Preliminary Design Tools & Methods for Airspace Systems Definition

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ABSTRACT

As the demands on the National Airspace System (NAS) have grown, and the systems have become more complex, the ability to make successful modernization decisions has become problematic. The future development of the U.S. air transportation system will require wise investment decisions with clear criteria and metrics. Systems engineering tools and processes can be developed to provide guidance for NAS modernization decisions. This paper compares the preliminary design tools and methods used for large commercial airplane design and those that are proposed for application to the airspace systems. Risk can be reduced while value is increased, by starting with the quantification of the primary long-range objectives that the system must support over its design life, then conducting baseline performance and mission analysis, and finally developing requirements, and doing critical technology tradeoff studies in a disciplined manner. The paper proposes a set of preliminary design tools and methods for airspace systems definition.

INTRODUCTION

Consistent with the needs outlined in the National Civil Aviation Review Commission (NCARC) report [1] and by the NAS Modernization Task Force, this paper identifies tools and methods to support decision making for the future development of the U.S. air transportation system. A preliminary design methodology is outlined, consisting of tools and processes to provide the basis for a detailed mission analysis, operational concept development, requirements allocation, and investment evaluation for airspace system modernization.

In the near term, the FAA is implementing selected Communication, Navigation, Surveillance (CNS) and Air Traffic Management (ATM) enhancements as recommended by the FAA Administrator's recent NAS Modernization Task Force. However, there is recognition by the FAA, airlines, and manufacturers that additional significant decisions are required to deploy appropriate CNS/ATM technology in the 2003+ time period to avoid traffic gridlock. By developing robust decision making tools and methods now, both near term project optimization and long term investment decisions will benefit. Risk and value can be better understood and factored into decision making. The existence of clear criteria, metrics and performance data will also enable scrutiny by stakeholders and facilitate agreements.

WHERE WE ARE WITH NAS MODERNIZATION

Figure 1 summarizes Boeing's interpretation of the current system architecture and modernization process. It begins by identifying system needs and technology opportunities. A proposed technology is then subjected to a cost/benefit assessment to determine payback for the investment. While the process is moving the infrastructure development toward a more business-like basis for decision making, many difficulties remain. Each project tends to be evaluated independently, so that competing and complementary enhancements are not considered in the decision making. Also, benefits tend to be overstated while costs and risks are understated.

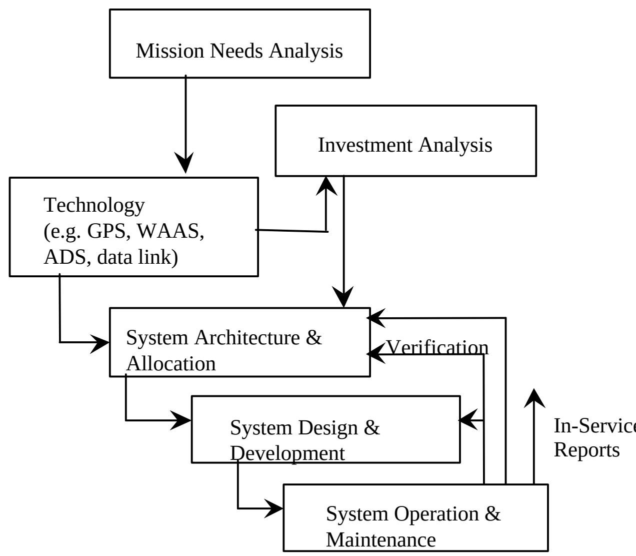

Figure 1. Existing System Development Process

System architecture efforts were also criticized for lacking an "operational concept[1]." To address this criticism, the FAA and RTCA have developed an operational concept for the NAS. Since the technology thinking had largely preceded the operational definition, the operational concept was centered on the insertion of technology into the existing system operation on an as-available basis. However, system goals and objectives should cause re-thinking of the operation.

[1] This term encompasses assumptions about roles and responsibilities of system agents (controllers, pilots, dispatchers, etc.), system resources (decision support tools, etc.) and their expected functions, and has a formal role in the system development process.

Thus we have arrived at a system architecture definition where it is difficult to assess the interrelationships among system long-range goals, system operational needs, subsystem technical requirements, and overall system architecture level investment

INDUSTRY SYSTEM DEVELOPMENT APPROACH

Figure 2 summarizes the systems engineering process used in the development of a large, complex system such as a major airplane program development or the National Airspace System modernization. This process divides the life cycle of a major system development into several distinct phases [2]. The definition of system requirements and objectives, analysis of functions and operations and definition of system architecture are termed "preliminary design." The remaining steps are the design and development of the system, integration of the system in the laboratory, validation testing, and system operation and maintenance. The discipline of the systems engineering process has been vital to the successful completion of airplane development programs, where a team of thousands of engineers develops and certifies a complex, real-time, human-in-the-loop, safety critical system. The development of a major Air Traffic Control (ATC) system upgrade is even more complex, because it shares the safety criticality and human-in-the-loop real-time nature of airplane development, and further requires that the existing system remain operational while supporting transition to the new system.

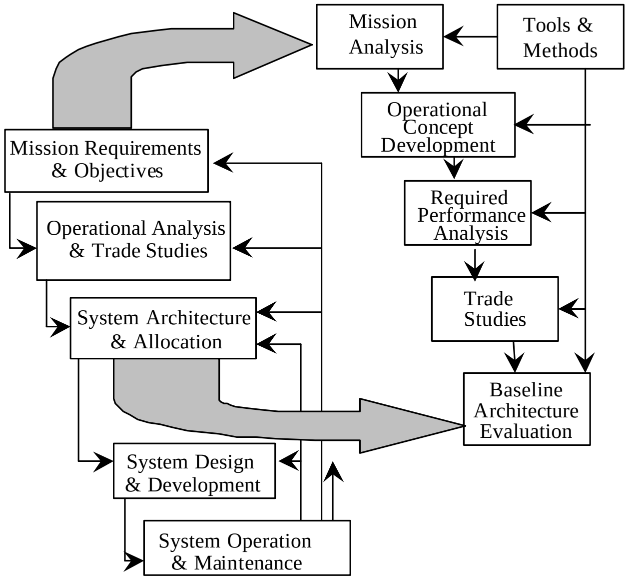

Figure 2. Systems Engineering and the Preliminary Design Process

In airplane development programs, the initial steps of the system engineering process and the initial steps leading to a system architecture are designated preliminary design. The function of the preliminary design is to clarify the product goals and objectives, to develop mission evaluation methods and tools, to define a wide range of configurations and technology options, to perform trade studies and to baseline a configuration for negotiation with customers. Figure 2 illustrates how this model can be expanded to perform the preliminary design of the NAS.

In the early development of the airspace system, technology opportunities were directly inserted into the architecture without conducting a full preliminary design process. As the airspace system was less complex and traffic demands were low, both the advantages and the method of inserting technology opportunities were more 'obvious', and an abbreviated design process was appropriate. In today's complex airspace system, which must meet increasingly demanding expectations while bearing very close scrutiny, a full preliminary design process is a necessity.

Preliminary design for the NAS has not been exercised to this extent before, and therefore tools and methods must be developed to support the preliminary design process. Boeing has proposed a framework for a NAS preliminary design activity [2,3,4]. To take a step toward implementation of this envisioned process will require applied research operations analysis, systems analysis, and significant analysis and simulation tools selection, some development, and integration into an analysis environment.

PRELIMINARY DESIGN FOR THE NAS

The envisioned approach starts with developing traffic demand scenarios and system missions analysis based on evaluating the capacity, safety and efficiency objectives of the various system stakeholders. An initial operational concept is developed to satisfy the system performance goals, based on available technology and human factors considerations. Operational requirements are allocated to subsystems and an evaluation of alternative technologies, human factors, and economics defines the architecture selection and transition planning.

Implementing a more complete preliminary design process for airspace system definition, as outlined above, will require customized tools and methods that can be used on a recurring basis as an aid to decision making.

ESTABLISH OBJECTIVES: This task is to identify the primary, quantified long-range objectives of the National Airspace System which the system architecture must support over its design life. These objectives are the basis of the mission analysis and requirements development, which in turn are used for technology tradeoff studies and baseline architecture. The system needs, requirements, operating concept and technologies must be evaluated against the long-range system objectives to assess the adequacy of a proposed system architecture.

Various airspace users may have conflicting views of future needs, so a forum is needed to derive a consensus set of system objectives. Methodology and decision aid tools can be defined to assist in the process of selecting airspace system objectives.

BASELINE CURRENT SYSTEM PERFORMANCE: This task involves the selection of system evaluation scenarios for establishing baseline performance of the current airspace system, and for evaluating the required performance in the future airspace system.

While the underlying functions of the airspace system may be simply characterized, the performance and behavior of the system agents (flow managers, air traffic controllers, pilots and dispatchers) is complex and difficult to characterize. The selected baseline of the current system provides a basis for the evaluation of the most important current and future system 'performance states'. The challenge here is to reduce the performance characterization to a manageable set of conditions which include weather, rare-normal and abnormal events in a set of baseline operational scenarios.

Subsystem performance benchmarking is also required to determine the performance of the CNS and ATM elements of the current system. Defining the performance of the existing navigation, communications, radar, and air traffic and flow management systems is an important indicator of current system operating capability.

A set of tools and methods can be developed to baseline current system performance. The delivered tools and methods may be applied on individual airports, or traffic centers, or to an entire airspace system.

PERFORM MISSION ANALYSIS: The Mission Analysis Task involves forecasting the future demand on the air transportation system. The generation of traffic demand involves the prediction of the commercial airplane, general aviation, military and business jet future flight activity levels. For the commercial airplane segment, the forecast begins with a city-pair analysis of U.S. domestic and international flight segments. Based on assumed economic growth, average airplane size, assumed airport infrastructure, and airline hubbing and schedule frequency assumptions, a nominal flight schedule (similar to the Official Airline Guide) can be developed.

The conversion of the flight schedule into a traffic demand model is based on a modeling of the system-wide flight planning activity, which translates the origin-destination schedule into flight profiles. These flight profiles are based on assumptions of the future concept of operations dealing with postulated airspace and airways future use. The flight profiles also are based on assumptions of how users will fly between city-pair destinations, e.g., how the airline fleet will be used including assumptions of single airplane flight planning criteria.

The traffic demand model is the basis of the derivation of a traffic loading model which estimates average and peak center, sector, terminal area, final approach and landing and surface operations counts. This model can be established, based not only on the nominal flight schedule, but assumptions of various contingency responses to system perturbations. The set of operational scenarios to be evaluated for the system loading model are established as part of setting the system baseline.

Mission analysis tools and methods can be developed into a standard protocol for recurring use.

DEVELOP OPERATIONAL CONCEPTS: An operational concept is a description of the functions performed in the system to deliver the required services, along with an assignment of these functions to system agents and/or equipment. The air traffic management process turns flight schedules into aircraft movement. Primary functions are flight planning, flow planning, air traffic control and guidance and navigation.

The full range of potential options for traffic flow planning must be investigated, and a tradeoff between potential benefits and the associated technology costs performed. The potential improvements in airspace system information infrastructure, automation tools for arrival management and en route control, and collaborative decision making are the cornerstones around which the future concept should be built. The optimum allocation of delay response to predicted capacity/demand imbalance must be explored, ranging from national, regional, facility to sector or multi-sector level. A key trade in this regard must be made between the uncertainty inherent in predicting conditions hours ahead and the need to protect elements of the system from overload and preserve safety.

The performance of the separation assurance function, which includes the guidance and navigation element, must also be examined for potential improvements against the capacity, safety and affordability objectives.

ANALYZE REQUIRED PERFORMANCE: The traffic loading model together with the baseline operational scenarios, the system performance targets and the operational concepts can be used to derive performance requirements for the various system functions. Concepts for changes in traffic flow management and separation assurance can be evaluated for each of the operating regions of the system and the various operational scenarios to derive requirements for subsystem performance to support a given system performance level.

Projected airspace operations create a traffic demand for future air traffic services. The nature of the service should be responsive to the complexity and density of the flights in a region of airspace. Boeing has been developing tools to analyze and structure the complex operational and performance elements of the airspace [5]. An airspace constraints model has been developed which identifies key performance parameters that affect the throughput for each operating region in the system. For each region a tradeoff can be made on the alternative performance factors that can achieve a certain throughput performance for that region.

The derivation of the technical performance requirements for each of the operating locations and flight conditions is based on a detailed operations analysis.

The technologies considered must be evaluated to assure they meet the technical requirements imposed for the design environment (system traffic loading), and for the design life of the system. In the examination of technical performance requirements, it is critical that we recognize not only the nominal performance requirements but also the detected failure performance and the undetected failure performance.

Analysis of the required performance can be facilitated with a set of appropriate tools and a structured methodology.

PERFORM TRADE STUDIES: Based on the requirements assessment, subsystem trades can be performed to evaluate the costs and effectiveness of candidate technologies in meeting requirements. Trade studies can be made using data drawn from a technology database, as well as a human performance database. Trade studies are performed to establish the alternative solutions for the communications, navigation, surveillance, air traffic management and traffic flow management subsystem technical requirements. Cost and performance across the range of requirements can be established. The tradeoff data will relate performance levels, life cycle costs (for both the agency and the users), operational benefits, and technical and functional integration risks. This forms the basis for architecture decisions based on what is affordable and delivers the needed NAS performance improvements. Generalized trade study methods and tools can be provided for airspace system applications.

PLAN SYSTEM TRANSITION: The selected architecture must be evaluated in terms of a transition plan, centered around the operational improvements supported by the introduction of groups of enabling technologies. The enablers are related to the enhancement steps, and consist of technologies, standards and criteria, and airspace and procedures design. The architecture represents the technology choices made across all system operating regions, and this view can have an influence on architecture choices and the phasing of technology introduction in the final system architecture.

System transition planning tools have been developed for evaluating complex airspace inter-relationships of technology element performance and system-level operational impact [5]. These tools can be provided for application to ongoing airspace system planning.

AIRSPACE SYSTEM DESIGN TOOLS: An extensive analysis and simulation tool set is necessary to support the forecasting, requirements allocation and evaluation phases of an airspace system preliminary design process. Along with focused methodologies for each area and a unifying methodology for the overall system, the tool set can greatly assist optimization of current modernization projects and decision making for future enhancements.

A MODEST PROPOSAL

The development and application of the tools and methods described in this paper needs to be undertaken to provide an improved basis for making future NAS technology investment decisions.

Figure 3 summarizes the recommended approach to be evaluated in a joint FAA, NASA and industry research project. This project would be based on the development of methods and tools for analysis and simulation to provide a disciplined framework for the evaluation of a wide range of possible future scenarios of growth, operational concepts, and technology investments. The approach emphasizes the generation of trade data for a broad range of alternative courses of action, rather than early prototyping and implementation of a point solution. The trade data and performance evaluations provide suitable metrics for measuring airspace system enhancement potential and on-going performance.

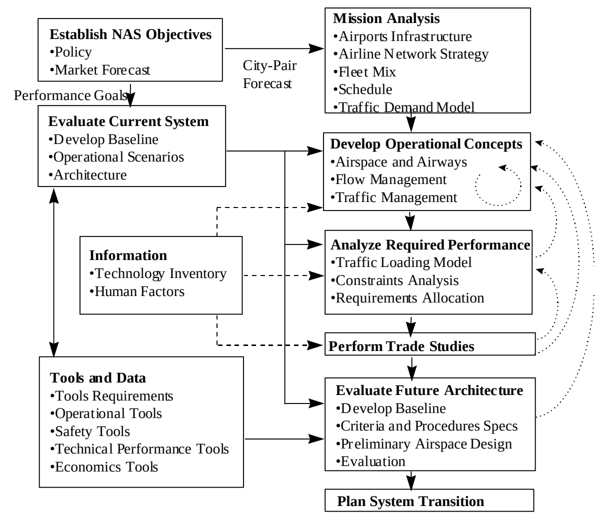

Figure 3. Methods & Tools Project Process

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