements, architecture and assessment , as illustrated in figure 1.

The concept development process is shown in the context of the other system engineering products. The process is very iterative, with most of the flow shown as bi-directional. Requirements, concept and architecture are the three primary artifacts of the process, with tools, modelling, and analysis used to converge to a solution.

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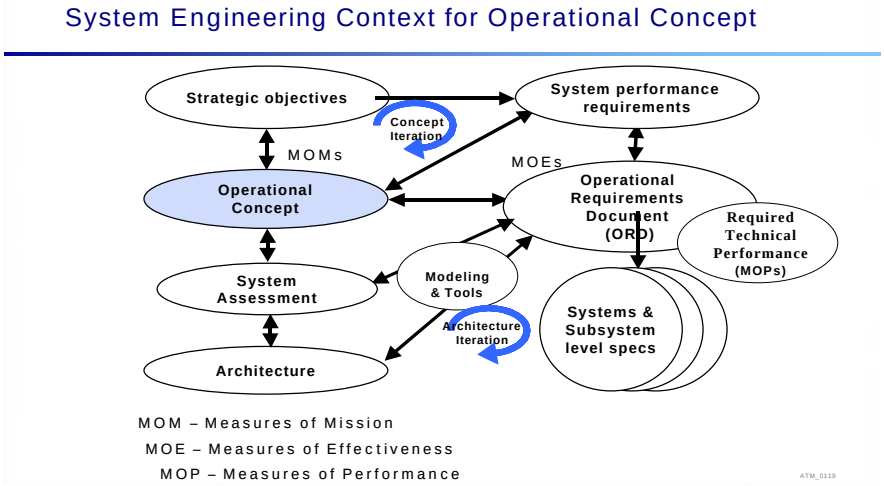

Figure 1. 2020 ATM Operational Concept Functional Flow

While the chart indicates a single time period, the process is iterative, with time-indexed mission needs, operational concept elements, requirements and architecture steps. We believe the architecture needs to be projected from today into the future, while the operational concept should be viewed as a future state that affects present decisions.

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 the basis of allocating measures of performance (MOP) to the system agents and resources in support of the system operation. An operational concept must be defined in the context of the system engineering process

3. Operational Concept Overview

The Boeing 2020 concept is built on three core ideas: Integrated Services**,** RTSP Based Airspace Control, and Precision Procedural Control. These ideas are explained in this section and amplified in the rest of this paper.

Integrated Services:

All services working to 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 (CTAS) to User Request Evaluation Tools (URET) to Enhanced Traffic Management Systems (ETMS). The Boeing 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: The 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 sub-function 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 & 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 re-configuration of sectors will also be accommodated.

Required total system performance (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 (LNAV) and vertical navigation (VNAV) flight modes. In the 2020 concept, the flight plan will reflect the user-desired flight trajectory.

Enriched flight planning, objectives as well as path: Today, the user files a flight plan for full IFR services. In the Boeing 2020 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.

4. Functional Analysis

A representation of the 2020 concept functional structure is shown in figure 2. 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 4-D 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 alert where overloading is detected, and generate a new plan to remove the overload condition.

As distinguished from current NAS operations, in our concept each function operates directly on individual trajectories to solve detected problems in its time horizon. In the current US and European systems, with the exception of flow management ground delay allocations, the services up-stream from the sector act only indirectly on flight plans. This is done by taking actions such as miles-in-trail spacing rules, airport ground stops, re-route advisories, and so on. While often effective in reducing system

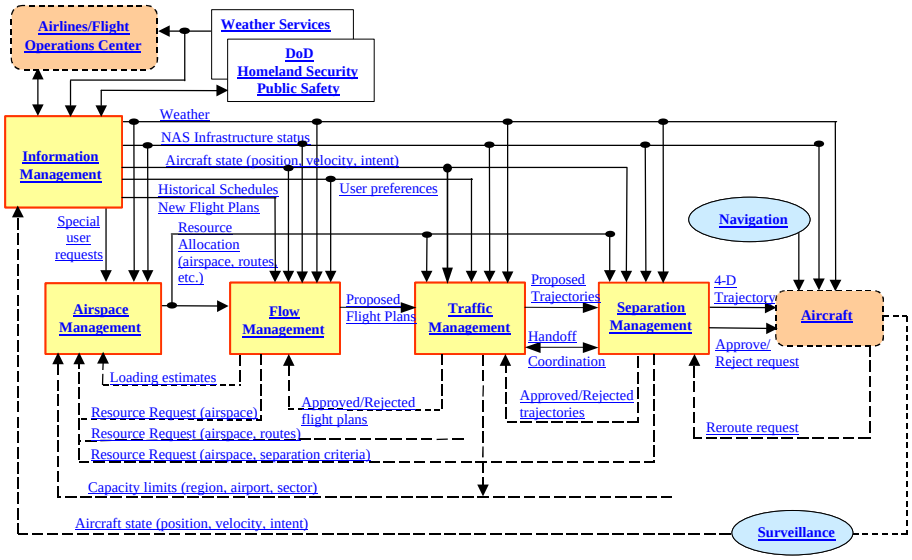

Figure 2. 2020 ATM Operational Concept Functional Flow

overloads, these actions can work at cross purposes, cause under-utilization 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 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 figure 3. The prediction time-horizons (PH) identify the overall temporal scope of a service. For example, re-routing around large convective weather

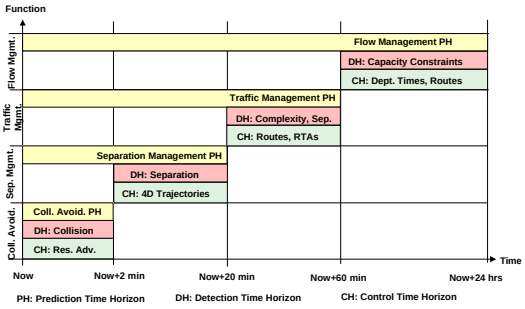

Figure 3. Time Horizon Partitioning for Services

areas in flow management will require a PH on the order of hours to capture the effects of a new plan, while collision avoidance is considered 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. The PH for the system functions may need to be adjusted dynamically, depending on system predictability for a given condition, and thus the boundaries between the services can vary with condition. Additionally, system predictability depends on the phase of flight and/or operational domain, e.g. the differences between pre-departure and in-flight state, and thus the time horizons are adjusted to operational domain and location.

The detection time horizon (DH) in figure 3 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 figure 3 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 detection horizon. 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 figure 3 is designed to avoid ambiguity in control authority. Section 8 presents a scenario that points to a number of details of the time horizon construct. The scenario brings to light coordination requirements between the functions, which, for the sake of clarity, are not illustrated in figure 3. 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.

5. 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), and assisting traffic and separation management in providing services with minimal disturbances from weather and congestion events. The flow management service detects capacity and demand imbalances across the NAS over a 24-hour 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.

Flow plan negotiations allow airlines to manage their schedules, to minimize the risks of delay propagation, cancellations and re-positioning flights. Inputs used by flow functions include the current state of aircraft, and wind data for trajectory predictions and resources capacity information for use by the capacity allocation functions, as indicated in figure 4 The flow management service is continually executed with an update rate sufficient to safely support other down-stream services. Depending on the dynamics of the NAS, weather or system disruptions may cause reduced predictability down to a few hours. Flight plan modifications in flow management are performed from 60 min. in the future up to the flow management prediction time horizon.

Collect Flight Plan Data: Accumulate flight plans for the planning horizon.

Allocate Flight Plans: Map flights onto resources by time slices. 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: Compare traffic loads with resource capacities. This function checks for resources 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, available for flight plan clearance at departure time. If capacity overloads are detected, a flow resolution action is initiated.

The resolution action is performed iteratively and collaboratively between the allocate capacity function and multiple FOC planner functions. The resolution includes a feedback loop through the allocate flight plans, detect overloads, allocate capacity, and the multiple FOC planner functions.

Allocate Capacity: Allocate capacities to individual users. This function first reduces available capacities by predicting usage by committed flights.

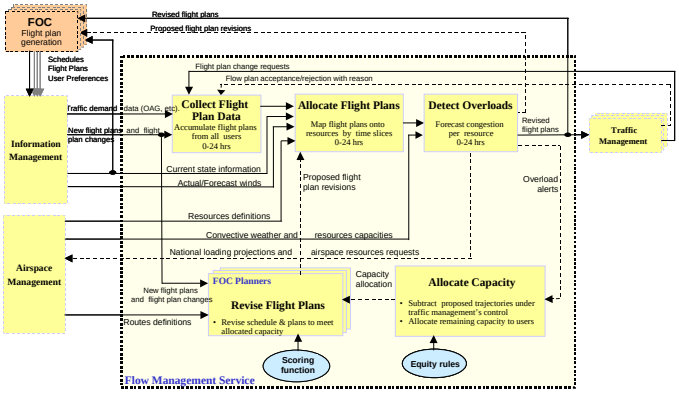

Figure 4. Flow Management Service

It then computes a time-dependent capacity constraint matrix for all resources and partitions the constrained resources to individual FOC planners using equity rules.

Revise Flight Plans: Negotiate revised schedules and flight plans among users. Individual flight operation planner functions use strategies and automation aids to examine their allocated capacity matrix and revise their schedules and flight plans to meet the allocated capacities. Each individual FOC planner uses its own objective function to balance re-routes with departure delays and cancellations and closely collaborates with the allocate capacity function to maximize capacity utilization and schedule integrity. The user objective function assigns value to each individual flight and considers such factors as number of seats or amount of cargo on board, the distance flown, the amount of delay incurred during the day or other cost and revenue related components of a flight. To account for delay propagation during the day, the revise flight plan function accesses the airlines flight planning databases. It has access to schedule connectivity information such as the equipment and passenger flows assigned to each flight. Once all flight plans have been allocated to resources and no overloads exist, revised flight plans are distributed to traffic managers and FOC agents.

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 such a flow plan is subject to a number of sources of uncertainty. They include the ability to accurately predict and continually update aircraft intent, the ability to predict departure times, and the ability to collect and store 4-D trajectory based flight plans and to determine their intent in the face of traffic and separation actions to 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 down stream 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.

6. 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 as 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 figure 5. Traffic assessment compares the current traffic situation with the traffic plan and

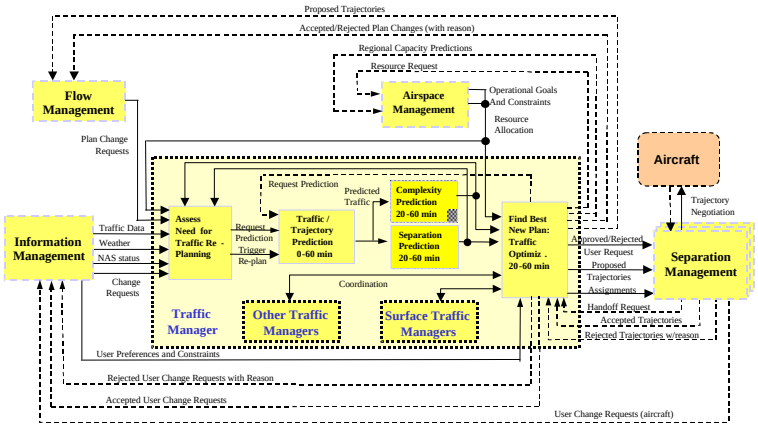

Figure 5. Traffic Management Service

evaluates the need for a replan. 4-D 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 multi-sector 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 pro-actively 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 using 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 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, 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 permit the determination of constraint violations. The computation of the spacing constraints may be based on pair-wise 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. Sub-functions of traffic optimization include: 1) Computing the efficiency metric for traffic planning; 2) Determining constraint compliance; 3) Defining a new trial plan considering user preferences; 4) inputs from other planning functions, constraints and performance goals.

The traffic management service will integrate planning of arrival, departure and en route traffic within the multi-sector 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 4-D 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 multi-sector region; 3) Dynamic 4-D trajectory allocation via waypoint designation and associated timing targets; and 4) Sequencing of aircraft through merges and intersections.

Inter-Sector Handoff and Coordination with other Traffic Managers: The traffic manager is responsible for handoff coordination between sectors as well as across multi-sector 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 multi-sector region are handed over to separation management for resolution. Conflict resolution on boundaries with other multi-sector regions are negotiated and resolved in cooperation with other traffic managers.

7. Separation Management Service

This service plans, communicates and monitors 4-D 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: 5 nm.
2) Terminal area: 3 nm, extending significantly farther from the airport than the current TRACON airspace.
3) In-trail final approach in VFR: determined by runway occupancy time.
4) In-trail final approach in IFR: limited only by low visibility runway exit performance.

5) Closely spaced parallel approaches: independent operations down to 750 ft centerline distance.

6) Vertical – 1000 ft all altitudes.

Figure 6 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 4-D trajectory for every aircraft in the sector or airport surface, out to the 20-min. prediction horizon, and communicates this 4-D 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.

The 4-D trajectory definition is a collection of 3-D (x, y, z) points in space, with associated estimated or required future time values. Associated with the trajectory definition is a 4-D conformance bound. The separation manager generates trajectories for each aircraft such that if they stay within their 4-D 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 upon 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 6 illustrates that the separation manager continuously monitors each aircraft's conformance to the cleared 4-D trajectory through the conformance monitoring function. This function will detect and alert 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. 4-D trajectory planning process, and the likely stringent safety and certification requirements on the separation management function, 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.

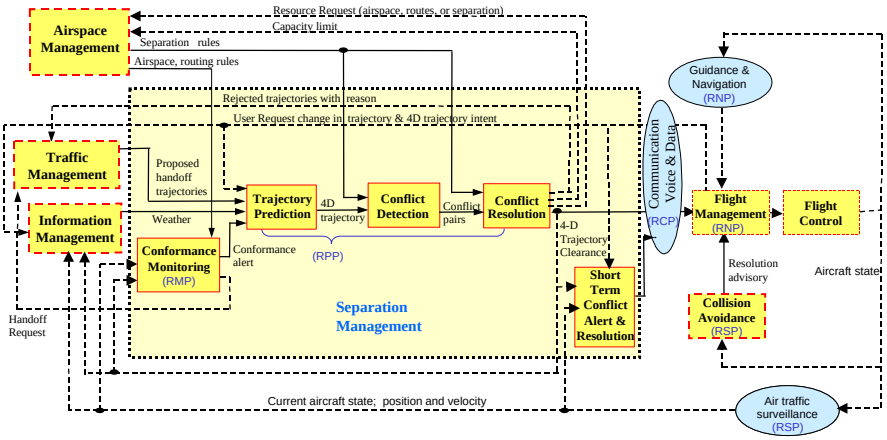

Figure 6. Separation Management Service

8. 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 [12].

As illustrated in Figure 7, 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.

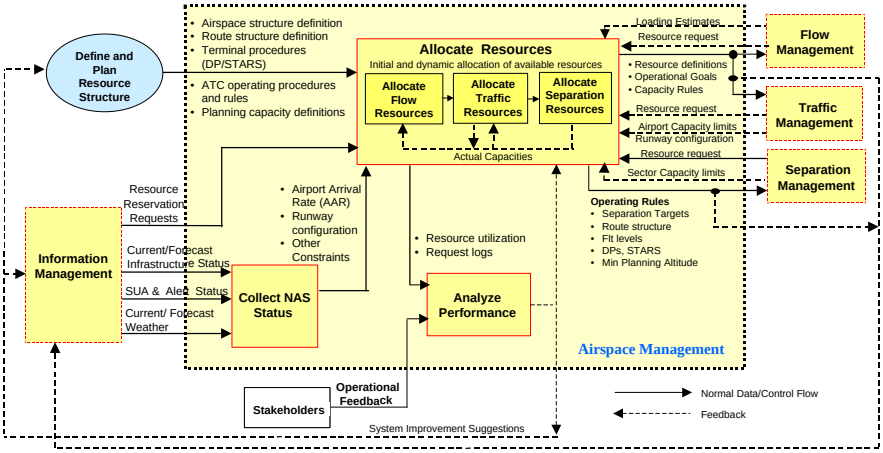

Figure 7 Airspace Management

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, etc. are collected to form the basis for an assessment of actual system performance levels (ATSP). 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 on-going 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.

9. 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. Latency, accuracy, staleness, and timeliness are performance characteristics of this service.

10. 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.

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 Boeing will evaluate the 2020 concept are: capacity, safety, security, access, flight path efficiency, environmental

efficiency, global interoperability, and affordability. Some measures will be quantitative (capacity) while 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. Since 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 which will provide a network-centric representation of NAS operations. The number and types of models required is 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 (FAA)'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 Boeing 2020 concept of operations. 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 system-wide 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 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 system-wide 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.

In order to identify the overall concept that adds the most value, a concept synthesis and assessment process is defined which will evaluate the OEP and the Boeing concepts of operations in the 2020 time period. The process starts with identifying the policies or assumptions that will guide the development of the overall operational concept. Solution elements (stand-alone concept elements that add value) will be identified and evaluated in terms of the incremental capacity, safety, and security benefits added and, the relative cost of implementing that solution element. When all the solution elements have been evaluated in a stand-alone manner, solutions will be combined into a solution package. Each solution package will impose requirements in terms of CNS, information, or decision support tools. Architecture requirements will then be identified that will take into account the baseline architecture that will be implemented by the OEP. Finally, solution packages will be evaluated against the entire set of MOMs and MOEs for the evaluation report card. If the solution packages do not satisfy the entire set of MOMs and MOEs, the process will be repeated with alternate solution packages.

Conclusion

We believe that a new methods and tools are required for concept exploration in order to better assess the costs and benefits of a new operating concepts and their associated ATM modernization costs. This requires a new standard for better defining and validating a future concept and a change to the process used to modernize ATM. The concept of operations summarized in this paper is the first step on the road to a new operational paradigm for air traffic management, one focused on a shared definition of flight and traffic intent. 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.

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References

1) Boeing Air Traffic Management, "Revolutionary Concepts That Enable Air Traffic Growth While Cutting Delays," June 2001.

2) Haraldsdottir, A., Schwab, R.W., and Alcabin, Monica S., "Air Traffic Management Capacity-Driven Operational Concept Through 2015," *Air Transportation Systems Engineering*, Donohue, G.L. and Zellweger, A.G., Editors, 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*, NEXTOR Report # RR-97-3, Oct. 31, 1997.

4) Boeing Air Traffic Management, *System Performance Requirements Document*, D780-10010-1, Seattle, Boeing ATM, January 31, 2002. Available online at http://www.boeing.com/atm/pdf/sprd.pdf.

5) International Civil Aviation Organization, "ATM Ops Concept document," Draft, March 26, 2002.

6) RTCA, Inc., Select Committee for Free Flight Implementation, *National Airspace System Concept of Operations*, Washington DC, RTCA, December 13, 2000.

7) Eurocontrol, *Operational Concept Document*, Edition 1.1, Brussels, Belgium, January 4, 1999.

8) Meckiff, C., Chone, R., and Nicolaon, J-P., "The Tactical Load Smoother for Multi-Sector Planning," *3rd USA/Europe Air Traffic Management Research and Development Seminar*, Orlando, Florida, December 1998.

9) NASA Ames Research Center, *Concept Definition for Distributed Air/Ground Traffic Management (DAG-TM)*, Version 1.0, NASA Advanced Air Transportation Technologies (AATT) Program, Moffett Field, California, September 30, 1999.

10) Boeing Air Traffic Management, "2020 Capacity Increasing Concept – Operational Concept Document," Seattle, Washington, January 15, 2003.

11) RTCA, "Application of Airborne Conflict Management: Detection, Prevention, and Resolution," DO-263, Washington, DC, 2000.

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