Common Trajectory Modeling Services for NAS

Decision Support Tools

Research Management Plan

30 May 2002

Common Trajectory Modeler Research Management Plan Approval Page

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1.0 Introduction

1.1 Purpose

The objective of this Research Management Plan (RMP) is to establish the approach by which the FAA can most effectively conduct the research and development (R&D) necessary to assess the feasibility of providing common trajectory modeling (TJM) services[1] for the various National Airspace System (NAS) Decision Support Tools (DSTs) that support en route, terminal, and TFM operations. Based on this research, a decision will be made on whether to pursue the deployment of these common services into the NAS. Candidate DSTs are trajectory modeling applications in Free Flight Phase 1 (FFP1), FFP2, and others in the research pipeline. The goal for common TJM services is to achieve R&D, F&E, and O&M cost savings, and to increase interoperability across DSTs by developing and maintaining the common services for shared use across the many current and future DSTs that require TJM services.

1.2 Background

The FAA/NASA Interagency Air Traffic Management (ATM) Integrated Product Team (IAIPT) was established in September 1995 to coordinate and manage the ATM R&D efforts of the two agencies. The IAIPT consists of an Interagency Integrated Management Team (IAIMT) responsible for providing executive leadership in the planning and performance of a relevant and dynamic national ATM R&D program, and six Area Work Teams (AWTs) tasked with planning and performing specific research activities in each of six areas (surface, terminal, en route, traffic flow management, oceanic, and system/cross-cutting). The topic of common trajectory modeling services comes under the purview of the cross-cutting area work team with support from the other area work teams.

A critical aspect of conducting a responsive ATM R&D improvement program is the ability to transition new capabilities out of the research arena into the operational environment of the NAS. The *Integrated Plan for ATM Research and Technology Development, Volume 1* [1] defines an ATM R&D program that reflects the system life-cycle realities. As identified in this plan, the FAA/NASA IAIPT currently plans and manages the Concept Exploration and Concept Development phases of the life cycle. Responsibilities for prototype development and validation[2], full-scale development, and deployment, transfer from the IAIPT to the appropriate domain integrated product team (IPT) as the research effort matures. With the establishment of the Free Flight Phase 2 (FFP2) program, it is anticipated that the Free Flight Program Office (AOZ) will oversee selected projects during the Concept Exploration phase and provide project management at the initiation of the Concept Development phase. The *Research Management Process for Developing New Concepts and Capabilities for the NAS* [2], currently being established by the Program Director for R&D (ARQ-20), provides overall guidance for the activities associated with the early life cycle phases. In addition, the *System Prototypes in Operational Air Traffic Control Facilities: Development and Evaluation Process Guidelines* [3], developed by the Program Director for Architecture and System Engineering (ASD-100), provides additional guidance for the field installation and evaluation of research prototypes. This RMP considers the guidelines established in both of those documents.

1.3 Scope

This RMP addresses the research necessary to define and establish requirements for common TJM services for NAS DSTs and the process for managing their possible development through the Concept Exploration, Concept Development, and Pre-Production Prototype Development phases.

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[1] The view that a common information network would support the sharing of trajectory-based information is also stated in Boeing's document, "Air Traffic Management: Revolutionary concepts that enable air traffic growth while cutting delays".

[2] As defined in the *Integrated Plan for ATM Research and Technology Development*, this phase may include continued coordination with the IAIPT and R&D resources.

An iterative process (see Figure 1.1) will be followed consisting of:

- Fidelity study
  - identify characteristics of trajectory modelers affecting trajectory accuracy
  - determine sensitivity of errors to identified characteristics
- Investigate evolution of services
  - define NAS evolution stages and operational needs for each stage of relevance to TJM
  - determine target requirements and required characteristics for TJM at each stage of NAS evolution
- Identify/refine and assess alternative approaches (cost/benefit) for the following
  - databases
  - algorithms
  - data standards
  - architecture
- Provide options with business case for the evolution of common trajectory services.

Given the diverse and complex nature of current and future ATM DST applications, it is anticipated common TJM services will be developed and introduced in a spiral-evolutionary approach. Research activities within the Concept Exploration stage will identify cost-beneficial "bundles" of common TJM that represent good candidates for further development. At the completion of the Concept Exploration phase, the FAA will determine which alternatives to further evaluate and pursue. After the Concept Development phase, for each spiral stage, the FAA will determine whether the alternative chosen is operationally suitable and acceptable and whether it needs to proceed to the Pre-Production Prototype Development phase. Upon such a decision, the capability will be transitioned to the appropriate IPTs for implementation and a facilities and equipment (F&E) program will be established.

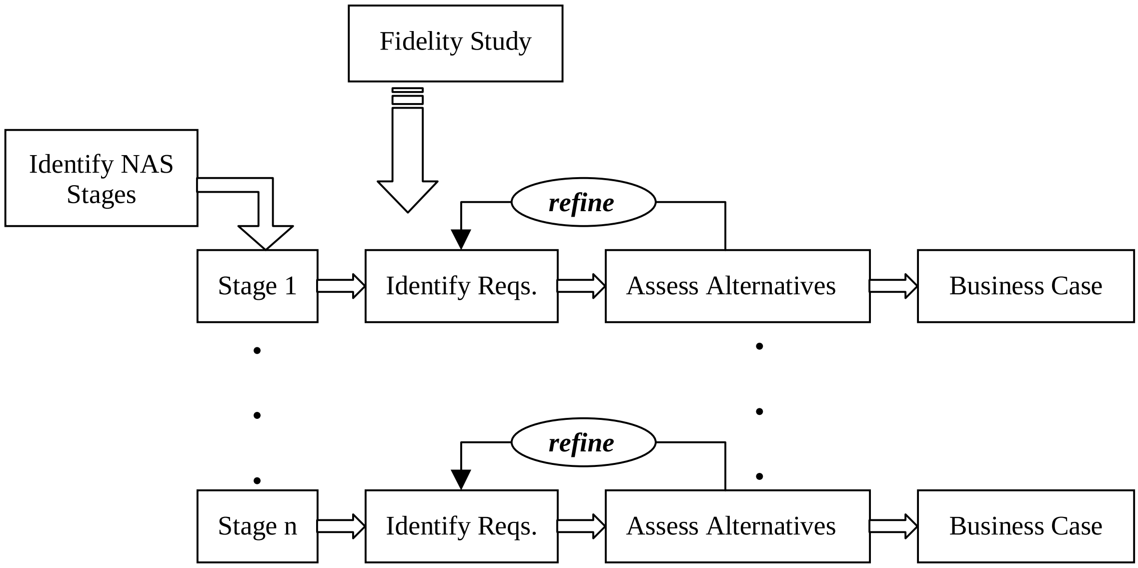

Figure 1.1 – Summary of iterative process.

1.4 Document Organization

This document is divided into five sections. Section 1 addresses the purpose and scope of this RMP, and provides background concerning the RMP process and rationale. Section 2 describes the candidate common TJM services, including their operational concept of use, functional/interface components, linkage to FAA planning documents, and expected outcomes and outputs. Section 3 provides a summary of the research management process, including development methodology, the roles and responsibilities of the participating organizations, and a milestone schedule (TBD). Section 4 (TBD) provides a summary of the current research status and issues, and an operational and technical issues resolution matrix. Finally, Section 5 (TBD) provides a plan to transition each capability to the implementing FAA organizations.

2.0 Description of Proposed Capability

Many FAA and NAS user decision support systems have underlying trajectory modelers. Trajectory modelers predict the path that aircraft will follow in three-dimensional space and in time. The trajectory modelers themselves, designed for different levels of fidelity, accuracy, and update rates, often differ in several ways. At the most fundamental level, different modelers are often based on different mathematical models. Differences also exist in terms of their input data sources. Finally, the modelers are typically operated at different update frequencies thus resulting in the asynchronous update of trajectory predictions (for any one flight) across DST applications. These differences might result in operational contradictions, inefficiencies, or incompatibilities.

Common trajectory modeling refers to a capability to provide common services to subscriber DSTs. Three distinct levels of common TJM services have been identified: common data; common modules, and common architecture. Although the ultimate extreme in common TJM services would result in the provision of a common trajectory prediction to all subscribing DST applications, it may be possible to achieve most of the benefits, by implementing simpler aspects of common TJM services.

The simplest level of common TJM services may be realized through the use of common sets of adaptation data.* This level of common TJM service involves the centralized compilation of adaptation data, as it is updated, and distribution for use by any DST application that subscribe to the data. Common modules refer to the use of common software routines that are compiled directly into the DST TJM applications. Common architecture refers to a broader level of common TJM services whereby the subscribing DST applications are modified to use a common TJM software architecture.

The definition of a common-TJM architecture is a part of the common TJM R&D. However, three candidate architectures—a central NAS server, a local server, and a distributed approach based on a library of common TJM service modules—are discussed below for illustrative purposes.

The following sections provide more detailed information about the various potential levels of common TJM services and about the common adaptation data capability. An operational concept is presented; required NAS interfaces are discussed; the capability is related to the *RTCA National Airspace System Concept of Operations* and *the NAS Architecture*; and the expected outcomes, outputs, and benefits are presented.

2.1 Operational Concept of Use

The direct users of the common TJM services are the DSTs, operated by the FAA and NAS users, that require these services. The capability is largely transparent to the human users of the systems, but resultant information is often presented to those users. The direct users of common airspace adaptation data are the DSTs and the software that provides the common TJM services. The DSTs will operate as designed and the common TJM services/common adaptation data capability is transparent to the human users of the systems.

Common trajectory and common adaptation data research is currently in the concept exploration stage and consequently, many operational concept details are unknown at this point. The following sections discuss known aspects of the operational concept for common trajectory modeling and common adaptation data. Where details are unknown, several options are presented.

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* Although there are some differences in the trajectory modelers' input data, all require and use airspace adaptation data. This adaptation data is typically updated on 28- and 56-day cycles. When this occurs, the adaptation data is recompiled independently for subscribing DSTs. Operations and maintenance costs could be reduced if the adaptation data processing were done once and the compiled data used by all applications. It is believed that a common trajectory, certain common services, and common adaptation data would prevent or at least minimize differences across DSTs and thereby solve or mitigate the problems that can result from these differences. The same issues and philosophy can be extended to include other types of TJM input data such as aircraft performance and aircraft operations data.

2.1.1 Common Trajectory Modeling Services

Common TJM service modules will be used to build trajectories for subscribing DSTs as needed by the DSTs. DSTs typically need trajectories modeled when they receive significant changes in aircraft state (e.g., track position and velocity) and intent (e.g., flight plans/amendments and interim altitude clearances). In addition, DSTs can request the modeling of candidate trajectories to support DST-specific functions (e.g., advisories for conflict resolution and/or flow conformance). For example, requests can include control inputs, or constraints that the modeler is to satisfy. These inputs and constraints can be generated manually or automatically by the DST.

The following bulletized list is an initial description of common TJM services required by DSTs. Considerable research and coordination will be needed to refine it. Sub-bullets describe the service and list the output from the service.

- Route Conversion – Transform flight plan route into a series of points in a given two-dimensional coordinate system. Route conversion includes airway expansion and preferential route application.
- Lateral Path Initialization – Determine a path from initial point to route. Service user can optionally control the initialization by specifying turn back to route and rejoin route positions.
- Transition Determination – Determine transitions needed to meet altitude, speed, and flight plan delay constraints. Constraints include assigned altitude and speed, altitude and speed restrictions, interim altitude, and flight plan delay. Service includes transition start time and other parameters specific to the transition.
- Altitude and Speed Modeling – Determine altitude, speed, gradient, bearing, acceleration at transition points and other cusps in route. Model constant rate turns. Results together with converted route represents trajectory.
- Boundary Crossing Determination – Determine points and times of center and sector boundary crossings.
- Trajectory Error Tolerance Specification – Specify maximum allowable trajectory – track difference in lateral, longitudinal, and vertical dimensions. Vary tolerances for special airspace, aircraft equipage, turns, and altitude transition.
- Trajectory Error Monitoring – Monitor trajectory error in lateral, longitudinal, and vertical dimensions. Generate a “tolerance exceeded” condition when error exceeds tolerance for a given dimension.
- Trajectory Recalibration **-** Given a “tolerance exceeded” condition, determine how the trajectory should be rebuilt.

The core common TJM service generates the predicted path of an aircraft. This trajectory is four dimensional, and is envisioned as being specified as a series of points in three dimensional space and time. Trajectory turns will be modeled as being instantaneous or alternatively as arcs (with turn paths modeled as “fly-by” or “fly-over” depending on the adaptation-specified nature of the turn waypoint). The trajectory will be specified using a selected coordinate system and selected units for coordinate components. DSTs will be responsible for any needed conversions from this format to their own.

Each of the common services presented above (high-level bullets) could be implemented as a module. The resulting set of modules can then be used as a common set of TJM building blocks to support any of the candidate architectures (presented in detail below). In cases where unique/different approaches (e.g., kinetic vs. kinematic) are needed within a module to support different DSTs (e.g., different vertical-profile modeling for CTAS FAST and EDA applications), the approach options may be modeled in one of two ways: either as options within the module, or alternatively as unique derivatives of the same module.

Trajectory modeling performance requirements, e.g., modeling fidelity, accuracy, and speed, are seen as part of the common TJM research and will be determined during the course of the research. The common TJM services must meet the collective “requirements” of subscribing DSTs.

2.1.2 Common Adaptation Data

The following is an initial list of common adaptation data.[3] The need for a high-priority task focusing on the standardization of adaptation data was identified in an FAA letter from AAR-230 to AIO-2.4

Two types of adaptation data are identified, airspace adaptation data, referring to data defining the structure of the airspace, and aircraft adaptation data, referring to data required to model the behavior of aircraft.

2.1.2.1 Airspace Adaptation Data

Airspace adaptation data will be compiled when scheduled (56-day) and interim (28-day) updates occur. The data will be gathered from selected sources (e.g. ACES, DACS, Jeppesen, etc.), compiled, and written out in a single, common format. All trajectory-modeling DSTs will have access to the common adaptation data. In particular, this data will be made available to the modules that provide common TJM services. Applications will be responsible for any needed conversions from common adaptation data units. Some adaptation data include default schedules (e.g. SUA, LOA, SOP) that can be dynamically updated during operations. The applications are again responsible for capturing the change and updating the runtime database.

The following is an initial list of common, airspace adaptation data.

- Airway definitions
  - High and low altitude routes
  - Preferential routes (PARs, PDRs, PDARs)
  - ATC preferred routes
  - SIDs and STARs
  - Coded routes
- Fix and airport definitions
- Center and sector definitions
- Special use airspace (SUA) definitions
- Planned holding areas
- Altitude restrictions
- Flow restrictions
- Transition lines
- Facility plan

2.1.2.2 Aircraft Adaptation Data

Aircraft characteristic data is likely to be less dynamic than the airspace adaptation data. This data will be compiled and updated in response to specific events (new aircraft, changes in company policies), or at regularly scheduled intervals. An initial list of aircraft adaptation data follows.

- Aircraft characteristics data
- Pilot models

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[3] Atmospheric data such as wind grid data is not really airspace adaptation data, but are needed by DSTs that perform TJM and benefits are likely to accrue from common standardized atmospheric data. Unlike adaptation mentioned here, wind forecast data is more dynamic, and may have to be converted (into a common format) when forecasts become available.

- Company preferences

2.1.3 Architecture

There are several architecture options that could be used in implementing common TJM services. Each approach has a set of associated benefits and drawbacks. Research will be needed to decide which approach would be the most effective. A few options are presented in this section.

- Central NAS server (option)
  - Fully functional trajectory modeler
  - Single location within NAS
  - Serves all DSTs within NAS
  - Architecture (sub-options):
    - Mainframe
    - Distributed Processing
      - By priority of service
- Local server (option)
  - Fully functional trajectory modeler
  - Located in each NAS facility (e.g. TRACON, ARTCC, ATCSCC)
  - Serves all DSTs within the facility
  - Architecture (sub-options):
    - Mainframe
    - Distributed Processing (sub-options)
      - By priority of service (e.g., Active vs. Provisional)
      - By DST. (e.g., several TJM servers could be deployed at each facility with each server providing services to a fixed set of DSTs).

- Common TJM Library approach (with supporting library of common modules)
  - Selected modules linked to build trajectory modeler for each DST
  - Custom trajectory modeler for each DST

Central Server

The central server approach is to develop a common trajectory modeler to provide TJM services to DSTs in the entire NAS. Two architectures are considered for the centralized server: a single-system architecture, and a distributed architecture.

Under the single-system architecture, all services would be provided by one system capable of providing services of various priorities. This approach ensures the highest level of consistency between modeling services at all priority levels. Note that this architecture does not preclude the existence of redundant hardware for reliability considerations.

Under the architecture distributed by priority of service, the same software would be located on two servers. Both would reside in a single location within the NAS. The high-priority server would provide the modeling services required to maintain current plan trajectories. The other server would provide the modeling services needed to support DST trajectory requests. All NAS DSTs could request and/or receive trajectories from the two servers.

The high-priority modeler would receive flight plans and amendments at the same time as the DSTs and would generate a single trajectory. It would receive reconformance requests from its track management function and remodel the current plan trajectory accordingly. Current plan trajectories are passed to the lower priority modeler and to subscribing DSTs. This ensures that all DSTs are using the same current plan trajectory for an aircraft at any given time. The lower priority common modeler would service requests for provisional plan and meet-goal trajectories.

The potential benefits and drawbacks of the central NAS server approach include:

- Potential Benefits
  - Maximum potential for common current plan trajectories across the NAS
  - Load sharing provides better utilization of hardware resources
  - Lower equipment and software maintenance costs
- Potential Drawbacks
  - Application-requested trajectories modeled at a remote location and response to requests may not be timely
  - Server is single point of failure across the NAS
  - Burdensome data processing and data communication requirements (e.g. flight plans, track reports, trajectories)

Because the data communication cost is expected to be excessive and the data latency is expected to be too great to meet the requirements of time-critical, tactical applications, the central NAS approach is not thought to be a viable one.

Local Server

The local server approach is similar to the centralized server approach in that two architectures sub-options may be considered: a single-system architecture and a distributed architecture. Unlike the centralized server, identical trajectory modelers would reside within each facility thus providing robustness to prevent a single national point of failure.

Under a single-system architecture, a single trajectory modeler would reside at each facility providing all priorities of services to all local DSTs. To ensure consistency between facilities, the trajectory modeler should be identical to trajectory modelers contained at other facilities. Figure 2-1 illustrates the mainframe architecture for the local server.

Under the distributed architecture, several possibilities are considered: distributed according to priority of services, distributed by DST, or a combination of the two. In all cases, common data would be shared facility-wide by all trajectory modelers. Figure 2-2 illustrates an architecture distributed by priority of service. In a manner similar to the distributed centralized server, identical copies of the trajectory modeler are used to provide either level of priority services to the individual DSTs.

Figure 2-3 illustrates an architecture distributed by DST. Multiple identical copies of the trajectory modeler would reside at the facility and support specific DST applications. At the most distributed level, each DST could have access to one trajectory modeler for its own exclusive use.

The potential benefits and drawbacks of the local server approach include:

- Potential Benefits

- Maximize potential for common current plan trajectories across DSTs operating within the same facility (if not distributed by application)
- Provides some measure of redundancy and backup in that it prevents a total collapse by a single point of failure (i.e., if one facility goes down, it doesn't take the other 20 facilities down as would the central server approach).
- Distribution by priority prevents lower priority TJM requests from impacting the performance of providing high-priority TJM services (i.e., current plan trajectories).
- Distribution by application provides a measure of redundancy to protect DST applications from a failure in the TJM services for another DST application (i.e., not all DSTs go down if one TJM modeler goes down.
- Lower intra-facility data communication requirements (if distributed by application)
- Lower equipment and software maintenance costs

- Potential Drawbacks
  - Application-requested trajectories modeled by a single processor within each facility, response to requests may not be timely
  - Server is single point of failure within facility
  - Heavy intrafacility data communication requirements (if not distributed by application)

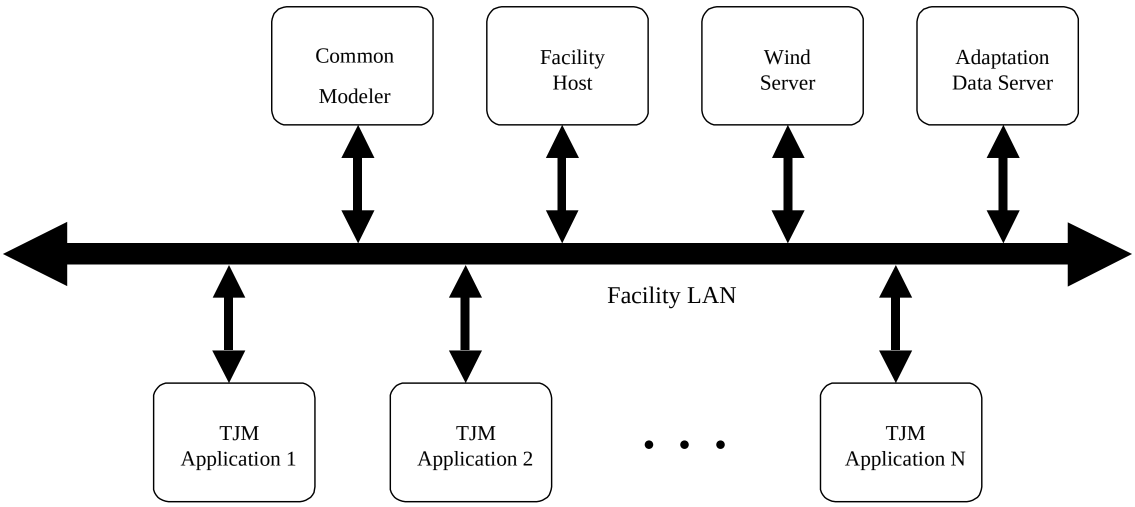

Figure 2-1. Architecture for Local Server Single-System Approach

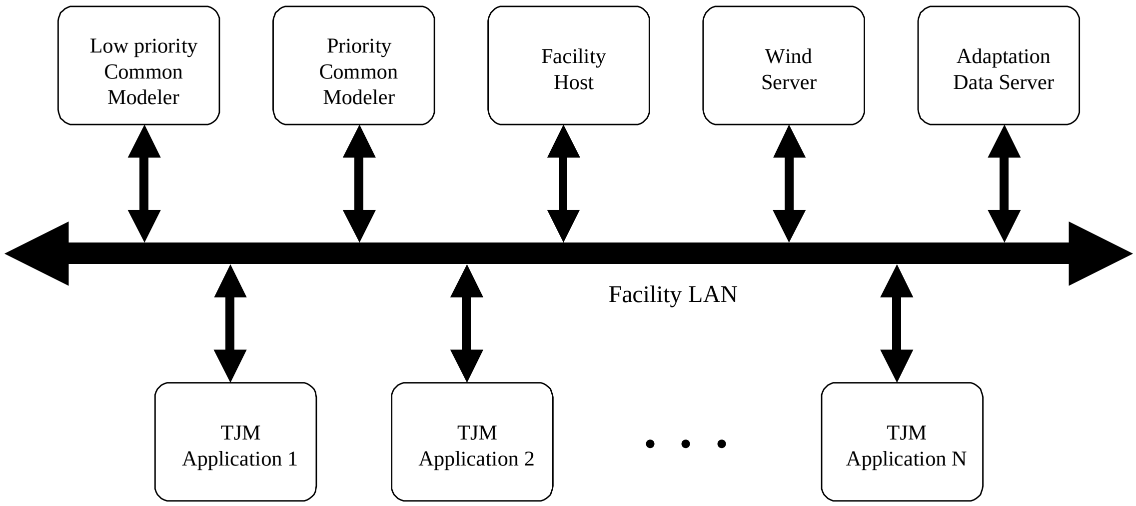

Figure 2-2. Architecture for Local Server Distributed by Priority of Service

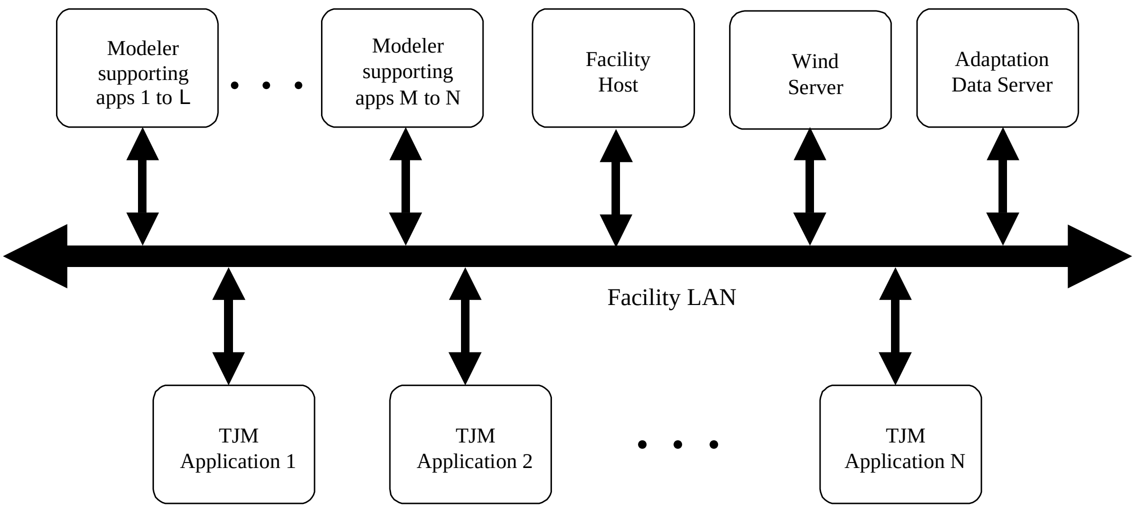

Figure 2-3. Architecture for Local Server Distributed by DST.

Common Library

Under the common library approach, each DST's trajectory modeler would be "custom-built" from modules in a common library. Not every component of a TJM would be required for each application, thereby tailoring performance for each DST. DST and modeler software would be collocated and trajectory modeling is distributed across DSTs. New DSTs would not be required to redefine trajectory-modeling functions from scratch, but would be required to use the applicable modules from the common library. Whenever a production version of the library is released, all DSTs using the library would have to be updated as part of the CM process. Figure 2-4 illustrates the distributed approach to provide common TJM services. The benefits and drawbacks of this approach include:

- Potential Benefits
  - Distributed trajectory modeling helps to ensure timely response to trajectory modeling requests
  - Little or no cost to send trajectory to applications
  - No single point of failure as in a server approach
  - Lower transition costs as it is potentially easier to replace modules than to implement/test a new system
- Potential Drawbacks
  - DST trajectories may not be "common" if DSTs use different set of services
  - Higher equipment and software maintenance cost than with a more centralized approach

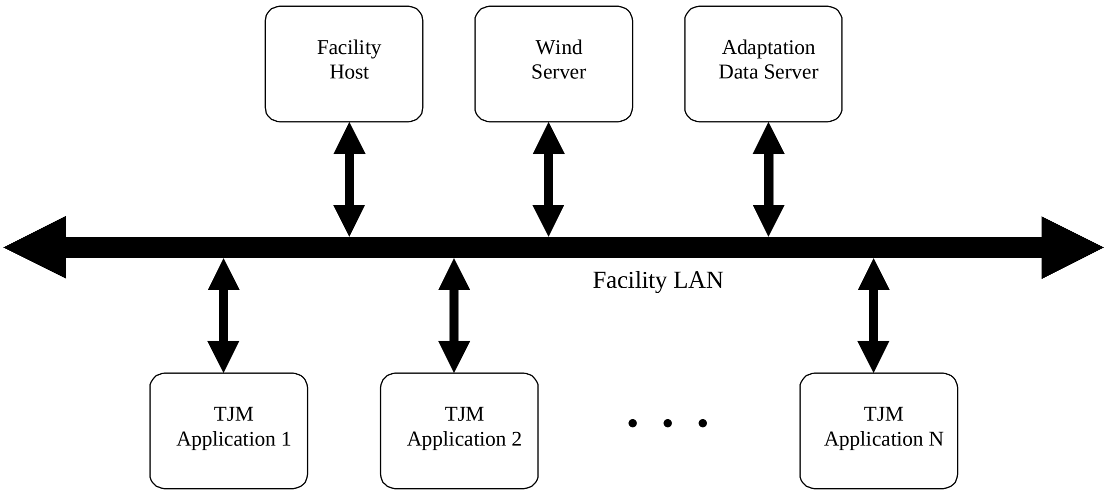

Figure 2-4. Architecture for Common Trajectory Modeling Services

2.1.4 Data Maintenance and Distribution

Trajectory modelers use data from various sources to model trajectories. These data include cleared intent data (e.g. flight plans, amendments, interim altitudes), application requests (e.g. trial plan, reconformance, and requests to model a trajectory to meet a specified goal), adaptation data, and wind forecasts. Most of these data are dynamic, being provided to the modeler in real-time by the facility computer (e.g. ARTCC Host) or the application program. As such, no off-line maintenance is needed for this data. Adaptation data, which consists of ATC adaptation and other data such as aircraft characteristics and modeler parameter settings, are more static. ATC adaptation data is updated periodically. When this occurs, the data will be collected, compiled, and stored electronically as common adaptation data for use by the common trajectory modeler. This task will be performed by a server located in each facility. After the compilation, the server will share the common adaptation data with the common trajectory modeler and subscribing applications within the facility.

A communication infrastructure will be needed to support data distribution among the common trajectory modeler, the TJM application, the ATC facility host computer, wind server, and adaptation data server. This infrastructure will be highly dependent on the architecture being used to provide common TJM services. Figure 2-1 illustrates a communication infrastructure that could be used with local server architecture. The facility host computer, the critical and non-critical common trajectory modelers, the wind server, the adaptation data server, and subscribing applications are interconnected via a LAN. Interface software can be located within each network member or in an interface box that connects each member to the network. Full connectivity is possible though not needed or desired in some cases. The non-critical common modeler can receive current plan trajectories from the critical modeler. Trial plans, and requests to meet specified goals, are processed by the non-critical modeler as modifications to the current plan. The LAN also allows applications to share results facilitating coordination between application users and possibly eliminating the need for duplicate processing.

Figure 2-2 illustrates a possible communication infrastructure for a distributed common-trajectory modeler architecture within a facility. This figure is very similar to Figure 2-1. The difference is that there is no box in the Figure 2-2 to depict the common trajectory modeler because, under the distributed architecture, the common modeler is a library of routines **that can** be linked with the application programs. Communication between applications and the common trajectory modeler is internal to the applications and the LAN is not needed to support it.

2.2 Functional/Interface Components

Common trajectory modeling and common adaptation research is in the early stages of concept exploration. If and when the concept is shown to be feasible, current and future NAS and user trajectory modeling applications will be candidates for integrating the common trajectory modeler. Current applications include the Host Computer, ETMS, URET, and TMA in the en route environment, FAST in the TRACON, ETMS at the ATCSCC and at Volpe, and FMS in the cockpit. Examples of future applications include PARR, Direct-To, and E/DA.

It is anticipated that development of common trajectory modeling services and compilation of common adaptation data will result in standardized interfaces for accessing the services and data. This will facilitate widespread use of the services and data across multiple trajectory modeling applications and across multiple domains.

2.3 Linkage to NAS ConOps/NAS Architecture

The *RTCA National Airspace System Concept of Operations* [5] and the *National Airspace System Architecture,* [6] both call for DSTs to improve air traffic management in the en route and terminal environments. These tools are being developed and deployed under the FFP1 and FFP2 programs. Several of these tools (e.g. TMA, URET) require an underlying trajectory modeler. This is also the case for some currently existing tools (e.g. ETMS, Host). These DSTs are all candidates for subscription to common TJM services.

The *National Airspace System Architecture* [6] calls for the sharing of common data across decision support systems. Implementation of common TJM services requires the use of common adaptation data by the modeler as well as the subscribing applications.

2.4 Expected Outcomes/Outputs

2.4.1 Outcomes

One of the mission goals in the *1998 FAA Strategic Plan* [7] is the efficient usage of FAA resources. The concept of common TJM services will support this objective, if proven feasible. Compilation and distribution of common adaptation data will reduce operations and maintenance costs for DSTs that need that data, even if common TJM services are not pursued for implementation. Long-term research and development costs may be reduced for DSTs that require TJM services.

2.4.2 Outputs/Expected Benefits

The expected benefits of the use of common TJM services include:

- Reduced operations and maintenance costs for subscribing applications
- Reduced probability that inconsistent or contradictory results are generated by subscribing DSTs
- Reduced long-term research and development costs for DSTs that use the common TJM services

The expected benefits of the use of common adaptation data include:

- Reduced probability that different results are generated by subscribing decision support tools
- Reduced operations and maintenance costs for subscribing tools

3.0 Research Project Summary

3.1 Research & Development Phases

A typical FAA research project life cycle consists of five phases: Concept Exploration, Concept Development, Pre-Production Prototype Development, Full-Scale Development, and Deployment/Operations. The approach proposed differs slightly in that all 5 phases will be applied to stages of NAS evolution. One of the early steps in the process will be to identify the stages of NAS evolution to which the research project life-cycle can be applied.

As indicated in Section 1.3, this RMP discusses the activities for the first three phases in the development of common TJM services.

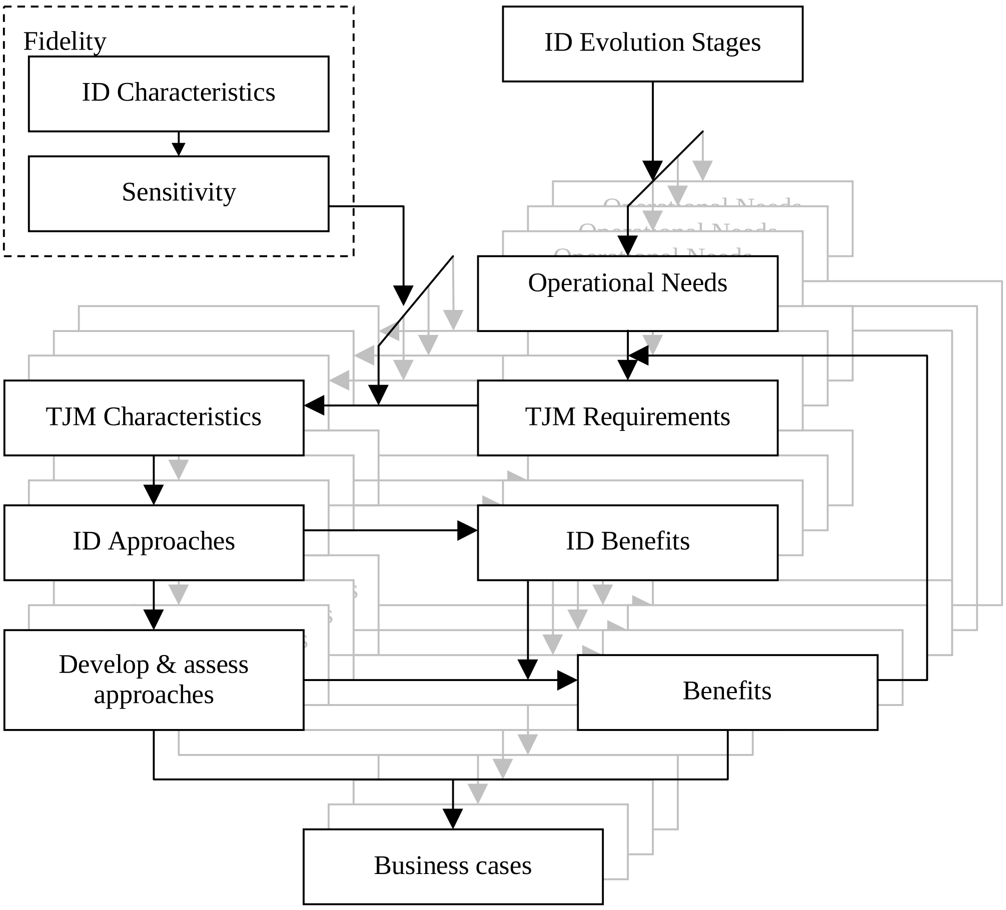

Figure 3.1. Flowchart of R&D approach.

3.1.1 Concept Exploration

During the Concept Exploration (CE) phase, the need for and feasibility of providing common TJM services will be assessed using the following iterative process (see Figure 3.1) consisting of the following steps:

- Fidelity study
    - identify characteristics of trajectory modelers affecting trajectory accuracy
    - determine sensitivity of errors to identified characteristics
- Investigate evolution of services
    - define NAS evolution stages and operational needs for each stage of relevance to TJM
    - determine target requirements and required characteristics for TJM at each stage of NAS evolution
- Identify and assess alternative approaches (cost/benefit) for the following
    - databases
    - algorithms
    - data standards
    - architecture
- Provide options with business case for the evolution of common trajectory services

The approach shown in Figure 3.1 begins with an identification of the trajectory modeler characteristics affecting trajectory forecast accuracy. Examples of these characteristics include such elements as: accuracy of wind forecast, accuracy of aircraft weight information, fidelity of aircraft performance data, flight technical errors, turn dynamics modeling and unknown pilot intent. Once an exhaustive list of characteristics has been identified, a sensitivity study is to be undertaken to quantitatively (if possible) determine the effect of the characteristics on the technical performance of the trajectory modeler. For example, the inclusion of turn dynamics in a trajectory modeler will yield certain errors within each domain of application. While these errors may not be significant in the short term, these errors may be significant for DSTs scheduled for deployment later in time. The time evolving nature of these accuracy requirements creates a need to investigate the time evolution of the NAS.

In tandem with the fidelity study, the stages of NAS evolution will be identified. The initial task in this phase is to assess the feasibility of common TJM services for FFP1 and FFP2 trajectory modeling applications and other relatively mature applications in the research pipeline. The common TJM services, if feasible, could be considered as a post-FFP2 enhancement. For each identified stage, the operational needs will be determined and translated into requirements for the common TJM. Using the results of the sensitivity analysis, necessary characteristics for the TJM will be derived from the requirements for each stage of NAS evolution. Requirements for the common TJM are expected to specify a certain level of model fidelity for each stage of NAS evolution. The sensitivity analysis will provide the mapping between the model fidelity and the modeling elements.

Alternative approaches incorporating the desired TJM characteristics will be identified, again for each stage of NAS evolution. These alternative approaches will determine the algorithms, databases, architecture, and data standards for common TJM services. Initial research on concept feasibility will be performed by MITRE/CAASD in collaboration with the application developers. Since implementation of common TJM services is predicated on the use of common adaptation data, candidate data will be identified for compilation and distribution as common adaptation data. Other research activities will be needed to complement CAASD's efforts and to address longer-term concepts of operation and their need for such services.

As alternative approaches are identified, the potential benefits (and costs) for that approach will be determined. Logical sets of approaches will be developed and evaluated for the identified benefits. During the evaluation of approaches, a more detailed understanding of the impact of requirements on cost and benefits will allow a feedback mechanism to develop between the assessment of benefits and the levied requirements. The aim is to provide a mapping between the requirements and the cost/benefits of meeting those requirements. The outcome of this process, for each stage of NAS evolution will be a business case articulating the cost and benefits of meeting requirements with data to support a logical “first order” trade off between alternative approaches to providing the same level of service.

Exit criteria for the CE phase include:

- Identification of a set of common TJM services that a trajectory modeler would be required to provide to subscribing NAS/user DSTs
- Identification of the level of modeling fidelity required in providing the common services
- Assessment of the feasibility of satisfactorily providing the common services to the subscribing applications
- Definition of a set of common adaptation data for use by the common trajectory modeler and the subscribing applications
- Presentation of the concept exploration results to the application developers
- Development of the business case for common trajectory services options
- Down select of TJM approaches for graduation to the Concept Development phase for further refinement.

3.1.2 Concept Development

During the Concept Development (CD) phase, for each stage of NAS evolution, common TJM services research prototype(s) is (are) developed and evaluated. The iterative process begun under the concept exploration phase will continue as a refinement of the initial CE analysis. For example, as prototypes are developed, more refinements are possible to the cost/benefit assessments and target requirements for the applications.

Tools are also developed to compile the common adaptation data. Concept development will be done in research laboratories, such as at MITRE/CAASD, the Integration and Interoperability Facility (I^2F) at the William J. Hughes Technical Center (WJHTC), and NASA Ames.

Any prototype will demonstrate the operation of multiple NAS/user trajectory modeling applications using common TJM services. The applications will be provided the set of common services identified in the concept exploration phase. The applications will also be provided with the common adaptation data identified in the concept exploration phase and the common TJM services will be based on this same adaptation data.

An architecture tradeoff analysis will be performed to select an architecture from several alternatives. Developers of the common TJM services software and of the common adaptation data compiler will collaborate with developers of the prototype applications to define the interface between the modeler and the applications and to define the format of the compiled common adaptation data. Application developers will modify the applications as needed to support interface with the common TJM services and input of the common adaptation data. The FAA, NASA, and supporting research organizations will develop the common TJM services software and integrate it with applications, a communications infrastructure, and any emulators needed to simulate the operational environment. It will also be necessary to generate the adaptation data compiler and use it to generate common adaptation data for use within the prototype. The prototype will be tested to ensure that all components are functioning properly.

Any research prototype will be evaluated at the WJHTC to verify its functionality and to verify non-interference with required NAS systems. Emphasis during these evaluations will be on the assessment of the operational suitability and usability of the common TJM services and common adaptation data, resolution of operational and technical issues (see Section 3.7), and identification of any necessary modifications.

During the CD phase, the appropriate FAA organizations will coordinate with the Office of System Architecture and Investment Analysis (ASD) to prepare the funding information necessary to plan for the possible future full-scale development of common TJM services as an F&E program. The resources necessary to convert existing laboratories must also be considered. Data obtained from CD phase activities will provide the FAA with quantitative information in order to make required investment decisions. In addition, the research product that is available upon the successful completion of this phase will more effectively serve as the government-furnished baseline for continued spiral development.

At the conclusion of the CD phase, the FAA will determine whether the common TJM services is operationally suitable and acceptable to proceed to the Pre-Production Prototype Development (PD) Phase. Upon such a decision, production responsibility will be transitioned to the appropriate IPTs (AUA-X00).

The exit criterion for the CD phase include:

- Approved Concept of Use document and plan for transitioning to this Concept of Use from current operations
- Data definitions and standards
- Summary of operational and technical issues
- Identification of risk areas, including likelihood and severity ratings, and summary of research efforts and findings related to risk items
- Estimation of cost and benefit
- Functional and performance requirements for common TJM services

3.1.3 Pre-Production Prototype Development and Validation

At the commencement of this phase, for each stage of NAS evolution, an F&E program will be established for common TJM services. The Free Flight Program Office (AOZ) and the appropriate IPTs (AUA-X00) will be responsible for managing this program. During this phase, a functional, full-featured prototype of the common TJM services software will be developed to identify and evaluate design features, to ensure that development risks have been identified and resolved to the extent possible, and to ensure that significant integration and compatibility issues are fully addressed. If necessary, knowledge gained during this phase will be used to further refine results from prior phases.

Exit criteria for the PD phase include:

- Execution and validation of complete cost/benefit analyses
- Development of requirements specification

3.2 Roles and Responsibilities

3.2.1 FAA/NASA Integrated Research (AOZ-30)

AOZ-30, as the FAA co-lead of the IAIPT, is responsible for overall oversight and management of the joint research projects defined in the *Integrated Plan for ATM Research and Technology Development* [1].

3.2.2 Architecture and System Engineering (ASD-100)

ASD-100 is the FAA/NASA Interagency IPT cross-cutting lead and is responsible for this RMP. ASD-100 is defining the FAA's common trajectory modeling research plans, and is also performing an analysis of planned NAS operational concepts to determine if there is a need for common TJM services to support NAS decision support systems. Underlying trajectory modelers for these applications are being analyzed to determine required input data and how that data is used.

ASD-100 will participate in the identification of the potential timelines and interdependencies for implementation of common TJM services in the NAS. ASD-100 will work with the research team to develop architectural implementation diagrams and related text, as well as to assure that the description of expected operational improvements is done in a system-based context and not as an individual excursion in only one dimension. This will include identification of the problem being mitigated as well as transition steps to and beyond the proposed implementation. In coordination with AOZ-30 and AUA-X00, ASD-100 will prepare the funding information necessary to plan for the possible future full-scale development of common TJM services as an F&E program, if deemed appropriate.

3.2.3 Engineering and Integration Services (ACT-250)

ACT-250 will, if a hardware/software alternative is chosen, design and conduct the sensitivity analyses required to determine the factors critical to a common trajectory modeling service. ACT-250 will also facilitate the use of the appropriate WJHTC laboratories necessary to accomplish the required R&D activity, and will provide technical and engineering support to assure that the common TJM hardware and software can be effectively integrated in the NAS.

3.2.4 Integrated Product Team for En Route/Terminal/Traffic Management Systems (AUA-X00)

AUA-200, AUA-300, and AUA-700 will support common trajectory modeling research as representatives of the en route ATC, terminal area ATC, and traffic management functions, respectively. Specific responsibilities include:

- Participating in the identification of technical issues associated with common TJM services
- Assisting in the definition of the architecture in which the common TJM service software/hardware will be expected to operate and in the development of the target environment
- Determining with ASD-100 and Air Traffic if common TJM services is ready to proceed to the prototype development phase
- Preparing the funding information necessary to plan for the possible future full-scale development of common TJM services as an F&D program, in coordination with AOZ-30, and ASD-100

3.2.5 Air Traffic Services (ATS)

3.2.5.1 Program Director for Research and Development (ARQ-20)

ARQ-20 has overall responsibility for the ATS management and coordination of this RMP.

3.2.5.2 Operations Concepts (ATP-410)

ATP-410 will participate in the identification and resolution of operational issues/questions associated with common TJM services, and the definition of supporting methodologies needed to address human factors and procedures, and is responsible for developing the Operational Concept document.

3.2.5.3 Operations Integration (ATP-420)

ATP-420 is the liaison to the field sites and regions for AT operational support and is the focal point for resolution of AT issues, program planning for field tests, and for providing AT's position on the common TJM services. ATP-420's specific responsibilities include:

- Participating in the identification and resolution of operational issues associated with common TJM services
- Participating in the definition of supporting methodologies needed to address human factors and procedures
- Determining the operational acceptability of the common TJM services
- Approving the Operational Concept and determining, with ARQ-20 and ASD-100 when, and if, the common TJM services is ready to be transitioned to AUA-X00
- Coordinating the availability of the field controllers to support operational assessments at CAASD and the WJHTC

3.2.5.6 National Air Traffic Controllers Association (NATCA)

NATCA will be involved in all phases of the development of common TJM services. This involvement will be modeled after the URET FFP1 effort.

3.2.5.7 Professional Airways Systems Specialists (PASS)

PASS involvement will be modeled after the URET FFP1 effort.

3.2.6 Research Centers

Research centers will participate in the common trajectory modeling research by assisting in the identification and assessment of operational and technical issues, and by providing feedback as the development proceeds. In addition, research facilities may be utilized in the evaluation of system concepts. These research centers will also be responsible for both forward and backwards compatibility integration of common TJM capabilities into their research facilities.

3.2.6.1 NASA Ames Research Center

NASA Ames is collaborating with MITRE/CAASD and the FAA to define common TJM issues and services. NASA Ames will continue to refine common TJM capabilities for the CTAS suite of DST capabilities and will participate in the exploration of opportunities for common TJM services for the NAS.

NASA Ames will continue to support common trajectory modeling research in the areas of concept assessment and evaluation of architecture alternatives.

3.2.6.2 MITRE/CAASD

MITRE/CAASD is engaged in a MITRE-sponsored research project to assess the feasibility of using common TJM services to support NAS/user DSTs that require trajectory modeling. Trajectory modeling requirements analysis have been conducted on a set of FFP1, FFP2, and future decision support tools. An initial set of common services has been developed and candidate data have been identified for compilation as common adaptation data. The next steps are to perform the feasibility analysis and to present the results to the FAA and to application developers to arrive at a consensus.

MITRE/CAASD will continue to support common trajectory modeling research in the areas of concept assessment and evaluation of architecture alternatives.

3.2.9 Regional Offices and Field Sites

Regional offices will facilitate the participation of field controllers from their constituent facilities to support laboratory evaluations, as necessary.

3.3 Schedule

Fidelity Study Schedule

Task	Completion Date
Identification of Factors	6/01
Importance and Prioritization of Factors	7/01
Determine Mechanisms for objective evaluation of factors and test matrix	TBD
Investigation of Factors	TBD

Evaluation of operational data	TBD

3.4 Work Breakdown Structure

0.1 Fidelity Study

1.0 Identification of NAS Evolution Stages

2.0 Development of requirements and characteristics (for each evolution stage)

3.0 Development and assessment of alternatives (for each evolution stage)

4.0 Development of business case by evolution stage

3.5 Funding

Organization	FY01	FY02
CAASD	1 FTE	TBD (3 FTE proposed)
NASA AMES	--	TBD
FAATC/ AOZ	--	TBD
FAA/ ASD	150K	TBD

3.6 Research Status

Common trajectory modeling research is currently in the concept exploration phase. The organizations that are actively engaged in research are ASD-100, ACT-250, NASA Ames and MITRE/CAASD.

3.7 Research Issues

The following paragraphs identify issues associated with the common trajectory modeler research. Appropriate resolution of these issues, at each stage of NAS evolution, will be required prior to the approval of an operational field site evaluation of any DST operating with the common TJM services. Subsequent versions of the common trajectory modeling services RMP will identify the research initiatives, the common trajectory modeling research phase, and estimated resolution date associated with each identified research issue. If a research issue cannot be resolved as part of the common trajectory modeling research (e.g. because of lack of resources), it will be identified in the RMP.

3.7.1 Operational Issues

- What are the major operational concepts (near and long term) that will establish trajectory modeling requirements?
- Which decision support tools and which domains should subscribe to the common trajectory modeling services?
- For each stage of the NAS, what are the operational problems that occur without a common model?

3.7.2 Technical Issues

- There is no single agreed upon definition of common trajectory modeling.
  - Single common trajectory modeler or library of common routines that could be linked to various applications?
  - What services should a common trajectory modeler provide?
  - Databases and adaptation data
- Development of advanced decision support tools may be negatively impacted.
  - Tools may be hampered by limitations of common trajectory modeling services.
  - Tools may have to provide for themselves advanced trajectory modeling services not available from the common trajectory modeler.
  - What criteria should be used to determine when a set of common services is obsolete?
- A common trajectory modeler will be challenged to simultaneously meet the varied requirements of the various decision support tools in the various domains.
  - Applications requiring high degree of accuracy (high modeling fidelity, fast trajectory update rate)
  - Applications requiring less accuracy (lower modeling fidelity)
  - Applications using kinetic and those using kinematic approach
- What is the level of TJM fidelity needed?
- What is the best approach to model that level of TJM fidelity?

3.7.3 Business Case Issues

- The transition from legacy systems (both research and operational systems) adds cost over and above the cost to develop the common trajectory modeler.
- The cost to develop the common trajectory modeler and to retrofit operational tools must be considered and weighed against the long term F&E savings that will result from the common modeler.
  - Who will pay for the time and resources needed to retrofit R&D products to the common modeler?
  - What is the programmatic impact of diverting R&D resources to retrofit research systems?
- What are the potential F&E benefits of common adaptation data supporting trajectory modelers?
- What is the potential F&E benefit for the common trajectory capabilities over and above common adaptation?
- How do total costs (R&D and F&E) compare with and without a common trajectory modeler?
- What costs are incurred by getting forward-looking R&D labs to adopt the CTJM?
- What are the O&M cost savings?

3.7.3 Collaboration Issues

- Development of common TJM services requires collaboration between the developer of the common services, the FAA services, and the application developers.
- The roles of the developer of the common services, the FAA services, and the application developers must be clearly defined.

- A process must be established for gaining agreement on the scope of and content of common trajectory modeling services.

4.0 Transition Plan

TBD **-** This section will define the process for transitioning the research results into NAS implementation (e.g. phasing for inserting common services into existing applications).

ACRONYMS

ACES	Adaptation Controlled Environment System
ARTCC	Air Route Traffic Control Center
ATC	Air Traffic Control
ATCSCC	Air Traffic Control System Command Center
ATM	Air Traffic Management
AWT	Area Work Team
CAASD	Center for Advanced Aviation System Development
CCLD	Core Capabilities Limited Deployment
CD	Concept Development
CE	Concept Exploration
ConOps	Concept of Operations
DACS	Digital Aeronautical Chart Supplement
DST	Decision Support Tool
ERAWT	En Route Area Work Team
ETMS	Enhanced Traffic Management System
F&E	Facilities and Equipment
FAST	Final Approach Spacing Tool
FFP1/2	Free Flight Phase 1/2
FMS	Flight Management System
IAIMT	Interagency Integrated Management Team
IAIPT	Interagency ATM IPT
IPT	Integrated Product Team
LAN	Local Area Network
NAS	National Airspace System
PAR	Preferential Arrival Route
PD	Pre-Production Prototype Development Phase
PDAR	Preferential Departure and Arrival Route
PDR	Preferential Departure Route
R&D	Research and Development
RMP	Research Management Plan
SID	Standard Instrument Departure
STAR	Standard Terminal Arrival Route
SUA	Special Use Airspace

TFM	Traffic Flow Management
TJM	Trajectory Modeling
TMA	Traffic Management Advisor
TRACON	Terminal Radar Approach Control (Facility)
URET	User Request Evaluation Tool
WBS	Work Breakdown Structure
WJHTC	FAA William J. Hughes Technical Center

REFERENCE DOCUMENTS

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