Joint Planning and Development Office

ATM-Weather Integration Plan

Version 0.8

July 10, 2009

NextGen

Next Generation Air Transportation System
Joint Planning and Development Office

Joint Planning and Development Office (JPDO)

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EXECUTIVE SUMMARY

Weather accounts for 70%[1] of the $41B annually[2].cost of air traffic delays within the United States NAS, or $28B annually. Approximately two thirds ($19B) of these delays are considered to be avoidable.[3] The Weather – Air Traffic Management (ATM) Integration Working Group (WAIWG) of the National Airspace System (NAS) Operations Subcommittee of the FAA's Research, Engineering and Development Advisory Committee (REDAC) conducted a twelve-month study to examine the potential benefits of integrating weather and air traffic management. The report of this committee made several recommendations regarding integration of weather and the potential for weather integration to help reduce delays. The way to mitigate these delays and eliminate those that are avoidable is to improve the quality and method of use of weather information and evolve (integrate) the weather support to the NAS.

This NextGen Weather Integration Plan provides the initial requirements, scope, and implementation roadmap to achieve the NextGen vision; to enable decision makers to identify areas where and when aircraft can fly safely with weather assimilated into the decision making process in order to optimize the entire NAS. It also addresses agency roles and responsibilities and includes resource requirements. This plan establishes the approach to deal with the integration of weather information into the ATM decision making process.

Integration, as used in this plan, refers to the inclusion of weather information into the logic of a decision process or a decision aid such that weather impacts are taken into account when the decision is made or recommended. The goal of weather integration is to minimize the need for humans to gauge NAS weather impacts or to determine the optimum mitigation.

KEY POINT: Weather information is not presently integrated into all ATM decision systems and processes.

This plan addresses the following problem:

b) Most weather support to ATM is manual, with weather displays that must be interpreted by the user.

- Weather products do not have the maturity required for direct insertion without interpretation.*
- Rules for interpretation and use of weather data are generally based on the experience of the user.
- ATM decisions based upon today's weather products are inconsistent from user to user.

c) * This aspect of the problem is addressed in the NextGen Weather Plan

The figure below illustrates the process of moving from raw current and forecast weather data through the creation of weather products that relate weather data to aviation impacts and on to

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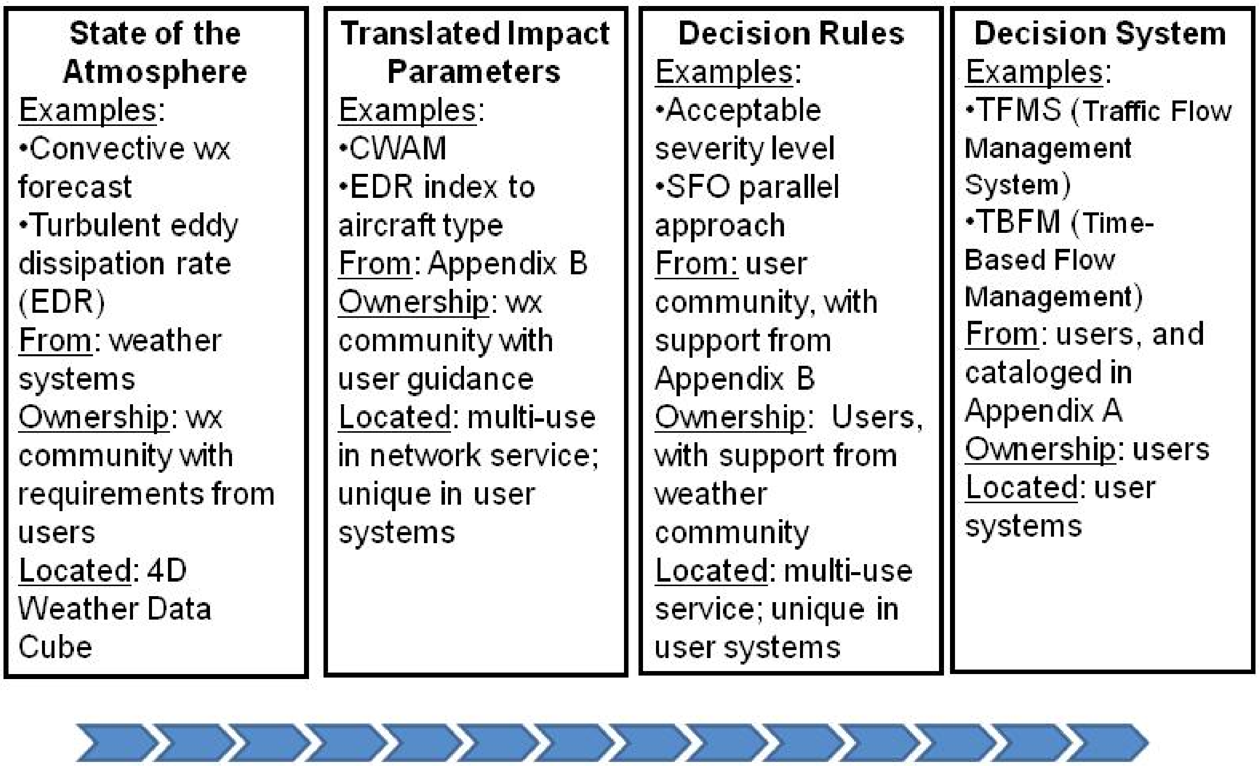
[1] OPSNET
[2] Congressional Joint Economic Committee; May 2008
[3] REDAC Weather-ATM Integration Working Group Report; Oct 3, 2007

the generation of rules for decisions to be made by ATM operators and other users and ultimately to the creation of automated decision support tools.

KEY POINT: The process to flow from information on the state of the atmosphere to translation into impacts to decision rules on dealing with impacts to inclusion into decision systems.



At NextGen IOC (2013), some weather data will flow machine-to-machine with real integration into decision support tools (DST), but most integration of weather information will still be handled manually, with some data and displays provided to the cockpit for pilot decision. By the 2018 mid-term some DSTs will have integrated weather, and by 2025, weather information will be automatically translated to impact and ingested into most decision algorithms, both on the ground and in the cockpit.

KEY POINT: An analysis of weather impacts into decision tools has been done.

An analysis of the current state of weather integration was conducted and this plan lays out the weather integration opportunity in the NextGen solution sets; Initiate Trajectory Based Operations, Increase Arrivals/Departures at High density airports, Increase Flexibility in the Terminal Environment, Improve Collaborative ATM, Increase Safety, Security, and Environmental Performance, and Transform Facilities. Each solution set was broken down into swim lanes, and then further into capabilities and associated Operational Improvements (OIs). This analysis is reflected in Section 3 of the Plan, along with the associated Appendix A.

KEY POINT: An analysis of available weather translation and decision methodologies has been done

ATM will require DSTs that can deal with the information from the 4-D Weather Data Cube (4D Wx Data Cube) which has been translated into NAS impacts and provide ATM with best choice options. The translation can be obtained by a network service for common use or by imbedding the translation capability in the DST for unique needs. Section 4 and the associated Appendix B provide a survey that identifies technologies and methodologies for translating weather information into ATM impacts in the NAS. The survey includes approaches for addressing weather-related uncertainty in ATM decision making – risk management processes. The survey is organized in two parts; ATM-Weather Impact Models and ATM-Weather Integration Techniques.

The Plan presents a summary of each of the surveyed ATM-impact models starting with models that were derived primarily for convection, and ending with a wide variety of models for several types of aviation hazards. This section assessed the maturity of the ATM-impact models presented, and identified gaps in technologies that must be addressed for NextGen.

KEY POINT: A foundation of mature, tested methodologies must be built and maintained, along with a capability for multi-use impacts translation.

Further research is required on the conversion of weather data into specific ATM impacts.

The execution of this plan will occur in four steps. The steps will be executed in sequential order from the start, but the steps will be repeated many times as new weather techniques and ATM tools are developed and may be occurring simultaneously at some point in the future. The steps are:

1. Align teams with each solution set and analyze weather integration requirements for a service and performance-based approach for weather integration as associated with operational relevance.
2. Identify the specific weather integration insertion points, including performance criteria and value, into ATM tool or decision platform functionality.
3. Identify and recommend the specific weather integration techniques and technologies that best fit the requirements of a particular traffic flow management tool under development and particularly the insertion points identified in the previous step.
4. Serve as the subject matter expert (SME) for the ATM tool development team to assist in integration of the weather methodologies and to evaluate test results.

KEY POINT: A DST-by-DST weather support activity must assist in successful weather integration.

The key interaction for success in weather integration will be the relationships established between the AWO and the ATM tool development community. The AWO role is to ensure proper use and application of weather data and techniques in development of specific DSTs. During development, the AWO will fund demonstrations for specific technologies in order to demonstrate both the quality and usability of weather information in the decision process. It is imperative that human factors (see C-5) be considered in the development of every DST. As DST development proceeds, weather data for specific DSTs will transition from a testing scenario to inclusion of production data directly from the 4D Wx Data Cube.

Anticipated initial activities

FY10:

- Building weather translation and decision foundation, including test and evaluation capability.
- Stand up Weather Leadership Team and Integration Sub-Teams.
- Identify initial set of DSTs that have the potential for successful weather integration by NextGen IOC. Identify candidate methodologies, brief users, and develop demonstrations of weather methodologies that will yield success.

FY11:

- Conduct successful demonstrations of weather products or methodologies that have the necessary maturity level for integration

FY12:

- Work with user community and DST developers to integrate weather products and methodologies into DSTs for IOC implementation

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ATM-Weather Integration Plan

1 INTRODUCTION

There is a need for a multi-agency, synchronized plan to achieve solutions to the problem of weather integration into ATM operations and decisions. As articulated in the NextGen vision, the solution must enable decision makers to identify areas where and when aircraft can fly safely with weather assimilated into the decision making process in order to optimize the entire national airspace system. The NextGen Weather Integration Plan provides the initial requirements, scope and implementation roadmap to achieve the NextGen vision. It also addresses agency roles and responsibilities and includes resource requirements.

1.1 Background

Weather accounts for 70 percent of all air traffic delays within the United States National Airspace System (NAS). The total cost of these delays has been estimated to be as much as $41B annually with weather delays costing over $28B annually. Approximately two thirds of weather delays have been estimated to be avoidable. The way to mitigate weather delays and eliminate avoidable delays is to improve the quality of weather information and to evolve weather support to the NAS both in quality and in methods of use, from its current levels to new targeted approaches.

1.2 Purpose

This plan establishes the approach to deal with the integration of weather information into the ATM decision making process.

1.2.1 Integration Definition

Integration as used in this plan refers to the inclusion of weather information into the logic of a decision process or a decision aid such that weather impacts are taken into account when the decision is made or recommended. This applies whether the decision is made individually or jointly by air navigation service providers and airspace users.

1.2.2 Integration Goal

The goal of weather integration is to minimize the need for humans to gauge NAS weather impacts or to determine the optimum mitigation. Today, weather integration is nearly all manual by decision makers after they view stand-alone weather products. Weather integration in NextGen will be an evolving process:

- At NextGen IOC (2013)
  - Some weather data will flow machine-to-machine with real integration into decision support tools (DST).
  - Most integration of weather information will still be handled manually but with improved "high glance value" products.
  - Some new data and displays will be provided to the cockpit for pilot decisions.

- By the 2018 mid-term some DSTs will have integrated weather.
- By 2025, weather information will be automatically translated to impacts and ingested into most decision algorithms both on the ground and in the cockpit.

1.3 Scope

This Plan addresses actions to be taken by the weather community, generally under weather community funding. Although it calls for close interaction with various user programs, it does not commit those programs or their managers to take any action or expend any funds. However, to benefit from the efforts described in the Plan, it is understood that the user programs must cooperate and participate in the process.

The cost of implementing the methodologies developed under and presented in the Plan will be born by the user programs. For example, where weather integration is to occur in some NAS system, the manager of that system must write the software code which implements the methodology. The weather community will support this by providing any reusable code to which it has access.

In the event that any user tool or capability must be cancelled or postponed, its description in this Plan does not in any way obligate the program manager to continue the program.

The Plan is intended to addresses weather integration into ATM decisions made by the ANSP or by the ANSP in collaboration with the AOC/FOC or operators. AOC/FOC and flight deck decisions unique to the operator (i.e. excluding ANSP participation) are not a subject for intervention in the Plan. Those are principally left for market innovation to develop and implement.

1.3.1 Assumptions

The creation and production of appropriate weather analyses and forecasts is to be addressed elsewhere and is outside of the scope of the integration effort. However, the Integration effort will address the identification of user requirements for weather information which will be conveyed to the developers.

The regulatory approval process for the use of new weather analyses and forecasts is to be addressed elsewhere and is outside of the scope of the integration effort. However, the Integration effort will support the regulatory process by providing rationale and other supporting documentation on how the information is to be used.

The SOA/IT infrastructure associated with publication of weather analyses and forecasts is to be addressed elsewhere and is outside of the scope of the integration effort. However, the Integration effort will act as an intermediary between the weather IT community and the user system owners to ensure that appropriate weather-related information flow occurs.

1.3.2 Roles and Responsibilities

Agency and community roles are as follows.

1.3.2.1 FAA

The FAA will be the primary actor to the extent that most ATM systems are owned by the FAA and the ATM-Weather Integration Process resides primarily within the FAA. However, for success, other agencies and stakeholders must be involved.

1.3.2.2 NASA

NASA will continue to be a major developer of ATM tools and techniques, and also of weather integration methodologies. NASA will share the fruits of its development with the other stakeholders for implementation and deployment.

1.3.2.3 DOD

The DOD has developed and is expected to continue to develop tools and methodologies which have application to the civil aviation community, including some relevant to weather integration efforts. To the extent possible, the DOD will share its developments with the broader NextGen weather integration community.

DOD will also cooperate in the development of weather integration capabilities

- When civil aircraft operate in military-controlled airspace.
- When civil aircraft operate at military airfields or joint-use fields operated by the DOD.
- When the weather integration community considers the hand-off point/procedures of aircraft between civil and military control.

1.3.2.4 NOAA

NOAA is the principal provider of weather information in the NextGen 4D Wx Data Cube, and that is the primary NOAA weather role, rather than integration into ATM decisions. For more information on NOAA and the 4D Wx Data Cube, see the NEXTGEN Weather Plan, which is a companion document to this Integration Plan.

1.3.2.5 Private Sector

This Plan does not in itself obligate the Private Sector to take any action. However, when weather-integrated ATM capabilities become operational, Private Sector users will be affected. To the maximum extent possible, writers and executors of this Plan will take the needs of the Private Sector into account, such as by refraining from unnecessary equipage requirements. Through the NextGen Institute, members of the Private Sector have participated in the preparation of the Plan and will be encouraged to continue their participation. The Government will make every effort to involve the Private Sector and keep the Private Sector informed of any decision which may affect the Private Sector.

1.3.2.6 International

Both weather and aviation are International enterprises. As with other NextGen developments, the weather Integration community will seek to harmonize itself with related International efforts, such as those in Single European Sky ATM Research (SESAR), the International Civil Aviation Organization (ICAO), and the World Meteorological Organization (WMO).

2 NEXTGEN WEATHER INTEGRATION OVERVIEW AND CONCEPT

Weather integration pertains to the inclusion of weather information into the logic of a decision process or decision aid such that weather impacts have already been taken into account when the decision (e.g. any decision affecting TFM) is made or recommended. Weather integration into NAS decisions is fundamentally the responsibility of the user community (i.e., ATC service providers and NAS operators), with the weather community in a supporting role. The ultimate goal of integration is to translate weather information as purely meteorological data into weather impacts on air traffic operations – essentially making weather transparent to its end users. The JPDO 4D Weather Functional Requirements for ATM calls for "weather integrated directly into sophisticated decision support capabilities to assist decision makers." Under the solution set of Reduce Weather Impacts within FAA's OEP program is a goal of making weather information seamless to users by integrating it into decision-making automation. As more meteorological parameters are fully integrated into DSTs, the need for direct M2M ingestion of weather data will increase. At the same time, the numbers of human-readable graphical displays and text messages may be allowed to decrease as appropriate. The previous notwithstanding, it is clear that operational decision makers on the ground and in the air will require both the graphical and textual representation of meteorological information for the foreseeable future.

Decision support will evolve over the next decade and beyond. Today, most weather-related decisions are made by ATM in a completely manual mode. With few exceptions, weather data are displayed as graphics or text at the Command Center, at TRACONs, ARTCCs, AOC/FOCs, Flight Services, and in cockpits all on stand-alone systems. By NextGen IOC in 2013 some weather data flow will be via M2M means. Most integration will remain in a manual mode but many weather displays will be improved to a "high glance value" mode. Data and displays will also be provided to the cockpit for pilot decision via electronic flight bags and existing on-board systems on some aircraft. By 2025 it is expected that weather information will be automatically translated into probabilistic weather impacts on air traffic and be ingested into decision algorithms (ground and aircraft).

Figure 2-1 first shows the process of moving from weather data which describes the state of the atmosphere at a current or future time through conversion of that data into weather impact parameters. As shown in the figure, the creation of the state of the atmosphere and then specific products which translate the raw weather information into impacts on aviation are the responsibility of the weather community in response to guidance from the user community. The user community then generates the rules for decisions that rely on weather data and impacts and then develops automated decision support tools which meet their specific operational needs. Once the process flow moves from weather impacts to development of decision rules, the weather community has the responsibility for support and advice to the user community related to the use and interpretation of the weather data or derived weather product.

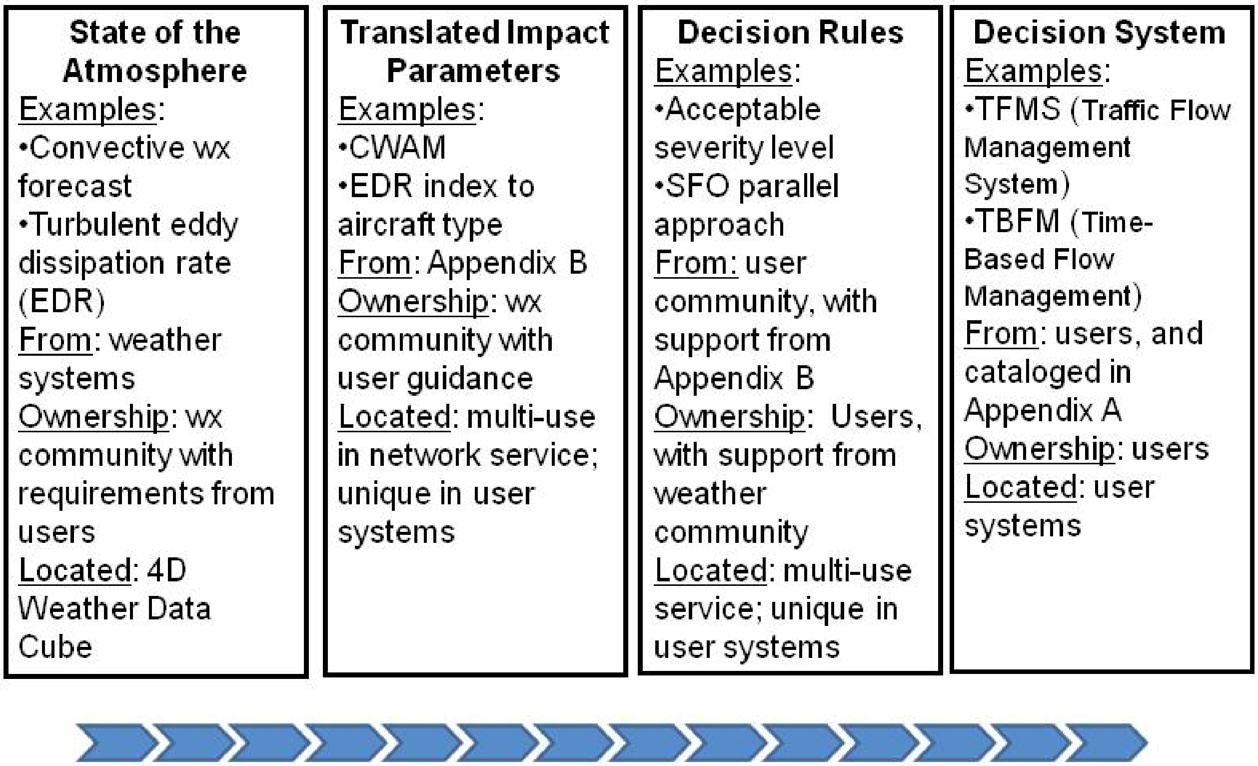


Figure 2-1 Conceptual Flow

2.1 Problem Statement

Problem Summary:

d) Most weather support to ATM is manual, with weather displays that must be interpreted by the user.

- Weather products do not have the maturity required for direct insertion without interpretation.*
- Rules for interpretation and use of weather data are generally based on the experience of the user.
- ATM decisions based upon today's weather products are inconsistent from user to user.

e) * This aspect of the problem is addressed in the NextGen Weather Plan

Discussion of the problem:

Today's national air transportation system is susceptible to weather disruptions causing flight delays, the impacts of which can be wide spread. Fast moving summer or winter storms impacting one hub airport or key transcontinental route can ground aircraft thousands of miles away, further propagating flight delays and cancellations. Weather delays are more than an inconvenience; they cost the nation's airlines, cargo carriers, corporate, and private users in excess of $28 billion annually. While severe weather will likely continue to prevent airspace and airport access in the immediate vicinity of the event, many delays could be avoided with better ways of dealing with weather throughout the national air transportation system.

Current weather products are not at a maturity level which allows direct machine-to-machine, automated use of weather data; rather, weather products today generally require human evaluation and interpretation. The skill in some key weather forecast products is inconsistent day-to-day and as a result, rules for making use of weather products in decisions are human derived, leading to inconsistent decisions by the user community. Many weather products or tools are "bolt on" systems that must be interpreted by the user and figured into traffic decisions based the user's understanding of the information presented. The weather data provided by these systems may not be provided in a manner that is useful in human made traffic flow decisions. Automated systems, many of which are designed around fair weather scenarios, must be shut down when significant weather impacts operations. Lack of automated tools necessitates a cognitive, reactive, inefficient weather-related decision making process and a meteorological competency of decision makers. The weather information used for this manual process is gathered from multiple sources. Individual controller perceptions are used to determine which is the "best source".

Where processes disregard weather data, many times this can be traced to the fact that the present weather data system is a collection of diverse, uncoordinated observations, forecasts and supporting systems. This does not support the need for "information rather than data" where information implies an underlying process and system to help make an informed decision. Indeed, today's weather system infrastructure to support timely and collaborative air transportation decisions necessary to effectively deal with bad weather does not exist.

DSTs are generally software applications used to automate the weather impact evaluation and air traffic/customer response. Mission Data are input into the DST, typically in the form of a proposed 4-dimensional trajectory through space and time. Along with trajectory information are added the particular weather sensitivities or risk tolerance of the flight under consideration. According to the spatial and temporal attributes of the mission (takeoff time/place, flight level, waypoints, and estimated landing time/place) relevant weather information is retrieved by subscription or by query/response from the 4-D Weather Data Cube (4-D Wx Data Cube) using XML standard queries. The DST then automatically compares the weather parameters to particular sensitivities of the mission under consideration. By applying relevant rules and thresholds (e.g. pilot landing minima, aircraft weather avoidance limits, risk tolerance, Federal Aviation Regulations, etc.) the DST converts weather information into weather impacts. The result of this logical integration is an output decision aid. For instance, the latter segments of a proposed trajectory may enter an area of forecast turbulence. If this forecast turbulence exceeds certain severity or probability limits the DST automatically flags these segments as, for example;

Red. More sophisticated DSTs may recommend weather-optimized trajectories through an iterative process of query and response. Thus, the trajectory flagged as Red for turbulence initially may be rendered Green by an earlier takeoff, a higher flight level, or a different route.

DSTs will take a number of forms and functions as NextGen evolves. There are 4 levels of integration each with increasing levels of complexity (note: The following does not consider where or how any DST will be displayed or used. Individual DSTs may require human factors (see C-5) consideration):

- Level 1: Stand-alone (little to no weather integration)
- Level 2: High “glance value” weather impact products
  - Operations-oriented weather impact data provided to the operator such as “stop light” displays, color coded views of aircraft trajectories according to weather impact
  - These displays allow the operator to mentally factor weather into decisions
- Level 3: User-in-the-loop tools
  - These tools have a M2M interface with algorithms suggesting solutions to the user for acceptance, rejection, or modification
  - Data for these tools will come from the 4-D4-D Wx Data Cube with associated confidence values
- Level 4: Fully integrated tools
  - These will be automated DSTs with full M2M data interface
  - Data will come from the 4-D4-D Wx Data Cube generally in probabilistic form with confidence values
  - No interpretation of weather will be required by the operator but the operator will be able to drill down into the decision if desired.

ATM will require DSTs that can deal with the information from the 4-D Wx Data Cube which has been translated into NAS traffic impact values impacts and provide ATM with best choice options. The translation can be obtained by a network service for common use or by imbedding the translation capability in the DST for unique needs. Section 4 and the associated Appendix B provide a survey that identifies technologies and methodologies for translating weather information into ATM impacts in the NAS. The survey includes approaches for addressing weather-related uncertainty in ATM decision making – risk management processes. The survey is organized in two parts; ATM-Weather Impact Models and ATM-Weather Integration Techniques. The Plan presents a summary of each of the surveyed ATM-impact models starting with models that were derived primarily for convection, and ending with a wide variety of models for several types of aviation hazards. This section assessed the maturity of the ATM-impact models presented, and identified gaps in technologies that must be addressed for NextGen.

ANSP needs are associated with weather impact on traffic flow and airspace constraints; AOC/FOC needs are associated with weather impact on system-wide airline operations (e.g., connecting flights); flight deck needs are associated with weather impact on current operation such as safety and comfort. As noted in paragraph 1.3, AOC/FOC and flight deck decisions unique to the operator (i.e. excluding ANSP participation) are not a subject for intervention in the Plan. Those are principally left for market innovation to develop and implement.

By 2023, weather information will be integrated into decision making, but weather per se will not appear in the output decision at all. Whether the output decision takes the form of a human-readable display, or is relayed to a larger decision support mechanism, automated integration basically renders weather transparent to NextGen decision makers. Probabilistic weather data will introduce more complexity; e.g. the DST will have to compare input risk tolerance to probabilities of occurrence of the relevant weather phenomena in order to render a decision-quality output. For instance, a particular flight may be able to tolerate a 30% probability of thunderstorms along the planned route of flight, but it could not tolerate a 70% probability, in which case alternatives would be sought.

The expectation is that the number, complexity, and sophistication of automated DSTs will increase over time as the 4D Wx Data Cube matures, expanding its available sets of gridded data. At present the number of automated decision tools in the NAS is fairly limited, with inputs provided by point-to-point weather data feeds. As the 4-D Wx Data Cube assimilates grids of all meteorological parameters relevant to aviation, developers will build DSTs tailored to the particular needs and decision spectra of particular users. Development of tailored DSTs will be largely the province of the commercial sector where there is tremendous opportunity for ingenuity in applying weather to a whole range of decisions. The prime requirement for the weather community is that the weather information available by subscription from the 4D Wx Data Cube be in a form, at a resolution and at a quality level that meets user needs and can be readily translated into impacts and assimilated by the users' DSTs. In order for this integration to be successful, Human Factors research needs to be conducted to ensure that developers understand how weather is used in decision making so that the impact of weather data can be correctly translated into DSTs. This research will also be critical in determining the level or amount of weather transparency needed given the user's role in decision making. In some cases, anomalies or special circumstances may require users to view weather products as opposed to DST output.

2.2 Weather Impacts on Solution Sets

This plan addresses weather integration in terms of six of the NextGen OEP Solution Sets;

Initiate Trajectory Based Operations (TBO)

Increase Arrivals/Departures at High Density Airports (HighDensity)

Increase Flexibility in the Terminal Environment (FlexTerm)

Improved Collaborative Air Traffic Management (CATM)

Increase Safety, Security and Environmental Performance (SSE)

Transform Facilities (Facilities)

Weather impacts the operational improvements of the solution sets in several ways, depending on the type of decisions being considered and its time horizon in the life cycle of a flight or a traffic flow. The integration of weather and ATM decisions can span from strategic pre-planning decisions to real-time tactical decision-making.Specific weather impacts are discussed in more detail in Section 3 and in Appendix A.

2.3 Alternatives Considered for Integration

The NextGen Weather concept of operations (ConOps) team recognized the need to look at improving the weather information infrastructure before it could be incorporated into the ATM decision support processes. This section briefly discusses three alternative approaches to weather integration. The emphasis of this discussion is on weather integration itself. The source of weather data (4-D4-D Wx Data Cube) and the network infrastructure that will distribute this information are considered separately.

Table 2-1 Alternatives Considered for Providing Weather Information

Alternatives	Description	Feasibility	Ability to Deliver NextGen Vision
Status quo – do nothing	Maintain current stand-alone text and graphical weather products	Green	Red
Improve Weather Products to Enhance Usability by ATM	Overlay weather data on to ATM displays and develop new weather displays with "high glance value"	Green	Yellow
Integrate Weather Information into ATM Decision Support Tools	Leverage net-centric standards and incorporate on-going research into weather impacts to add new weather algorithms to existing and developing TFM decision support tools.	Green	Green

2.3.1 Status Quo – Do Nothing

There are currently very few instances of the integration of weather data into ATM tools. Flight planning systems incorporate winds aloft and temperatures. Some tools are available involving the timing of deicing. Generally, weather is used manually, with stand-alone tools and displays. This situation requires controllers and decision makers to consult several unrelated displays in a manual mode in order to make critical decision. As stated earlier, weather accounts for more than 70% of flight delays. The current system is inadequate to mitigate this problem.

The baseline, multi-agency weather data processing, access, and dissemination architecture consists of multiple distributed processing systems collecting sensor data and producing value-added analysis and forecast products. Organizations access the data by approaching weather processing systems and agency telecommunication systems to arrange for point-to-point transport of the weather products. Some data is also available via access to special web pages (e.g., Aviation Digital Data Service [ADDS]). The status quo is an unacceptable option because it involves diverse architectures, technologies, and standards; it does not meet numerous NextGen requirements (e.g., publication/subscription registry, push/pull access, tailored information, and a single authoritative source of weather information).

By maintaining the status quo, integration and automation would not be achieved.

2.3.2 Improve Weather Products to Enhance Usability by ATM

The second alternative considered is to improve current weather products in ways that improve their usability by TFM decision makers. Weather information can be overlaid on air traffic displays and weather displays can be upgraded to reduce the amount of interpretation required for rapid understanding of the weather situation. These “high glance value” displays reduce TFM decision-makers’ requirement to have a deep understanding of weather situations.

This alternative can be accomplished without general improvements to the underlying weather delivery systems; however, significant improvements are required in weather processing to achieve reductions in avoidable delays. This alternative would not achieve NextGen goals nor would it allow for improvements in TFM tools such as TMA which now require the tool to be turned off during adverse weather because of lack of weather integration. Accordingly, the integration of a common weather picture into all of the ATM decision support systems and planned automation systems would not be achieved.

2.3.3 Integrate Weather Information into ATM Decision Support Tools

The last alternative is to integrate weather information into ATM decision support tools. This alternative meets the goals and recommendations set out by the Weather – ATM Integration Working group of the national Airspace Systems Operations Subcommittee, Federal Aviation Administration Research, Engineering and Development Advisory Committee (REDAC) in their report dated October 3, 2007. A key finding of this report “is that a risk management approach with adaptive, incremental decision making, based on automatically translating weather forecasts into air traffic impacts, presents a major new opportunity for reducing weather related delays in the future NAS.” Achievement of this alternative requires development of a new weather data architecture by heavily leveraging net-centric standards and incorporating legacy architectures. This option overcomes the deficiencies of the other alternatives, meets all NextGen goals and requirements, is the most cost effective, and involves acceptable implementation risk. It also allows for the provision of current regulatory weather products (e.g., convective Significant Meteorological Information [SIGMETS]), while policy is changed to transition the NAS from a ‘product’ to an ‘information’ environment. This option includes distributed data processing, with centralized publication/subscription, using much of the current baseline architecture; and develops a single authoritative source of weather information for collaborative decision making involving ground and airborne platforms. The underlying architecture developed to achieve NextGen goals provides the necessary platforms and capabilities for the integration of weather information directly into DSTs.

2.4 Recommended Solution: Integrate Weather into ATM Decision Support Tools

The recommended solution is to integrate weather directly into ATM Decision Support Tools. Weather integration will simplify the decision process for humans and make weather data seamless to NAS users. Weather integration allows user decision tools to have the best available weather information and to use that information in a wide range of decisions both on the ground and in the cockpit.

The 4-D4-D Wx Data Cube is not part of this plan, however, this alternative assumes the existence of the 4-D4-D Wx Data Cube, a virtual database of information - separate weather databases located in different locations such as National Weather Service (NWS), other Agency processing facilities, research or laboratories, etc. and connected via a net-centric infrastructure. Rapid updates of weather data used in TFM tools is essential to successful weather integration and therefore, the underlying infrastructure being developed for NextGen is key to the success of the weather integration effort. The 4-D4-D Wx Data Cube is essential to the development of DSTs which integrate weather directly into the decision making process.

2.5 Anticipated Benefits and Impact

Advances in weather information content and dissemination provide users and/or their decision support with the ability to identify specific weather impacts on operations (e.g., trajectory management and impacts on specific airframes, arrival/departure planning) to ensure continued safe and efficient flight. Users will be able to retrieve (and subscribe to automatic updates of) weather information to support assessment of flight-specific thresholds that indicate re-planning actions are needed. In particular, the 4D Wx Data Cube (and later The 4D Weather Single Authoritative Source (4D Wx SAS)) will support enhanced volumetric extractions, by time frame of interest, of weather information by NAS users to quickly filter the enhanced weather content to the region of interest for impact analysis. This will streamline the process by which the user with decision support ATM tools - conducts system-wide risk management in planning for both individual flight trajectories and flows.

Because of the profound impact of adverse weather on the safety, efficiency, and capacity of the NAS, improved decision making when weather impacts operations is a key NextGen objective. The initial 4D Wx SAS, a subset of the 4D Wx Data Cube, provides a consistent, de-conflicted common weather picture (e.g., observations, forecasts, and climatology, from the surface to the top of the NAS) that will provide Air Navigation Service Providers (ANSPs) and airspace users with a common view of the weather situation.

Using the 4D Wx SAS, ANSPs, users and their decision support systems will be able to make trajectory-oriented or area-oriented requests for weather information so that they can determine its effect on the flight trajectory being evaluated. This customized weather information will be integrated into initial tactical and strategic decision support tools developed under the TBO, CATM, Flexible Terminal, and High Density Terminal solution sets. These tools will assess the risk management of the operational impact of weather on flights/trajectories and provide candidate actions to the ANSP that mitigate these impacts on safety and traffic flow. These tools support real time “what if” assessments, support common situation awareness within and between domains, and can be tailored to support different user preferences (e.g., displays, lists, alert modes, flight specific probabilistic thresholds, and format tailoring). The 4-D Wx SAS provides a single and authoritative definition of the current weather state and prediction of the future weather, as well as the user-requested high resolution, high temporal characteristics of importance to aviation users. The 4D Wx SAS will also provide proactive updates (“push”) to requestors based on user requests.

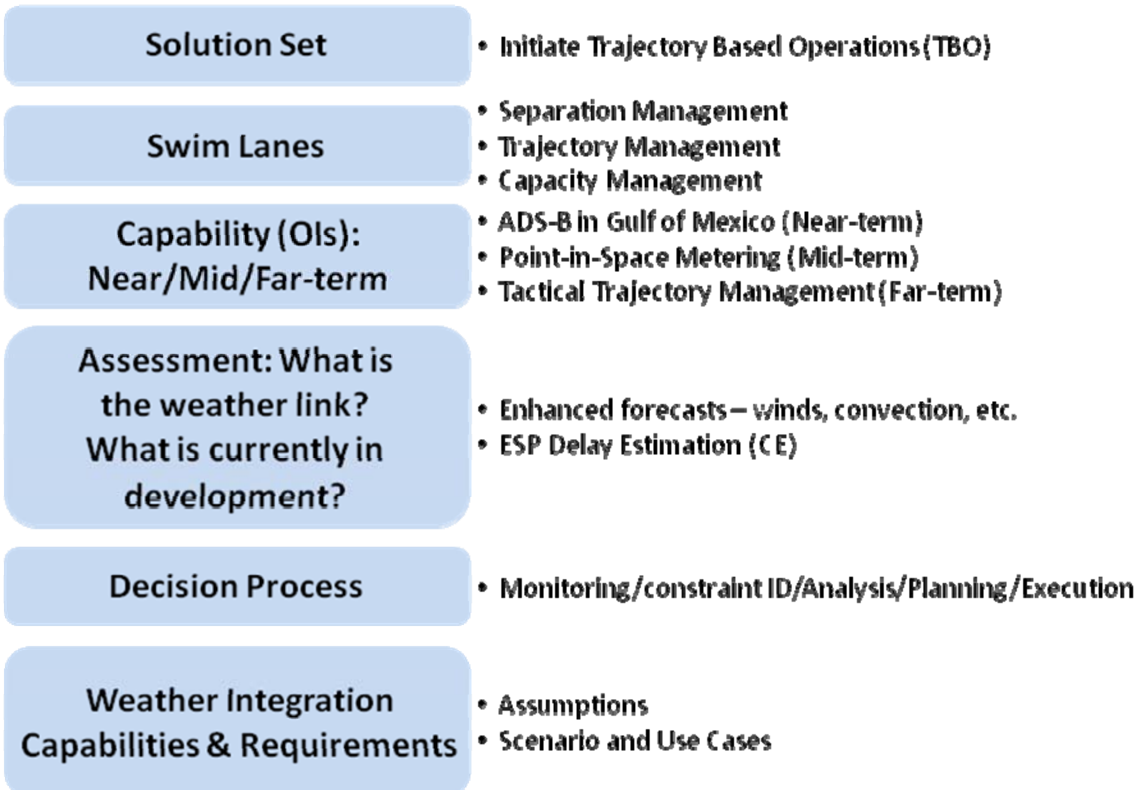
The combination of consistent weather information integrated into decision support tools will enable more effective and timely decision making by both ANSPs and users, for meeting capacity, efficiency and safety objectives. This also supports the alignment of traffic flows that best achieve a balanced capacity, safety and end user desires. It effectively enables a common understanding of the uncertainty of the future state of the atmosphere, supports traffic flow management by trajectory, and provides for improved weather avoidance.

3 NEXTGEN WEATHER INTEGRATION: DECISION SUPPORT TOOLS

This section contains an analysis of the need and opportunity for weather integration into NAS operations. This section and its associated Appendix A are to be expanded and refined as more information becomes available through execution of the Plan. Until more facts are known about the target capabilities, the section will rely on appropriate assumptions on the kinds of weather information required for integration into decision support tools and capabilities. It is aimed at ATO solution sets as defined in the NextGen Implementation Plan (NIP): Initiate Trajectory Based Operations (TBO), Increase Arrivals/Departures at High-Density Airports (High Density), Increase Flexibility in the Terminal Environment (Flex Term), Improved Collaborative Air Traffic Management (CATM), Increase Safety, Security, and Environmental Performance (SSE), and Transform Facilities (Facilities).

Each solution set was broken down into swim lanes and then further into Capabilities and associated Operational Improvements (OIs). Capabilities fell within either the Near, Mid, or Far-Term time frame as consistent with the solution set. Where possible, an assessment of each capability was done with reference to its link to weather and current developments, from the exploration (CE) to development (CD) to prototype (PD) phase. Beginning with a set of assumptions the value of integrated weather was examined within the context of an overarching scenario or concept of operations. The scenario was further broken down into individual use cases, where possible, to help define and draw out user needs and points of integration. Decision support tools, information threads, and weather linkages were closely examined, where possible to fully inform the integration solution. The work is iterative and will require continued effort as time, resources and understanding evolve.

The information for each solution set below follows the same general flow as mentioned above, with minor variances due to inherent differences in individual solution sets.



The expected weather and weather integration requirements of the capabilities were extracted from several different sources, including the REDAC Weather/ATM Integration report, the JPDO Weather Integration Conference report, the MITRE Initial Evolution Analysis for Achieving NAS Mid-term Operations and Capabilities report, the MIT/LL Roadmap for Weather integration into Traffic Flow Management Modernization report, the FAA Traffic Flow Management Concept Engineering Plan FY09 and the FAA Infrastructure Roadmap – Mid-term Integration Worksheets.

Beyond this, additional commentary, analysis, or planning information was added. Interviews with JPDO WG Subject Matter Experts and FAA Solution Set Coordinators, to the extent possible, helped to extract additional capability/weather information. Assumptions were written based on viewpoints of the three Collaborative Decision Making (CDM) participants (Aircraft, Airline Operations Control, and Air Traffic Control). In some cases, scenarios were created in which the use of weather information in support of the mid-term capability was explored.

General Assumptions

One of the assumptions associated with all the solution sets is that near-term stand-alone decision tools will begin to move from the current state of little to no weather integration to being fully integrated with weather (including uncertainty) in the far-term. Specifically, four levels of weather integration are expected:

Level 1 Stand alone (little to no weather integration)

Level 2 Over-lapping (high "glance value" weather impact information overlaid with decision support tool outputs)

Level 3 Minor human involvement (user-in-the-loop tools: Weather fully integrated within tool but separate weather information also provided for human understanding)

Level 4 Fully integrated (machine-to-machine: Weather and uncertainty fully integrated into decision tool outputs)

Another assumption is that weather is addressed for all temporal and spatial operational needs for all airspace from strategic planning and risk assessment to the tactical environment that surrounds, or is on the airport surface.

Solution Set Representation

Section 3.1, Trajectory Based Operations (TBO), identifies and briefly describes potential TBO weather integration opportunities, based on an on-going discussion of the mid-term OIs contained in the Initiate TBO solution set. Appendix A-1 defines key terms (TBO, Initiate TBO, 4D Trajectory); documents OI goals, needs/shortfalls, descriptions, and design/architecture; contains a discussion of the Initiate TBO solution set OI descriptions; describes weather integration opportunities in more detail; develops weather integration scenarios; and identifies potential mid-term functional weather requirements. This is a work in-progress intended to help communicate and refine the developing mid-term weather integration story for the Initiate TBO solution set. The mid-term OIs included in the Initiate TBO solution set are:

f) *Delegated Responsibility for Separation*
g) *Oceanic In-trail Climb and Descent*
h) *Automation Support for Mixed Environments*
i) *Initial Conflict Resolution Advisories*
j) *Flexible Entry Times for Oceanic Tracks*
k) *Point-in-Space Metering*
l) *Flexible Airspace Management*

- *Increase Capacity and Efficiency Using Area Navigation (RNAV) and Required Navigational Performance (RNP)*

The Increase Arrivals/Departures at High Density Airports (High Density) solution set involves airports (and the airspaces that access those airports) in which:

- Demand for runway capacity is high;
- There are multiple runways with both airspace and taxiing interactions, or;
- There are close proximity airports with the potential for airspace or approach interference.

High density airports require all the capabilities of flexible terminals and surrounding airspace plus integrated tactical and strategic flow capabilities. Decision support tools may require higher performance navigation and communications capabilities, including higher fidelity weather information for integration, for air traffic and the aircraft to support these additional operational requirements. High density corridors will serve as transitions to and from trajectory-based en-route airspace. High density operations will seamlessly integrate surface operations through transition altitudes to en-route airspace.

The Flexible Terminal solution set has a focus on improvements to the management of separation at all airports. Such capabilities will improve safety, efficiency and maintain capacity in reduced visibility high density terminal operations. At airports where traffic demand is lower, and at high density airports during times of low demand, operations requiring lesser aircraft capability are conducted, allowing access to a wider range of operators while retaining the throughput and efficiency advantages of high density operations. Both trajectory and non trajectory-based operations may be conducted within flexible terminal operations.

The Collaborative Air Traffic Management (CATM) solution set covers strategic and tactical flow management, including interactions with operators to mitigate situations when the desired use of capacity cannot be accommodated. This solution set includes flow programs and collaboration on procedures that will shift demand to alternate resources (e.g. routings, altitudes, and times). CATM also addresses the management of aeronautical information necessary for all operations within the NAS, including the management of airspace reservation and flight information from pre-flight planning to post-flight analysis.

A summary of results is given here, with more details presented in Appendix A.

3.1 Trajectory Based Operations

This section is a summary of Appendix A, section A-1. The paper on TBO found in A-1 is a work in-progress intended to help communicate and refine the developing mid-term weather integration story for the Initiate Trajectory Based Operation (TBO) solution set. Mid-term Operational Improvement (OI) descriptions, contained in this paper, go somewhat beyond what current NextGen and Federal Aviation Administration (FAA) documentation provide. The reason for this is to develop a more complete understanding of these OIs, so mid-term weather integration candidates can be more easily identified. Although these extensions to mid-term capability descriptions have not yet received review and vetting, this paper provides a vehicle by which these assumptions can obtain needed feedback, thereby furthering our understanding of mid-term OIs. These mid-term OIs begin the journey towards a full NextGen capability. This document describes these initial steps and their future evolution.

The purpose of A-1 is to support drafting of the Joint Planning and Development Office's (JPDO) Air Traffic Management (ATM) Weather Integration Plan by:

- Identifying and describing likely Traffic Flow Management (TFM) by trajectory weather integration opportunities based on the mid-term OIs contained in the Initiate TBO solution set and

- Developing weather integration scenarios to help identify potential mid-term functional weather requirements.

Section A-1 may also be useful in supporting other activities such as the:

- Refinement of OI descriptions in the Initiate TBO solution set,
- Scenario development by the FAA's Implementation and Integration (I&I) team,
- Drafting of en route TBO white papers by the JPDO's Air Navigation Services (ANS) Working Group (WG), and
- Drafting of TBO Concept of Operations (ConOps) and Concept of Use (ConUse) documents.

To-date, the following mid-term, Initiate TBO, weather-related, operational capabilities have been identified as 'potential' candidates for inclusion into decision support tools (DSTs). More analysis and discussion are required before a final set can be presented. From among these weather integration candidates, some may be incorporated into TBO ConOps documents, forming the basis for NextGen weather integration requirements.

Initial Conflict Resolution Advisories

- Controller weather problem detection decision support to:
  - Prevent directing aircraft into hazardous weather inadvertently when resolving aircraft-to-aircraft conflicts
  - Evaluate a pilot requested maneuver around the weather to ensure it will not send the aircraft into another area of convection not yet visible on the aircraft's airborne radar
- Controller weather problem resolution decision support to respond to pilot requests for assistance to:
  - Route around significant areas of convective weather that are rapidly and unexpectedly worsening
  - Return aircraft to original flight plan when convective weather rapidly and unexpectedly improves

Flexible Entry Times for Oceanic Tracks

- Integrate oceanic wind forecast information with the calculation of flexible entry times for oceanic tracks

Point-in-Space Metering

- Calculation of a sequence of recommended upstream Controlled Times of Arrival (CTAs) to a downstream capacity-constrained point, integrating weather and aircraft performance information, and conversion of these CTAs into desired airspeed changes

Flexible Airspace Management

- Determination of pre-defined airspace configurations, using existing traffic patterns and climatological weather
- Identification of airspace needs and development of a baseline plan for the given flight day, 1 to 5 days ahead, using forecasted weather information
- Establishment of a baseline airspace configuration for the day, 8-24 hours in advance, using forecasted weather information
- Determination of alternative airspace configurations, 4-8 hours in advance, using forecasted weather information
- Selection and implementation of specific airspace configuration alternatives, 1- 4 hours in advance, using forecasted weather information

Increase Capacity and Efficiency Using Area Navigation (RNAV) and Required Navigational Performance (RNP)

- Determination of whether fixed RNAV/RNP routes are or soon will be blocked by convective weather

Additionally, the following mid-term, en route TBO, weather-related, operational decisions have been identified as 'potential' candidates for common weather situational awareness among decision makers:

Delegated Responsibility for Separation

- Delegated responsibility for pair-wise separation in convective weather (i.e., aircraft following a 'pathfinder')

Initial Conflict Resolution Advisories

- Controller vectors an aircraft around a convective weather cell with an open-loop clearance.

3.2 High Density Airports

This section is a summary of Appendix A, section A-2. The paper on High Density Airports found in A-2 is a work in-progress intended to help communicate and refine the developing mid-term weather integration story for the Increase Arrivals/Departures at High Density Airport solution set. Mid-term Operational Improvement (OI) descriptions, contained in this paper, go somewhat beyond what current NextGen and Federal Aviation Administration (FAA) documentation provide. The reason for this is to develop a more complete understanding of these OIs, so mid-term weather integration candidates can be more easily identified. Although these extensions to mid-term capability descriptions have not yet received review and vetting, this paper provides a vehicle by which these assumptions can obtain needed feedback, thereby furthering our understanding of mid-term OIs. These mid-term OIs begin the journey towards a full NextGen capability. This document describes these initial steps and their future evolution.

The purpose of A-2 is to support drafting of the Joint Planning and Development Office's (JPDO) Air Traffic Management (ATM) Weather Integration Plan by:

- Identifying and describing likely high density airport weather integration opportunities based on the mid-term OIs contained in the Increase Arrivals/Departures at High Density Airports solution set and
- Developing weather integration scenarios to help identify mid-term functional weather requirements.

Section A-2 may also be useful in supporting other activities such as the:

- Refinement of OI descriptions in the Increase Arrivals/Departures at High Density Airports solution set,
- Scenario development by the FAA's Implementation and Integration (I&I) team,
- Drafting of high density airport white papers by the JPDO's Air Navigation Services (ANS) Working Group (WG), and
- Drafting of Increase Arrivals/Departures at High Density Airports Concept of Operations (ConOps) and Concept of Use (ConUse) documents.

To-date, the following mid-term, weather-related, operational decisions for Increase Arrivals/Departures at High Density Airports have been identified as 'potential' candidates for inclusion into decision support tools (DSTs). More analysis and discussion are required before a final set can be presented. From among these weather integration candidates, some may be incorporated into Increase Arrivals/Departures at High Density Airports ConOps documents, forming the basis for NextGen weather integration requirements.

Integrated Arrival/Departure Airspace Management

- Support/recommend a stable, baseline arrival/departure configuration plan for the flight day
- Proactively support/recommend arrival/departure configuration modifications, far enough in advance of predicted weather (e.g., wind shift), to efficiently move traffic to new arrival/departure configurations
- Reactively support/recommend arrival/departure configuration modifications in response to rapidly changing and highly localized weather conditions (e.g., pop-up thunderstorms on arrival/departure routes)

Time-Based Metering Using RNP and RNAV Route Assignments

- Calculation of a set of 'attainable' Controlled Time of Arrivals (CTAs) to an arrival metering fix, taking weather's impact on aircraft speed and performance into account
- Improve departure routing, by increasing the accuracy of predicted trajectories

Initial Surface Traffic Management

- Support/recommend a stable, baseline airport configuration plan for the flight day
- Proactively support/recommend airport configuration modifications, far enough in advance of predicted weather (e.g., wind shift), to efficiently move traffic to new airport and arrival/departure configurations
- Support/recommend surface sequencing and staging lists and determine (current and predicted) average departure delays

3.3 Flexible Airspace in the Terminal Area

3.3.1 Separation Management

Wake Turbulence Mitigation for Departures (WTMD) - Wind-Based Wake Procedures relies on improved wake vortex (WV) prediction capabilities, and the integration of that WV information into display systems and decision support tools (DSTs) which identify and mitigate the impact of wake turbulence generated by one aircraft on a following aircraft. As compared to the generalized methodologies employed today, this flight pair-specific approach to dealing with wake turbulence should allow for the reduction of spacing between aircraft, thereby improving runway capacities across a range of weather conditions and operating regimes. Implicit in this statement is that existing wake vortex-based separation rules will be changed based on the capability of WTMD-based systems to predict the transport or decay of wake vortices and their precise impact on the trailing aircraft.

Although this Operational Improvement (OI) specifically focuses on wake mitigation in the departure regime, and is therefore assumed to be concerned primarily with longitudinal separation between departing aircraft, there is also the need for similar capabilities in the arrival regime, and especially for arrivals to Closely Spaced Parallel Runways (CSPRs). It is almost certain that the display systems and DSTs created to provide Wake Turbulence Mitigation for Arrivals (WTMA) will require the same weather inputs as will procedures and DSTs designed to provide WTMD, despite the fact that the resultant arrival processes are likely to be concerned with the lateral, instead of longitudinal, separation of aircraft landing on adjacent runways. See Appendix A-2.3, Improved Operations to Closely Spaced Runways, for additional WTMA discussion in the context of closely spaced parallel runways.

WTMD and WTMA display systems and DSTs are likely to depend on the integration of real time local wind data and high resolution, high refresh wind profile forecasts into a wind forecast algorithm, whose output in turn will then need to be integrated into the appropriate wake turbulence mitigation processing function. Based on the precision required of WTMD and WTMA DSTs, it is thought that enhanced forecasts of terminal winds will be needed, thus creating high temporal and spatial wind observation and reporting requirements.

m) WTMD/WTMA weather integration is envisioned to mean that high resolution, real time local wind data and high resolution, high refresh rate wind forecasts are part of a wind forecast algorithm which in turn is integrated into the WTMD/WTMA processing function.

n)

o) ATC policies and procedures will have to be changed to allow differing separation criteria based on information from wake turbulence mitigation models, regardless of whether the separation criteria are calculated and assigned manually or automatically.

- Integrated Work Plan (IWP) enablers (i.e., EN-0029 and EN-0030) describe a ground-based wake vortex advisory system that presumably includes high spatial and temporal wind observations and whose sole focus is on wake vortex detection, prediction and aircraft spacing guidance in the terminal area – especially for impacts to operations on CSPR. It has been estimated in the NextGen Portfolio Work Plan on Resource Planning Data (RPD) that several additional departures per hour from closely-spaced parallel runways are possible, if the dissipation of the wake turbulence can be predicted. Regardless of where or how weather information is integrated, the net effect on improved operations will be driven by changes in separation standards and procedures.

Ground-Based Augmentation System (GBAS) Precision Approaches will support precision approaches to Category I (as a non-federal system), and eventually Category II/III minimums for properly equipped runways and aircraft. GBAS can support approach minimums at airports with fewer restrictions to surface movement and offers the potential for curved precision approaches. GBAS also can support high-integrity surface movement requirements.

GBAS increases the accuracy of position information from GPS/GNSS satellites to a level appropriate to the procedure being conducted. Like any system which relies on radio wave communications through the atmosphere, the performance capability of GBAS may be affected by significant solar activity. Consequently, it is possible that components of a GBAS and onboard systems which utilize GBAS may have to include information on the start and end times, expected duration, intensity and anticipated impact of solar activity on the accuracy of the system.

3.3.2 Trajectory Management

Optimized Profile Descents (OPDs) (also known as Continuous Descent Arrivals -- CDAs) will permit aircraft to remain at higher altitudes on arrival at the airport and use lower power settings during descent. OPD arrival procedures will provide for lower noise and more fuel-efficient operations.

The integration of high resolution terminal winds into aircraft equipped with onboard energy management guidance systems may allow these aircraft to fly precise 4DTs that are highly optimized for fuel efficiency. Minimally equipped aircraft, in contrast, may fly a more basic OPD that simply applies idle thrust wherever possible. In addition, the precise 4DT flown by an aircraft on an OPD will vary by a number of factors including winds aloft, aircraft weight, and top of descent point.

Although this capability focuses on the need for accurate winds aloft data for OPD operations, pilots and controllers will need more information in order to consistently plan and complete OPDs, such as improved observations and forecasts of winds and hazards to aviation such as convectively induced turbulence (CIT), clear air turbulence (CAT), lightning and hail. Further investigation of these weather factors, any or all of which can impact OPD operations, and how to integrate them into OPD-related decision support tools, needs to be undertaken in order to improve OPD planning and operations.

To that end, existing airborne capabilities of measuring wind, turbulence, temperature, humidity and icing need to be improved and fully leveraged. Processes which enable and encourage the transmission of this information to ground systems and adjacent aircraft must be developed, and then that information must be incorporated into weather forecast models and ATM and onboard decision support tools as appropriate.

It would seem that the eventual migration of the Descent Advisor functionality would be the likely target for weather integration of high resolution terminal winds and wind shear zones. Tools that help determine compression spacing needs would also likely need similar weather information integration.

3.3.3 Flight and State Data Management

Provision of Full Surface Situation Information will involve automated broadcasts of aircraft and vehicle positions to ground and aircraft sensors/receivers. This information will then be used to populate a digital display of the airport environment. Aircraft and vehicles will be identified and tracked, providing a full comprehensive picture of the surface environment to the Air Navigation Service Provider (ANSP), equipped aircraft, and AOC/FOCs.

Decision support tool (DST) algorithms will use this enhanced target data to support identification and alerting of those aircraft at risk of runway incursion. This surface situation information will complement visual observation of the airport surface. Service providers, AOC/FOCs, and equipped aircraft need an accurate real time view of airport surface traffic and movement, as well as obstacle location, to increase situational awareness of surface operations. Currently, this can be difficult because of several factors, including, but not limited to poor visibility caused by weather or nighttime conditions.

Enhanced Surface Traffic Operations involve data communication between aircraft and Air Navigation Service Provider (ANSP) and is envisioned to be used to exchange clearances, amendments, requests, NAS status, weather information, and surface movement instructions. At specified airports data communications is the principal means of communication between ANSP and equipped aircraft. Among the information being sent to the aircraft and integrated into on-board aircraft systems will be On-Demand NAS Information from the Super Computer Aided Operational Support System (S-CAOSS), the tower platform for Data Comm Program Segment 1 (e.g., OI 103305 for 2013-2017). Terminal aeronautical information will be available to equipped aircraft and provided on demand via data communications between the FAA ground automation and the aircraft. This includes current weather, altimeter settings, runways in use, and other departure and destination airport information.

This initiative has a communications focus aspect – not necessarily the weather information aspect. However, there needs to be adequate bandwidth provided for the communication of weather information so that it can then be integrated. It is understood that other informational sources will command higher availability. To this extent, advanced on-board Flight Management

Systems, integrated with surface weather conditions need to be coupled with the broadcast of aircraft position, state, and intent information. There is a need to assist air traffic controllers to clear aircraft to follow other aircraft on the cockpit display on an approach, at separation minimums much less than those that are applied today in bad weather.

3.4 Collaborative Air Traffic Management

3.4.1 Flight Contingency Management

Continuous Flight Day Evaluation concepts involve ANSPs and users to collaboratively and continuously assess (monitor and evaluate) constraints (e.g., airport, airspace, hazardous weather, sector workload, Navigational Aid (NAVAID) outages, security) and associated TMI mitigation strategies. Performance analysis, where throughput is constrained, is the basis for strategic operations planning. Continuous (real time) constraints are provided to ANSP traffic management decision support tools and National Airspace System (NAS) users. Evaluation of NAS performance is both a real time activity feedback tool and a post-event analysis process. Flight day evaluation metrics are complementary and consistent with collateral sets of metrics for airspace, airport, and flight operations.

Mid-term continuous flight day evaluation with integrated weather supports performance analysis and improvement capabilities, congestion prediction and decision-making, and enhanced post operations analysis. Capacity prediction improvements especially are a significant enhancement for TFM in the mid-term, with the most value resulting from the integration of weather prediction information (uncertainty). This will allow weather information to be used not only in capacity predictions, but in demand prediction and aircraft trajectory modeling displays as well, further improving the TMs understanding of NAS status and managed risk. Later in the mid-term, automation will predict sector capacity based on traffic flows and weather predictions instead of using the Monitor Alert Parameter as a proxy for sector capacity. Mitigation of congestion will be supported by TFM automation which will disseminate probabilistic (integrated weather uncertainty) demand and capacity predictions for all monitored NAS resources to TMs and NAS customers.

It was concluded that weather integration may additionally have a role in the support of the following Traffic Flow Management concept engineering CATM-related Mid-Term initiatives:

- Enhanced Flight Segment Forecasting
- Airborne Delay Research
- Integrated Program Execution (IPE)
- Integrated Program Modeling (IPM) Phase 2
- NextGen of FSM slot assignment logic
- Pre-day of Operations TFM concepts
- System Integrated TMI’s
- Analyze Uncertainty in Sector Demand Prediction

- Prototype a New Metric for Sector Alerts

Traffic Management Initiatives with Flight-Specific Trajectories (Go Button) refers to individual flight-specific trajectory changes resulting from Traffic Management Initiatives (TMIs) will be disseminated to the appropriate Air Navigation Service Provider (ANSP) automation for tactical approval and execution. This capability will increase the agility of the NAS to adjust and respond to dynamically changing conditions such as bad weather, congestion, and system outages.

Decision support tool functionality that support this capability will require integration of probabilistic information, management of uncertainty, what-if analysis, and incremental resolution of alternatives supporting development and implementation of flexible, incremental traffic management strategies to maintain the congestion risk to an acceptable level and to minimize the impact to the flights involved in the congestion.

3.4.2 Capacity Management

Improved Management of Airspace for Special Use includes assignments, schedules, coordination, and status changes of special use airspace (SUA) are conducted machine-to-machine. Changes to status of airspace for special use are readily available for operators and Air Navigation Service Providers (ANSPs). Status changes are transmitted to the flight deck via voice or data communications. Flight trajectory planning is managed dynamically based on real time use of airspace.

The need for weather integration is envisioned to be similar to that for flight contingency management with an emphasis on more effective informational exchange between TFM and NAS users. Coordination between civilian NAS users and military NAS users regarding weather impacts and the availability of SUAs is particularly important. Weather informational needs will include predicted weather constraints (e.g. convection, turbulence, ceiling/visibility or runway winds limitations at an airport), estimates of weather uncertainty, and quantitative, time-varying forecasts of the reduction in NAS resource availability due to the weather.

Informational exchange between TFM and controllers, including Tower/TRACON supervisors and en-route area managers would benefit from broad-area depictions of weather-related constraints in place, forecasts of future constraints and an effective means of collaborating with their facility's Traffic Management unit in developing tactical response strategies for these constraints. National TM personnel should have improved visibility into weather constraints affecting the tactical environment in key en-route and terminal facilities.

3.4.3 Flight and State Data Management

Trajectory Flight Data Management improves the operational efficiency and increases the use of available capacity by providing for improved flight data coordination between facilities. This will enable access to airports by readily facilitating reroutes. Additionally, it will support more flexible use of controller/capacity assets by managing data based on volumes of interest that can be redefined to meet change to airspace/routings. Trajectory Flight Data Management will also provide continuous monitoring of the status of all flights – quickly alerting the system to unexpected termination of a flight and rapid identification of last known position. Weather integration can support this capability and likely will consist of improved observations, enhanced forecasts and a de-conflicted common weather picture.

It was concluded that weather integration may additionally have a supporting role in the following Traffic Flow Management concept engineering CATM-related Mid-Term initiatives:

- Additional AFP capabilities and usage
- Environmental modeling and analysis of TFM performance (fuel burn estimation)
- Reroute impact assessment
- Special use airspace information research

Weather integration in support of common flight profiles may have value for functions that determine trajectory changes and problem predictions/resolutions (aircraft-to-aircraft, aircraft-to-airspace, aircraft-to-TFM Flow Constraint, Aircraft-to-Severe Weather).

The functional evolution Traffic Management Advisor (TMA) is a candidate for weather integration since the TMA is envisioned to continue in operation at several locations that are frequently impacted by convective weather. The integration of weather products into TMA is underway.

Integrated Time-Based Flow Management (ITBFM) will provide traffic managers an improved capability to develop, execute and adjust a common and integrated departure-to-arrival schedule for all aircraft that supports both TFM objectives and, to the extent possible, NAS customer preferences. There may well be differences in the details of the weather forecast translation into ATC impacts for DFM versus TMA. Hence, it will be important to determine the anticipated mode of operation for ITBFM so as to determine if there are additional weather-to-capacity translation issues that need to be considered in achieving an operationally useful ITBFM.

Provide Full Flight Plan Constraint Evaluation with Feedback involves timely and accurate NAS information that allows users to plan and fly routings that meet their objectives. Constraint information that impacts proposed flight routes is incorporated into Air Navigation Service Provider (ANSP) automation, and is available to users for their pre-departure flight planning. Examples of constraint information include special use airspace status, significant meteorological information (SIGMET), infrastructure outages, and significant congestion events. Weather needs identified include a common weather picture of enhanced forecasts of convection, turbulence and icing. Improved observations are also needed.

Specifically the feedback will include weather information, probabilistic information, TMIs (including delay information), airspace information (e.g., High Performance Airspace (HPA)/Mixed Performance Airspace (MPA), Area Navigation (RNAV) routes), required aircraft performance characteristics (e.g., Required Navigation Performance (RNP), RNAV requirements), active routes, restrictions (e.g., Letter of Agreements (LOAs), Standard Operating Procedures (SOPs), Special Activity Airspace (SAA)), terminal status information (e.g., airport conditions, runway closures, wind, arrival rates, Runway Visual Range (RVR), airport (current and planned) configurations, surface information and other NAS status information and changes along the path of the evaluated route or filed route.

Realizing a robust capacity prediction capability will require major effort in at least three areas. Continued progress in diagnosing and forecasting relevant weather phenomena over the 0-24 hour time scales needed for TFM is essential. Research may be focused on extending the look-ahead-time for convective weather forecasts to 6-24 hours, and on improved 0-2 hour "nowcasts" of turbulence and airport weather conditions (ceiling and visibility, winds, winter precipitation) that affect capacity. Viable methods for estimating and conveying the uncertainty of future resource capacity predictions must be defined. Dynamic capacity estimation models will need to consider weather in their capacity estimates.

On-Demand NAS Information means that National Airspace System (NAS) and aeronautical information will be available to users on demand. NAS and aeronautical information is consistent across applications and locations, and available to authorized subscribers and equipped aircraft. Proprietary and security sensitive information is not shared with unauthorized agencies/individuals. Dynamic NAS status information includes current weather constraints and SIGMETs. As mentioned before for other CATM capabilities, weather integration will need to be accompanied by a de-conflicted common weather picture and made available for TFM and AOC/FOCs.

3.5 Increase Safety, Security and Environmental Performance (SSE)

3.6 Transform Facilities (Facilities)

3.7 Additional Initiatives and Targets:

The System Enhancement for Versatile Electronic Negotiation (SEVEN) initiative involves rerouting flights. This can be a manually intensive, time and attention-consuming effort while giving little consideration to NAS customer input. SEVEN provides a concept for managing en-route congestion that allows NAS customers to submit prioritized lists of alternative routing options for their flights. SEVEN has the potential to reduce traffic manager workload, while allowing better traffic control in uncertain weather situations.

Traffic managers can assess the impact of various flight plan options on system congestion using an Interactive Dynamic Flight Lists (IDFL) and choose an option from the customer submitted list that provides weather avoidance and meets airspace capacity constraints. The utility of this concept when it is used to mitigate weather impacts on NAS customers will vary substantially from case to case, depending on the weather forecasts, which is a function of the type of weather and the look-ahead-time, the ability to accurately estimate NAS resource constraints from these forecasts, and the sophistication of the customer's process for utilizing this information to define and prioritize alternatives for the impacted aircraft.

4 TECHNOLOGY AND METHODOLOGY CONCEPTS

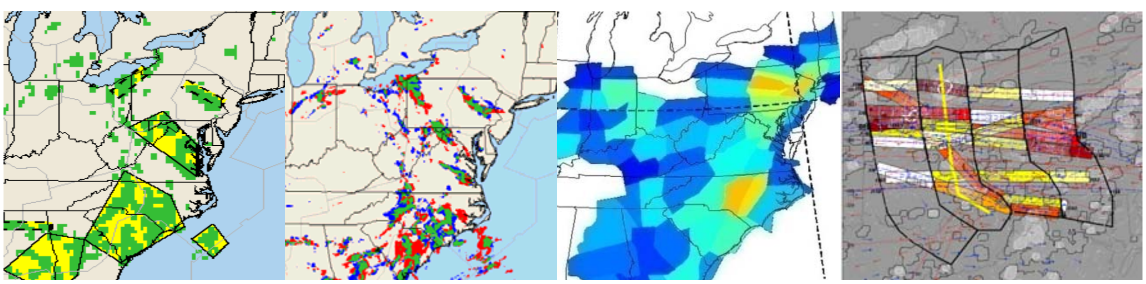
This section, with more detail in Appendix B provides a survey that identifies technologies and methodologies for translating weather information into Air Traffic Management (ATM) impacts in the National Airspace System (NAS). The survey includes approaches for addressing weather-related uncertainty in ATM decision making – risk management processes. The survey is organized into two parts:

- ATM-Weather Impact Models – these describe the translation of weather information into ATM impacts as outputs, and
- ATM-Weather Integration Techniques – these describe how ATM-weather impact models may be integrated into Decision Support Tools (DSTs) or in other ways to manage uncertainties in NAS decision making.

For each part, the maturity of the state of the art is determined and gaps in technology are identified. These methodologies emphasize solutions for ATM-weather integration for the Next Generation Air Transportation System (NextGen).

4.1 Survey of ATM-Weather Impact Models

In the NAS, en route Traffic Flow Management (TFM) balances air traffic demand against available capacity, to ensure a safe and expeditious flow of aircraft. TFM resources may be expressed in terms of airspace availability; this includes fix availability, route availability, and airspace availability (e.g., grid cell, hex cell, sector, center, or Flow Constrained Area (FCA)). For example, Figure 4-1 illustrates the transformation of weather forecast data into point-impacts (suitable for assessing fix availability), route-impacts (suitable for assessing route blockage), and sector-based impacts (suitable for TFM flow planning). TFM resources also include airport resources, including Airport Arrival Rate (AAR), Airport Departure Rate (ADR), runway availability, and others. All these resources are important and are mentioned in the survey where applicable.



(a) Convective Forecast (b) Pixel-based impact (c) Sector-based impact (d) Route-based impact

Figure 4-1 Convective forecast transformed into ATM impact in various formats.

The majority of the ATM-impact models address airspace capacity issues. In today's NAS, there is no automation tool to predict airspace capacity, since there is no established and accepted indicator of airspace capacity. The Enhanced Traffic Management System (ETMS) [E02] provides a congestion alerting function which uses the peak one-minute aircraft count as a sector congestion alerting criterion (the Monitor Alert Parameter (MAP)). The MAP is not meant to be a measure of airspace capacity, but rather a threshold which, when exceeded by predicted demand, alerts traffic managers to examine the sector for potential congestion. The MAP value is typically designed to account for the nominal traffic structure experienced in the airspace rather than a hypothetical structure designed to maximize capacity. ATM-impact models that address the structure from nominal routing along today's jet routes as well as ATM-impact models that design new traffic flow structures that maximize capacity are included in the survey, since it is clear that airspace capacity models are needed for today's routing structures as well as NextGen's more flexible routing structures.

As demonstrated by the survey, estimating capacity has many difficulties due to the complexity of weather forecasting and demand estimation. One difficulty is that weather forecasts all have some degree of uncertainty. To address this, several of the ATM-impact methods go beyond deterministic weather forecasts and into probabilistic weather forecasts, both in terms of probability distributions as well as ensemble weather forecasts. In addition to weather forecast errors, minor differences in how weather develops, for instance, the weather organization, can lead to major differences in the impacts on the NAS. Small storms located at critical locations in the NAS can have more impact than larger storms in less critical locations. In the case of a squall line, for instance, many of the westbound flights in a sector may be blocked, while several northbound flights can make it through. One ATM-impact method specifically addresses the issue of directional capacity. Furthermore, ATM-impact models for en route airspace must be modified to address transition or terminal area airspaces. Sector capacity in particular, is a function of the traffic flow pattern, whether it is a pattern established by jet routes, a uniform distribution of flow in a standard direction (e.g., East-to-West), or random, as is the case of Free Flight (if implemented in NextGen). Capacity is not strictly independent of demand; the trajectories and altitude profiles of flights that plan to use an airspace can significantly alter how many flights can be managed. Some researchers refer to this as "demand-driven capacity."

Next, we present a summary of each of the surveyed ATM-impact models starting with models that were derived primarily for convection, and ending with a wide variety of models for several types of aviation hazards, including turbulence, icing, winter weather, and others.

Empirical Methods. Empirical methods do not model capacity directly. They infer the capacity from historical traffic data and they infer the relationship between capacity reduction and weather by comparing historical traffic to weather data. This may be accomplished from a range of techniques from statistical testing to cluster analysis. Empirical methods may be applied to all types of weather, such as convective weather, turbulence, icing, ceiling and visibility, and surface winds. Also, empirical methods may be applied to assess the capacity of a wide variety of NAS resources, including metering fix capacity, route capacity, sector and center capacity, and even overall NAS capacity.

Rational Methods. Rational methods model capacity directly. They deduce the capacity from traffic models, operational procedures, airspace geometry, weather models, and so forth. Some models use current-day jet routes, while others assume that the routing across the airspace can be redesigned to maximize capacity (e.g., parallel flows of traffic across FCAs) or maximize user preferences (Free Flight). The ATM-impact evaluation can be done for different parameterizations (from conservative to aggressive, with a variety of safety margins representing pilot and airline preferences), to evaluate a range of impacts of the weather on the nominal capacity. Modeling errors will result in capacity estimation errors.

En route Convective Weather Avoidance Modeling. An en route Convective Weather Avoidance Model (CWAM) calculates Weather Avoidance Fields (WAFs) as a function of observed and/or forecast weather. WAFs are 2D or 3D grids whose grid points are assigned either a probability of deviation or a binary deviation decision value (0 or 1). CWAM requires both the inference of pilot intent from an analysis of trajectory and weather data and an operational definition of deviation. Two approaches have been taken to model and validate weather-avoiding deviations using trajectory and weather data: trajectory classification and spatial cross-correlation.

Terminal Convective Weather Avoidance Modeling. In order to determine the impacts of convective weather on terminal air traffic operations, CWAM models must be modified to take into account the constraints of terminal area flight to calculate WAFs that apply specifically to terminal area operations. Each WAF grid point is assigned a probability and/or a binary value (0 or 1) that represents that likelihood that pilots will choose to avoid convective weather at a point location in the terminal area. For instance, departures and arrivals are constrained to follow ascending or descending trajectories between the surface and cruise altitude, leaving little flexibility to avoid weather by flying over it. Aircraft flying at low altitudes in the terminal area appear to penetrate weather that en route traffic generally avoids. The willingness of pilots to penetrate severe weather on arrival increases as they approach landing.

Mincut Algorithms to determine Maximum Airspace Capacity. For NextGen when jet routes can be dynamically redefined to adjust flows of traffic around weather constraints, the maximum capacity of an airspace may be determined using extensions of MaxFlow/Mincut Theory. A continuous flow version of the network MaxFlow/Mincut Theorem is suitable for estimating the maximum throughput across an en route airspace given a traffic flow pattern, a uniform distribution of flow monotonically traversing in a standard direction (e.g., East-to-West), or random, Free Flight conditions. Given a required gap size between weather constraints (how big the gap must be to safely fly through it), an algorithm identifies the mincut bottleneck line – this mincut determines the maximum capacity in terms of the maximum number of air lanes that can pass through the gaps in the weather for a specified altitude range. Capacity is determined by analyzing mincut values from the lowest to highest altitude in a sector as a function of time given a weather forecast.

Weather-Impacted Sector Capacity considering CWAM and Flow Structure. NAS sectors typically exhibit a small set of common traffic flow patterns, and different patterns represent different levels of traffic complexity. Quantifying sector capacity as a function of traffic flow pattern provides a basis for capturing weather impact on sector capacity. The future traffic flow pattern in the sector is predicted and described with flows and flow features. The available flow capacity of each flow in the predicted traffic flow pattern is determined by MaxFlow/Mincut Theory applied to a Weather Avoidance Altitude Field (WAAF) – a 3D version of the CWAM WAF. The available flow capacities are combined and translated to the available sector capacity based on the traffic on each flow and the normal sector capacity given the predicted traffic flow pattern.

Route Availability. Several ATM tasks, including departure and arrival flow management and the planning of weather-avoiding reroutes, require the assessment of the availability and/or capacity of individual traffic routes or flows. Thus, it is natural to extend Maxflow/Mincut, CWAM, and WAF concepts into route availability. A route is available if traffic can follow a route and stay within acceptable deviation limits around the route centerline while avoiding hazardous weather. The route capacity indicates the rate of traffic flow that an available route can support. Estimating route availability may be achieved by Maxflow/Mincut and Route Blockage techniques. Capacity estimates must account for the workload and uncertainty involved in flying the weather-avoiding trajectories that they identify.

Directional Capacity and Directional Demand. Since traffic flow patterns are directional, capacity is also directional. The capacity of an airspace can be estimated for a series of ‘cardinal’ directions, e.g., North (N), East (E), South (S), West (W) and the diagonals NE, NW, SE, and SW. Also, directions can be quantified every Θ degrees (e.g., Θ=20 deg.), spaced around a given NAS resource, for instance, around an airport, metroplex, or fix location, or within a section of airspace. For each angular wedge of airspace, the maximum capacity for traffic arriving from a specified direction may be established. MaxFlow/Mincut techniques as well as scan line techniques have been demonstrated. The maximum capacity for a particular angular wedge of airspace will quantify the permeability of the weather with respect to traffic arriving from a specified direction. The challenge is to determine acceptable amounts of traffic that may pass through in given directions, subject to controller workload limits.

The Weather Impacted Traffic Index. The Weather Impacted Traffic Index (WITI) measures the number of flights impacted by weather. Each weather constraint is weighted by the number of flights encountering that constraint in order to measure the impact of weather on NAS traffic at a given location. Historically, WITI has focused on en route convective weather, but the approach is now applied to other weather hazard types as well. A WITI-B variation evaluates the extent to which a flight would have to reroute in order to avoid severe weather. The En route WITI (E-WITI) for a flow is the product of its hourly flight frequency and the amount of convective reports in a region of airspace. Another approach apportions all en route WITI measures to origin and destination airports. Terminal WITI (T-WITI) considers terminal area weather, ranked by severity of impact, and weights it by the departures and arrivals at an airport. The National Weather Index (NWX) implements the WITI on a NAS-wide scale.

Weather-Weighted Periodic Auto Regressive Models for Sector Demand Prediction. Traditional air traffic flow prediction models track the aircraft count in a region of the airspace based on the trajectories of proposed flights. Deterministic forecasting of sector demand is routinely done within ETMS, which relies on the computation of each aircraft's entry and exit times at each sector along the flight path. Since the accuracy of these predictions is impacted by departure time and weather uncertainties, and since weather forecast uncertainty causes errors in the sector count predictions, traditional methods can only predict the behavior of NAS for short durations of time – up to 20 minutes or so. It is difficult to make sound strategic ATM decisions with such a short prediction time. An empirical sector prediction model accounts for weather impact on both short-term (15 minutes) and mid-term (30 minutes to 2 hours) predictions. Different from traditional trajectory-based methods, Periodic Auto-Regressive (PAR) models evaluate the performance of various demand prediction models considering both the historical traffic flows to capture the mid-term trend, and flows in the near past to capture the transient response. A component is embedded in the model to reflect weather impacts on sector demand.

Stochastic Congestion Grids. A stochastic congestion grid quantifies congestion (density of aircraft) in a way that accounts for the uncertainty of the aircraft demand and uncertainty of the weather forecast (convection, turbulence, or icing) for long look-ahead times, as required by strategic TFM planning processes. Each grid cell records an estimate of the probability that the expected traffic exceeds a threshold level. In NextGen, 4D trajectories are stored in the 4D congestion grid by projecting the 4D trajectory onto the grid with an error model for along track error and cross track error. An increase in probability of congestion occurs where the traffic flow increase coincides with a predicted weather constraint. A probability that a weather constraint will exist is described on a grid cell instead of a binary value for a constraint versus no constraint. If the probability that traffic in any 4D grid cell exceeds tolerable thresholds, then appropriate TFM planning is warranted.

Translation of Ensemble Weather Forecasts into Probabilistic ATM Impacts. In NextGen, in order to capture the uncertainties posed by long-term weather forecasting, strategic TFM planning will rely on probabilistic ensemble weather forecast information. Ensemble forecast systems generate a series of deterministic forecasts of potential weather outcomes (i.e., members of the ensemble). Each forecast represents a possible weather scenario that may emerge later in the day. These weather forecasts, in turn, are translated into ATM impacts with relative likelihoods and probability density functions (pdfs) for either use by humans-over-the-loop or computer-to-computer ATM applications. The definition of a weather hazard could be for convection, turbulence, icing, or other aviation-relevant hazards and events (e.g., major wind shifts at an airport), and any appropriate weather hazard model can be placed into the ensemble-translation process; for instance, the CWAM WAF for a given altitude range.

Translation of a Deterministic Weather Forecast into Probabilistic ATM Impacts. NextGen systems can benefit from understanding how a single deterministic forecast in a grid-based format, and some error bounds associated with the forecast, can be used to create probabilistic ATM impacts for airspace regions. Variations on a single deterministic forecast are created by considering error models that account for errors in timing, errors in coverage, translational errors, and echo top errors. A synthetic ensemble of forecasts is created that are similar (perturbations) to the input deterministic forecast. The set of erroneous forecasts represents “what if” cases; “what if the weather system arrives early (late)”, “what if it is larger (smaller) than expected”, etc. The underlying assumption is that the weather organization has been correctly forecasted, but the speed, growth, or decay of weather cells may be in error. The synthetic ensemble of erroneous forecasts is then input into an ATM-impact model, for instance, a Maxflow/Mincut method, route blockage method, or CWAM model, and a set of ATM-impacts is output. This probabilistic estimate may assist users or the ANSP in assessing risks associated with weather impacts.

Sensitivity of NAS-wide ATM Performance to Weather Forecasting Uncertainty. Planners need to understand sensitivity of ATM performance to the weather forecasting uncertainty in order to make research and development decisions. The ATM performance improvement (benefit) is determined by comparing the performance sensitivity and a contemplated forecasting uncertainty reduction. Simulation is typically required to model ATM performance. Such a simulation must include effects of the weather and its forecast in order to model the sensitivity to the weather forecasting uncertainty. For instance, such effects might include the modeling of vectoring, rerouting and ground hold decision making models in response to weather forecasts. The ATM performance simulations require weather forecasts of varying accuracy in order to evaluate the sensitivity to forecasting uncertainty.

Use of Probabilistic Convective Weather Forecasts to Assess Pilot Deviation Probability. The operational probabilistic weather product called the National Convective Weather Product–6 (NCWP-6) provides up to 6-hour forecasts of the probability of convection. One way to translate probabilities of convective to ATM impact is to determine a correlation between aircraft position and NCWF-6 convective probability values, at the appropriate flight level and relative distance above the echo top. Using the correlation, a decision-maker could assess the NCWF-6 probability that aircraft are willing to traverse, and in turn, the risk associated with traveling in the vicinity of forecasted NCWF-6 probability contours. The Probability Cut-off Parameter (PCP) is the maximum NCWF-6 probability contour which correlates with a majority of aircraft positions based on historical analysis. PCP values differ with forecast times and they can be established for a local scope, at sector and center levels.

Integrated Forecast Quality Assessment with ATM Impacts. In order to better understand the application of convective weather forecasts into the ATM planning process, convective forecast products need to be objectively evaluated at key strategic decision points throughout the day. For example, a sector-based verification approach along ATM strategic planning decision points and a measure of weather impact across the NAS can be used to evaluate convective weather forecast quality in an operational context. The fundamental unit of measure is applied to super high sectors – the volumes that are used for strategic air traffic planning of en route air traffic. The goal is to correctly transform the forecast into sector impacts quantified by the ATM impact model that applies, for instance a directional capacity impact in the direction of flow established by the ATM flow plan. ATM impact models must be tied into the evaluation of weather forecast quality in a way that the ATM impact is accurately predicted in measures that are meaningful to the ATM application.

Conditioning ATM Impact Models into User-relevant Metrics. In order to translate weather forecasts into useful information for ATM planners, weather forecasts need to be calibrated, not with respect to meteorological criteria, but with respect to operational planning criteria. Since the airlines participate in the ATM process through Collaborative Decision Making (CDM) processes, calibrated ATM-impacts must be expressed in meaningful terms to the airlines (dispatch and ATC coordinators) as well as to the ANSP. When planning and scheduling flows of air traffic to cross the NAS, one must project flight schedules and trajectories and weather forecast information into an ATM impact model to arrive at delay estimates (arrival and airborne delays), cancellation estimates, and cost estimates. In NextGen, post-process analysis can be used to adjust the bias on ATM impact models so that future ATM impacts best model actual costs. In NextGen, it will be critical that the impacts of weather information be calibrated with respect to ATM operational decisions for effective planning and automated decision support.

Integration of the Probabilistic Fog Burn Off Forecast into TFM Decision Making. The situation at San Francisco (SFO) International Airport provides an opportunity to explore the integration of probabilistic weather forecasts into TFM decision making. This case involves a forecast of a single weather parameter – the marine stratus (fog) burn off time – at a fixed geographical location (the SFO approach zone). Traffic managers initiate a Ground Delay Program (GDP) to reduce the inflow of aircraft when fog at SFO lingers well into the morning arrival rush, thereby reducing the AAR in half (because only one runway can be used instead of two). One must rate the confidence of each of several forecasts, and use empirical errors of historical forecasts in order to create a probabilistic forecast in terms of a cumulative distribution function of clearing time. To address the ATM impact, a weather translation model must integrate SFO's probabilistic fog burn off forecast in with GDP algorithms.

Mincut Algorithms given Hard/Soft Constraints to determine Maximum Capacity. The Maxflow/Mincut problem assumes that weather hazards are classified in a binary way: traversable or not (hazardous or not). The assumption is that all hazards are hard constraints. However, weather hazards, including the "types" of convection, turbulence, icing, and other weather effects may more generally be classified into hard and soft constraints. Hard constraints are formed by weather hazards that no aircraft can safely fly through (e.g., severe convection, turbulence or in-flight icing). Soft constraints are formed by weather hazards which some pilots or airlines decide to fly through while others do not (e.g., moderate turbulence or icing). Define Class 1 aircraft to be those that avoid both hard and soft constraints, and Class 2 aircraft to be those that avoid hard constraints but are willing to fly through soft constraints. The problem is that of multi-commodity flow, in which the goal is to determine if there exists a set of air lanes, each with an associated Class of aircraft (the "commodity"), such that each air lane satisfies all constraints from the weather types that impact the Class, and such that the air lanes yield a set of flows that satisfy the demand, or some fraction of the demand.

ATM Impact of Turbulence. Unexpected turbulence injures crew and passengers, and potentially can damage aircraft. The hazard results from several different atmospheric phenomena including jet stream interaction, shear, mountain wave generation, and convection. Two distinct types of turbulence are of concern – Clear Air Turbulence (CAT) and Convective Induced Turbulence (CIT). The ATM impact results from pilots desiring to avoid or exit turbulent conditions for safety reasons. This may happen tactically or strategically. Alerting to potential turbulence is important so that the cabin can be properly secured prior to an encounter. Exiting an unplanned encounter requires information to identify an acceptable exit strategy (that is, climb or descend to airspace clear of turbulence, or avoid by changing horizontal flight path to a region clear of turbulence). The exit strategy can be determined tactically, essentially as an aircraft is experiencing turbulence, or is warned that it is about to enter it, or strategically, with sufficient planning time to enter into a region of potential turbulence or avoid it altogether.

Tactical Feedback of Automated Turbulence electronic Pilot Reports. NextGen will likely automate the process of collecting and distributing turbulence (as well as other) PIREP information. Such automated e-PIREPs will automatically and frequently report PIREPs by data link to ATC and to nearby aircraft. With a collection of e-PIREP information reported at a wide variety of flight levels (null as well as hazard reports), turbulence information can be data linked directly to nearby aircraft or collected and distributed via a centralized database. Thus, hazardous airspace as well as airspace clear of turbulence can be communicated to nearby aircraft that are soon to pass into such airspace. Since turbulence is a transient hazard, this process needs to be automated, a data link needs to quickly communicate information to nearby aircraft, and the process must repeat throughout the day for detecting CIT and CAT hazards.

ATM Impact of Winter Weather at Airports. The accumulation of ice on aircraft prior to take off is a significant safety hazard affecting aircraft. Research indicates that the icing hazard for aircraft directly corresponds to the amount of water in the snow, rather than visibility – the traditional metric used to determine de-icing and take off decisions. Results from field tests of de-icing fluids have identified the liquid-equivalent snowfall rate as the most important factor determining the holdover time (time until a fluid fails to protect against further ice build-up). The ATM impact of decisions made regarding aircraft de-icing holdover times, de-icing fluid types, and application procedures have yet to be defined and integrated into a NextGen gate-to-gate concept of operations.

ATM Impact of In-Flight Icing. In-flight icing impacts air traffic flow in complex ways. For aircraft not certified for icing conditions, all known or forecast icing is prohibited airspace. Some situations have icing severity and aircraft equipage combined to define a "soft" constraint – some properly equipped aircraft may penetrate the icing volume for limited exposure times. In-flight icing is typically a low altitude hazard, generally less than FL200. Major ATM impacts, therefore, are seen for low-end General Aviation (GA) and for all aircraft in the arrival/departure and terminal phases of flight. National ATM impact can be significant when icing affects large airport metroplexes.

ATM Impacts derived from Probabilistic Forecasts for Ceiling and Visibility and Obstructions to Visibility. The Ceiling and Visibility (C&V), and Obstructions to Visibility (OTV) impacts differ depending on the flight regime (terminal, en route, ground operations) and type of aircraft operation. The core forecast technology for OTV, plus translation to ATM impact and decision support dealing with uncertainty, are technology gaps that still need to be addressed for NextGen.

Improved Wind Forecasts to predict Runway Configuration Changes. The airport configuration is a primary factor in various airport characteristics such as arrival and departure capacities (AARs and ADRs) and terminal area traffic patterns. The wind speed and direction is essential in determining which runways are feasible. Terminal Aerodrome Forecasts (TAFs) do not currently predict wind conditions precisely enough or accurately enough to enable airport configuration prediction. NextGen weather forecast systems must correct this in order to assimilate weather into DSTs for airport surface operations as well as TFM decision making. As for modeling the ATM impact, there is also research needed to establish the relationship between how controllers choose between viable configurations to meet the arrival and departure demands of an airport.

Improved Wind Forecasts to facilitate Wake Vortex Decision Support. Knowledge of wake vortex characteristics and behavior in near real time allows the opportunity to safely reduce existing separation standards to increase throughput, particularly within the terminal airspace.

Recent efforts have focused on wind dependent solutions where a very short term wind forecast (20 minutes) is sufficient to determine when persistent transport crosswinds protect specific Closely Spaced Parallel Runways (CSPR) from the threat of a wake vortex moving into the departure flight path, thereby safely allowing reduced separations.

Impact of Winds Aloft on the Compression of Terminal Area Traffic Flows. Generally, when strong winds aloft are present, the wind speed will vary considerably with altitude. This will cause large variations in groundspeeds between aircraft at different altitudes and thus in trail spacing becomes difficult to maintain. From an ATM perspective, currently, larger MIT restrictions are issued to deal with this effect, which controllers refer to as compression. Generally when winds aloft impact the airspace, MIT restrictions have to be increased, and there is also the possibility of impacting performance with a lower AARs with the potential of GDPs and Ground Stops (GS). The outstanding issue is how to translate this information to determine compression effects on ATM, and how the requirements relate to the weather forecast accuracy.

Oceanic/Remote Weather Integration. The NextGen Concept of Operations envisions a seamless transition between CONUS, terminal, and oceanic domains. Weather information for oceanic and remote areas will be integrated with ATM at the same level as for CONUS operations. However, weather information for remote and oceanic regions is more difficult to create than for the CONUS because data is sparse. This requires creative use of available data from satellites and other limited sources, and is an area of active research. Prototype algorithms have been developed for regional use, but not integrated with ATM procedures. For instance, studies demonstrate how wind data can be used to generate wind optimal routes, transitioning away from the fixed oceanic routes to user-preferred routes. While such routing takes advantage of the jet stream, it also must take into account turbulence that can be found near the jet stream, which is an area of future research.

Translation of Volcanic Ash Plume Hazards onto ATM Impacts. Advanced techniques are needed in NextGen that will detect, forecast, and disseminate information on volcanic ash plume hazards and how the hazards will affect ATM resources to aviation operators and users. Airborne volcanic ash constitutes a recognized threat to aviation that can severely damage jet aircraft engines through erosion, corrosion, and congestion. Volcanic ash contamination may render large volumes of airspace unavailable, necessitating costly rerouting contingencies, degrades braking action at affected airports, as well as completely closes contaminated airports. The weather translation model for volcanic ash plume hazards requires further advancement of both science and operational modeling.

Translation of Atmospheric Effects into Environmental and ATM Impacts. Environmental impacts will be significant constraints on the capacity and flexibility of NextGen. The major environmental effects include emissions of pollutants, greenhouse gases, aircraft noise, and water pollution via de-icing agents, spilled fuel, etc. Most environmental impacts are affected by the atmosphere and will require the integration of probabilistic weather forecast elements for proper risk management. Weather affects the strength and direction of acoustic propagation, dispersion of mixing of air pollutants, and effects on engine performance and fuel usage. Environmental impacts are translated into ATM impacts via several mechanisms, including: Mitigation measures such as specialized departure and arrival procedures and routings, as well as restricted periods of operation; Routing and altitude assignments that seek to minimize fuel consumption (and possibly contrail formation); and Surface and system management that seeks to minimize taxi times and delays on the ground with engines running.

ATM Impact of Space Weather. There is a growing threat from space weather as aviation's dependence on space and terrestrial networks vulnerable to solar weather continues to grow. The threat also exists for communication and navigation services for long-haul polar flights. Even relatively minor solar storms can affect these services and cause flights to reroute, divert, or not even dispatch over polar regions. Thus, an increase in polar flight activity in NextGen will bring about an increase in NAS delays from space weather impacts during times of high solar activity. We can expect an as-yet undefined impact to the net-centric NextGen infrastructure in the CONUS as well. Moreover, the human exposure to space radiation is significantly higher on polar routes, which poses a potential health risk.

ATM Impact of Weather Constraints on General Aviation. While the number of studies that have been performed to build ATM impact translation models has been increasing over the years, few and possibly none of these have focused on the particular parameters that model GA aircraft in particular, or have quantified the overall impacts to GA pilots in the aggregate.

4.2 Maturity and Gap Analysis

This section is to assess the maturity of the ATM-impact models presented, and to identify gaps in technologies that must be addressed for NextGen. In order to assess the maturity of each ATM-impact model, we use the following criteria:

- Low Maturity – The concept is defined, however, there is no theoretical foundation or scientific data gathered to build the mathematical model for the concept
- Medium Maturity – The concept is defined and a theoretical foundation or scientific data is gathered for a mathematical model for the concept
- High Maturity – The concept is defined, a mathematical model is established, and effort has been made to verify and refine the model for acceptable operational use, and
- Full Maturity – The concept is an acceptable method of modeling ATM-impact and is in operational use.

Note that no ATM-impact model that has been reviewed is at full maturity. For instance, there is no established and accepted indicator of airspace capacity in the NAS today. Most of the ATM-impact models fall in the low and medium maturity levels, with further research, development, and deployment needed. Table 4-1 provides an assessment of the maturity of the ATM-impact models described in this survey.

Table 4-1. Level of Maturity for ATM-impact Models.

ATM-impact Model	Low	Medium	High	Full
CWAM for En Route Airspace			x	

Table 4-1. Level of Maturity for ATM-impact Models.

ATM-impact Model	Low	Medium	High	Full
CWAM for Terminal Airspace		x		
CWAM with Flow Structures		x		
Maxflow/Mincut Methods for Convection		x		
Route Availability Methods			x	
Directional Capacity Methods		x		
WITI Metric Models		x		
Periodic Auto Regressive (PAR) Models		x		
Stochastic Congestion Grids		x		
Ensemble Forecasts translated into Probabilistic ATM impacts		x		
Deterministic Forecasts translated into Probabilistic ATM impacts		x		
Sensitivity of ATM Performance to Weather Forecast Uncertainty		x		
Probabilistic Convective Forecasts and Pilot Deviation Models		x		
Integrated Forecast Quality Metrics in ATM-impact Models		x		
Conditioning ATM-impact models for User relevant Metrics		x		
Probabilistic Fog-Burnoff Modeling for AAR Planning			x	
Maxflow/Mincut Methods for Hard/Soft Constraints		x		
Tactical e-PIREP Feedback		x		
ATM-impact Models for Turbulence		x		
ATM-impact Models for In-flight Icing		x		
ATM-impact Models for Winter Weather at Airports		x		
ATM-impact Models for C&V and OTV	x			
Improved Wind Forecasts to Predict Runway Configuration Changes	x			
Improved Tactical Wind Forecasts for Wake Vortex Mitigation			x	
ATM-impact Models for Oceanic/Remote Weather	x			
ATM-impact Models for Volcanic Ash	x			

Table 4-1. Level of Maturity for ATM-impact Models.

ATM-impact Model	Low	Medium	High	Full
ATM-impact Models for Space Weather	x			
ATM-impact Models based on Environmental Factors	x			
ATM-impact Models affecting GA	x			

Gaps in ATM-impact modeling include the following:

- Human Factors (see C-5, including Human-in-the-Loop (HITL) Simulations, Roles and Responsibilities, and Culture, need be included into ATM-impact models to adequately address capacity limitations that are driven by controller, dispatcher, and pilot workload, complexity, displays, collaboration and team work between various decision makers, etc.
- The role of Collaborative Decision Making (CDM) and how it influences the demand on a weather-impacted resource, enforcement of company policy, and the coordination and collaboration of TFM solutions needs to be integrated in with future ATM integration solutions.
- Any model that observes how pilots fly in today's NAS does not represent how pilots may fly in NextGen when new technology and new procedures are likely to be in place. There is a need to transform a lot of ATM-impact models into NextGen conditions. However, it is difficult to validate such models, except in simulation environments. Similarly, as various air traffic automation tools to assist in separation of aircraft from other aircraft are introduced, it will be necessary to recalibrate the models that translate weather impacts into capacity impacts. Here again, simulations may be needed.
- Work is also required to determine how to properly combine impacts from multiple ATM-impact models to evaluate the magnitude of expected ATM impact from multiple weather types. For example a segment of airspace may be simultaneously experiencing impacts from convection, elevated haze, turbulence and volcanic ash. The impact of each environmental condition may be calculated (deterministically or stochastically) by individual impact models; yet rolling them up into an integrated impact will not likely be commutative since each of these events are not likely statistically independent. Complicating the task of integrating these various impact models into one is the fact that each model reviewed in this section is at a different level of maturity, as indicated in Table 4-1.
- 4D hazard information needs to be integrated with winds and temperature effects on all flight profiles. Airline dispatchers and pilots using 4D flight planning systems can then strategically plan flight profiles and, most importantly, pilots can prepare to react tactically to real-time hazard information prior to an encounter with any aviation weather hazard.

- This discussion on gap analysis is at a very high level because that is work that needs to be done. Performing a gap analysis is part of the foundation building called for in paragraph 5.1.1, performed by the team identified in paragraph 5.2.2.2 and under the oversight of the board identified in paragraph 5.2.3

4.3 Survey of ATM-Weather Integration Technologies

Many of the ATM-impact models will eventually be integrated into DSTs in order to help users reason about the impacts of weather while solving ATM problems. The survey includes approaches for addressing weather-related uncertainty in ATM decision making for strategic look ahead times – risk management processes – as well as approaches that wait until the tactical look ahead times to address deterministic forecasts after the uncertainties diminish. The ATM-weather integration techniques make reference to ATM-impact models as appropriate. An assessment of maturity of these ATM-weather integration technologies and a gap analysis are given at the end of the section.

Sequential, Probabilistic Congestion Management for addressing Weather Impacts. Flexibility and adaptability in the presence of severe weather is an essential NextGen characteristic. Sequential, probabilistic congestion management describes how to incrementally manage en route airspace congestion in the presence of uncertainties. Sequential, probabilistic congestion management can take advantage of probabilistic weather forecasts to reduce weather impact on en route airspace. It would also provide an effective “inner loop” to be used in conjunction with strategic flow management initiatives, based on longer-range weather forecasts. Note that an alternate, multiple-timescale sequential congestion management approach has also been proposed. This method does not employ probabilistic forecasts, but rather relies on adapting to observed weather development.

Sequential Traffic Flow Optimization with Tactical Flight Control Heuristics. A deterministic sequential optimization approach integrates a strategic departure control model with a fast-time simulation environment to reactively control flights subject to system uncertainties, such as imperfect weather and flight intent information. To reduce the computational complexity of the strategic model, only departure delays are assigned, while tactical en route flight control is accomplished through heuristic techniques.

Airspace Flow Programs to address 4D Probabilistic Weather Constraints. An Airspace Flow Program (AFP) is a particular type of Traffic Management Initiative (TMI) that controls traffic flowing into an airspace where demand is predicted to exceed capacity. A FCA is defined to be the boundary of the region of airspace where demand exceeds capacity – most typically, due to convective weather constraints. Today’s AFPs use fixed locations for FCA boundaries used for AFPs, and these regions are defined by air traffic control center and sector boundaries, not the location of the weather constraint itself. In NextGen, the FCA is likely to be a 4D volume that describes the space-time region where weather constraints (not only convection, but severe turbulence and icing regions as well) cause significant ATM impacts. Because the AFP must reason about the effects of weather on airspace capacity for long lookahead times, it is necessary for the AFP to reason about a probabilistic estimate of capacity.

Ground Delay Program Planning under Capacity Uncertainty. Uncertainty in capacity forecasts poses significant challenge in planning and controlling a GDP. There are two main decisions associated with any GDP: (1) setting the AAR, and (2) allocating landing slots to flights, and hence, to the airlines who operate those flights. Static and dynamic stochastic optimization models are appropriate for NextGen.

Contingency Planning with Ensemble Weather Forecasts and Probabalistic Decision Trees. Management of the complex interaction between potential weather outcomes and TMIs can be modeled using a collection of potential weather scenarios. These would be retained in an ensemble forecast, which would serve as input to a Probabilistic Decision Tree. Flow planners would make use of this to form a primary plan and contingency flow plans (one for each possible weather scenario) (for instance, strategic two to four hours in the future). This assists in the strategic planning of GDPs, AFPs across FCAs as well as tactical GSs, holding, metering, reroutes, and other plans.

Probabilistic Traffic Flow Management. The strategic TFM problem is inherently stochastic since both the traffic loadings and system capacities are difficult to forecast precisely over such long time horizons. Strategic TFM solutions need to account for forecasting uncertainties, forecasted traffic loadings, and estimated system capacities. The specific solution method can take several forms. One is a resource allocation solution involving a combination of rerouting and ground delay. This probabilistic TFM concept has a high maturity level, as it has been defined, analyzed and verified at various levels.

A Heuristic Search for Resolution Actions in Response to Weather Impacts. Uncertainties present in demand, weather, and capacity, create a need to resolve congestion in an efficient and flexible manner. In both the strategic and tactical time frames, the methods utilized to resolve congestion should provide metrics to measure the quality of the proposed solutions. A Generalized Random Adaptive Search Procedure (GRASP) can address this problem through a computationally-efficient heuristic optimization approach. GRASP finds feasible solutions quickly and evaluates proposed solutions against defined metrics to determine the set of resolution maneuvers that best satisfies the objectives.

Integrated Departure Route Planning with Weather Constraints. NextGen will require an Integrated Departure Route Planning (IDRP) capability in order to handle departure traffic efficiently and safely. The IDRP capability must integrate departure route and en route sector congestion information, especially when weather constraints are present and traffic demand must dynamically adjust to predicted downstream capacity fluctuations. This concept also applies to downstream weather constraints such as convection, turbulence, or icing. The IDRP capability reduces the time needed to coordinate and implement TMIs and supporting departure management plans.

Tactical Flow-based Rerouting. This concept for rerouting air traffic flows around severe weather is for a tactical timeframe (0 to 2 hours out) and requires an ATM-impact model for route blockage. In this timeframe, weather predictions are relatively good, so the reroutes can be closer to the weather than strategic reroutes and thread through smaller gaps between weather cells. Automated solutions makes tactical rerouting easier, increasing the ability of traffic managers to implement them. Moving this activity from controllers to traffic managers will reduce controller workload, thereby safely increasing airspace capacity during severe weather.

Ta**ctical On-Demand Coded Departure Routes.** This concept for rerouting air traffic flows around severe weather is based on moving today's static, fixed Coded Departure Route (CDR) framework for rerouting traffic on jet routes during severe weather events into a dynamically defined "On Demand" CDR framework for NextGen for routing 4D trajectories in a tactical timeframe (0 to 2 hours out). An ATM-impact model is needed to identify route blockage ahead of time as well as the ability to design space-time reroutes between city pairs with a 1-2 hour look ahead time. The purpose of On-Demand CDRs is to move the rerouting decision as close to the tactical time horizon as possible to eliminate the uncertainty in rerouting – eliminating the potential for several weather outcomes, as is the case in ensemble weather forecasts, and focusing in on one projected weather outcome in the tactical time frame.

4.4 Maturity and Gap Analysis

This section is to assess the maturity of the ATM-weather integration technologies, and to identify gaps in technologies that must be addressed for NextGen. In order to assess the maturity of each ATM-weather integration technology, we use the following criteria:

- Low Maturity – The concept is defined (e.g., in the form of an operational concept), however, there is no theoretical foundation or scientific data gathered to explore the ATM-impact models and performance of the ATM-weather integration technology.
- Medium Maturity – The concept is defined and a theoretical foundation and/or scientific data is gathered for a mathematical model for ATM-impact components, components of the technology have been assembled in a prototype system, and some evaluation of performance has been demonstrated.
- High Maturity – The concept is defined, a models have been established, and effort has been made to verify and refine the models and prepare the technology for acceptable operational use, and
- Full Maturity – The integrated technology is an acceptable technology in operational use integrating an ATM-impact model with a deployed DST in the NAS.

Note that no ATM-integration technology that has been reviewed is at full maturity. For instance, just as there is no established and accepted indicator of airspace capacity in the NAS today, there is also no indicated airspace capacity ATM-model imbedded into any DST in use in the NAS. Most of the ATM-impact models fall in the low and medium maturity levels, with further research, development, and deployment needed. Table 2 provides an assessment of the maturity of the ATM-weather integration technologies described in this survey.

Table 4-2. Level of Maturity for ATM-Weather Integration Technologies

ATM-Weather Integration Technology	Low	Medium	High	Full
Sequential Probabilistic Congestion Management		x		
Sequential TFM with Tactical Flight Control		x		

Table 4-2. Level of Maturity for ATM-Weather Integration Technologies

ATM-Weather Integration Technology	Low	Medium	High	Full
AFPs with 4D Probabilistic Weather Constraints	x			
GDPs with Capacity Uncertainty		x		
Contingency planning with Probabilistic Decision Trees		x		
Probabilistic TFM		x		
Heuristic Search for Resolution Actions		x		
Integrated Departure Route Planning		x		
Tactical Flow-based Rerouting		x		
Tactical On-Demand CDRs		x		

Gaps in ATM-weather integration technologies include the following:

- As was the case in ATM-impact models, human factors (see C-5) work seems to be missing in a lot of the ATM-weather integration technologies.
- Many of the ATM-weather integration technologies are tied to how pilots may fly in the NAS today, using jet routes, current day sector definitions, and current day traffic demand loads. In NextGen when new technology and new procedures are likely to be in place, and when new concepts allow for more flexible routing strategies (no longer tied to Navaids and jet routes), some technologies may have to change to address such conditions. There is a need to transform ATM-impact models into NextGen conditions, and a need to transform ATM-weather integration technologies to NextGen conditions.
- Work is required for NextGen to determine how to combine impacts from multiple ATM-impact models to ensure the DSTs receive proper magnitude of expected ATM impact from multiple weather types. Not only may an airspace be simultaneously experiencing multiple types of weather impacts, the effects from these impacts in one part of the NAS may affect ATM in other parts of the NAS with upstream and downstream propagation. The ATM-integration effort should not be limited in spatial or temporal scope nor or in the breadth of weather phenomena.
- This discussion on gap analysis is at a very high level because that is work that needs to be done. Performing a gap analysis is part of the foundation building called for in paragraph 5.1.1, performed by the team identified in paragraph 5.2.2.2 and under the oversight of the board identified in paragraph 5.2.3

5 WEATHER INTEGRATION PLAN EXECUTION

The purpose of this section of the plan is to describe first, how the plan will be executed, second, organizational issues and the Weather Integration Methodologies Management Team, and third, the relationship between weather integration, ATM tool developers and the major Aviation Weather Office programs: Reduce Weather Impact (RWI), NextGen Network Enabled Weather (NNEW), Weather Technology in the Cockpit (WTIC), and Aviation Weather Research Program (AWRP).

5.1 Plan Execution

The execution of this plan will occur in four steps. The steps will be executed more or less in sequential order from the start for any given ATM tool, but as will become evident, the steps will be repeated many times as new weather techniques and ATM tools are developed and may be occurring simultaneously at some point in the future. Note that the term "tool" may refer to an automation system for decision support or to a human decision process. The execution steps are:

First, to align teams with each solution set and analyze weather integration requirements for a service and performance-based approach for weather integration as associated with operational relevance. This step will require a mix of operations, programmatic, and meteorological personnel.

Second, to identify the specific weather integration need and insertion points, including performance criteria and value, into ATM tool or decision platform functionality. This step will be highly dependent upon collaboration with the ATM user community and decision tool developers. This step will require a mix of system engineering, tool/design, operations, and meteorological personnel.

Third, to identify and recommend the specific weather integration techniques and technologies that best fit the requirements of a particular TFM tool under development and particularly the insertion points identified in the previous step. This step will require a combination of meteorological, system engineering, and programmatic personnel.

Fourth, to serve as the SME for the ATM Tool development team to assist in interpretation and integration of the weather impacts and methodologies and to evaluate test results. This step will require meteorological and system engineering personnel.

Prior to proceeding with full-scale integration, it is essential that the weather community develop the foundation of data, products and methodologies that will make integration possible.

5.1.1 Foundation for Integration

In order for weather integration to be successful, a robust set of Weather Methodologies must be available. The Methodologies may deal with the translation of weather into impacts or may center more on decision processes, such as dealing with uncertainty in weather forecasts. Appendix B to this plan shows the Methodology set. Members of the set are at varying levels of maturity. Before they are ready for implementation, they will be winnowed down to the most applicable methodologies, brought to a high level of maturity, prototyped in a generic application, and classified according to their proper use and their Technology Readiness Level.

The following will be accomplished in establishing the foundation for integration:

- Conduct preliminary selection of the most promising methodologies based on potential skill, applicability to NextGen needs, cost, and schedule
- Continue engineering development of selected methodologies
- Establish and apply a testbed
- Perform Technology Readiness Level (TRL) assessments of selected methodologies
- Characterize appropriate applications for each selected methodology
- Perform gap analysis to identify un-met user needs
- Demonstrate the methodologies with sample NextGen applications
- Establish a network service for generating multiple-use translated products and supplying them to user systems
- For unique applications, provide user systems with documentation

5.1.2 Integration Process

The following sections describe the four steps for weather integration. These steps are executed sequentially; however, while later steps are being executed, the process can be started at step 1 when new tools or methodologies are developed that support additional integration possibilities.

5.1.2.1 Step 1: Team Alignment and Analysis

There will be teams aligned with the six non-weather Solution Sets: Initiate Trajectory-Based Operation (TBO), Improve Collaborative Air Traffic Management (CATM), Increase Flexibility in the Terminal Environment (FlexTerm), Increase Arrivals/Departures at High Density Airports (HiDensity), Increase Safety, Security, and Environmental Performance (SSE), and Transform Facilities (Facilities). Some teams may support more than one Solution Set. Using the identified assumptions and determination for weather integration for decision support in section 5, each team is to identify the set of operational tools, processes and initiatives which will support their solution set capabilities.

The team is to be comprised of a broad cross-section of operational users, planners, and engineers, who are intimately familiar with the use and relative value of each identified tool. Additional team members include those who can describe Near-Term functional migration of these tools (operational functions) and who could verify/validate further functional migration into Mid-Term and Far-Term timeframes. If there is no migration path, then team members must be capable of joining with the Solution Set Coordinators in making appropriate assumptions in regard to what tools and what functions will support the capabilities.

There is a need for team members who can identify, either through previous documentation or perception, which of the entire operational tool list qualifies as a potential candidate for weather integration need. This will be a subset of the entire tool set.

The team is to contain operational users that can describe various levels of real or perceived tool improvement (first based on current operational practices and use and then via assumptions on how functionality from tool migration may work). Many tools for the mid-term and far-term do not yet exist, and the team is to apply their judgment in combination with that of the tool creators andowners. By understanding the kinds of output changes a tool must demonstrate for value to be perceived, the relative value of weather, including the relative success of the integration, can be more easily measured against tool improved value from the perspective of the end user.

The meteorological team members would verify/validate the assumptions used in Section 3 and Appendix A of this plan for the need for and use of weather. They would also validate the methodology described there. Programmatic team members would verify migration and/or functionality evolution plan within the enterprise architecture, office coordination and funding.

Information developed in Step 1 will be documented as an update to Appendix A of this plan.

Step 1 Exit Criteria: Step 1 has been completed when the weather team has identified decision functionality that requires integrated weather and has developed a framework or roadmap for moving forward toward user capabilities. This includes the human resources required to complete the integration process.

5.1.2.2 Step 2: Weather Integration Insertion Determination

Step 2 addresses user needs and tool requirements for weather integration and specifically where weather integration should focus (i.e., weather insertion points within the tools or processes as identified in Step 1).

Together with the user tool developers, during this step the weather integration team members consider the decision processes and tool functionality that would be affected when weather occurs. For example:

The presence of convective weather would reduce the capacity of a route and alter use of that route; that would be noted as a weather impact point.

Ceiling and visibility conditions may determine whether an airport should be operating under IFR or VFR, thereby impacting airport capacity.

Cross winds and turbulence paired with lateral runway separation may determine impact the decision of whether an airport should run dependant or independent runway operations.

Space weather introducing errors into GPS position information may impact the landing categories.

The weather phenomena will be prioritized according to the severity and likelihood of occurrence of their impacts (exactly how to perform this prioritization is a topic for future research). If it is not practical to address all possible weather impacts, the prioritization will be a basis for choosing among them.

The combined team will consider the time scale of the impact and whether probabilistic information can be applied as a risk management technique. On very short time scales, especially with regard to an individual flight, the single best deterministic weather impact information may be called for. For strategic decisions over a multi-hour period or when a number of aircraft may be affected, a probabilistic forecast is usually the appropriate way to deal with uncertainty.

This analysis identifies (with assumptions) where weather needs to be integrated into tools and processes that can affect decisions, the types of weather information needed, and may provide a preliminary indication of the performance requirements for the weather impact information. Weather informational gaps can be identified (weather information available today vs. what is needed) to satisfy the need for weather integration within each application at the identified insertion points.

Information developed in Step 2 will be documented as an update to Appendix A of this plan.

Step 2 Exit Criteria: Step 2 has been completed when there has been a decomposition of a decision tool or process to determine the weather integration insertion points and the weather impacts and their characteristics have been identified and prioritized.

5.1.2.3 Step 3: Identification of Specific Weather Techniques

Step 3 is the crucial intersection of user needs and weather impact support. The weather team will support users in considering the decision, tool, and process characteristics from Step 2 and compare those to available weather translation and decision methodologies documented in Appendix B of this plan to identify the best concept to apply. It is incumbent upon the weather community to supply needed weather information. In this step, performance needs (e.g. resolution in time and space of the weather information) will be determined and related to the weather provider teams.

This step will be taken in close cooperation with the ATM tool owners, who have the overall say as to what goes into their tool. It will also be done after coordination with the weather team leadership.

A key technique for making the methodology selection is the use of a demonstration or prototype. Weather methodologies can be demonstrated in a generic sense as a means of showing their benefits and application possibilities. If needed, the ATM tool owners together with weather team members can view the methodology in prototype action in an Integration Laboratory. This will help them to envision how the methodology would be applicable to their own ATM tool.

"Intersections" are a consideration when choosing a methodology. In this use, "intersections" refers to decisions with more than one tool involved or even more than one solution set. The weather team representatives must coordinate with their counterparts on related decision tool teams to ensure that the concept is consistent with team doctrine and a collaborative and coherent NAS.

In the text of this plan, weather methodologies and user capabilities were kept separate in order to facilitate the use of any given methodology with multiple user capabilities. In actual practice, during Step 3, the two may overlap. Tailoring of a methodology to the needs of a particular user capability can occur. What's more, a developmental effort can occur in which user capabilities and weather methodologies can be matured together. What's more, the developments can cross over lines between tools, solution sets, near-mid-far-term, strategic versus tactical, and agency roles. Flexibility, focus, discipline, and creativity will all be hallmarks of successful integration.

Key decisions in the process are which specific weather impact parameters are needed for decision support and whether the impacts could be taken from a common use network service or are sufficiently unique that the translation should occur within the ATM tool itself.

Information developed in Step 3 will be documented as an update to Appendix A of this plan and also to Appendix B if applicable.

Step 3 Exit Criteria: Step 3 has been completed when a weather integration methodology has been developed by the tool owners with the assistance of the weather team representative.

5.1.2.4 Step 4: Integration of Weather Technology into TFM Tool

Step 4 takes the selections made in Step 3 and turns them into reality in the context of an ATM tool or decision process. The weather team representative continues to work with the tool owners, providing advice, interpretation, and assistance throughout the development cycle. This extends even into the development of user training.

Information developed in Step 4 will be documented as an update to Appendix A of this plan. Roadmaps and other baseline documents will also be updated if that has not already occurred.

Step 4 Exit Criteria: Step 4 has been completed when the ATM tool or decision process has successfully reached a mature state and has been accepted for use by the user community.

5.2 Organization

5.2.1 Weather Leadership Team

The Weather Leadership Team is the senior management level for weather integration into ATM operations. It consists of the weather integration manager, the FAA Reduce Weather Impact Solution Set Coordinator, representatives from other stakeholder agencies (NASA, DOD, and NOAA), representatives from implementing organizations (such as Systems Operations, Technical Operations, Terminal Services, En Route and Oceanic Service), the leaders of all sub-teams, and others as needed.

The Weather Leadership Team has the following functions and responsibilities

- Carrying out the tasks in the Integration Plan
- Track TRL of target programs
- Provide basis for business decisions, including benefits, cost, risk, schedule
- Track and project Integration level (1 to 4) for target programs, with benefits being derived from each level increase
- Manage the various integration laboratory activities and infrastructure for testing and prototyping and objective inputs to the Weather Integration Technology Evaluation Board on TRL levels

- Track progress
- Make commitments on progress

5.2.2 Weather Integration Sub-Teams

Weather integration sub-teams will carry out the actual work of the integration effort by working with inside ATM program offices to provide support and to suggest weather integration solutions to implementing programs. They will be comprised of systems engineers with an operations background/understanding, programmatic personnel, and meteorologists. The team will execute the steps described in section 5.1.

5.2.2.1 Weather Integration Customer Team.

The Weather Integration Customer Team is predominately a team of operations personnel and ATM Tool developers with knowledge and training in tool operation and weather methodologies. This team will interface directly with members of the target ATM tool and process owners and developers. They will be the weather team representatives whose work is described in Steps 1 through 4 of Section 5.1 of this plan. They will serve as subject matter experts, assisting tool development experts in the best methodologies for insertion of weather into ATM tools.

Members of the Weather Integration Customer Team will be trained on all current weather integration methodologies, ATM operations, NextGen plans and priorities.

5.2.2.2 Weather Integration Techniques Team.

The Weather Integration Techniques Team: is composed of FAA, NASA, NOAA, and DOD representatives with knowledge of weather integration research and ATM decision processes. This team's work is described in Section 5.1 of this plan. This sub-team will conduct weather integration laboratory activities. Roles include:

- Estimate the time needed to advance to the next TRL
- Track and manage methodology developments
- Document what problems are being solved by each developer
- Give users (e.g. DST developers) insight into technologies
- Recommend developmental priorities
- Recommend developmental funding
- Establish and maintain a prototype and demonstration capability for use in refining weather methodologies and in conjunction with users, for assessing and choosing methodologies for a specific integration opportunity.

5.2.2.3 Weather Integration Program Team.

The Weather Integration Program Team will support programmatic elements of the integration effort, including budget, schedule, benefits assessments, and other tasks needed by the integration manager.

5.2.3 Weather Integration Technology Evaluation Board

The role of the Weather Integration Technology Evaluation Board is to provide objective evaluation and grading of the methodologies presented by the Weather Integration Techniques Team. Specifically they will:

- Oversee development of methodologies
- Evaluate and assign TRLs
- Recommend developmental priorities
- State deliverables for each developmental project and evaluate their completion
- Bring focus, discipline, and creativity to the methodology engineering process
- Sponsor development of new weather methodologies to meet needs expressed by the ATM community for which current methodologies do not meet the need on a resolution, accuracy, or timeliness basis.
- Partner with a "Strategic Planning Advisory Review Cadre" (SPARC) to help with TRL assessments.

5.3 Cost, Benefits, and Schedule

Anticipated initial activities

FY10:

- Building weather translation and decision foundation, including test and evaluation capability.
- Stand up Weather Leadership Team and Integration Sub-Teams.
- Identify initial set of DSTs that have the potential for successful weather integration by NextGen IOC. Identify candidate methodologies, brief users, and develop demonstrations of weather methodologies that will yield success.

FY11:

- Conduct successful demonstrations of weather products or methodologies that have the necessary maturity level for integration

FY12:

- Work with user community and DST developers to integrate weather products and methodologies into DSTs for IOC implementation

Detailed weather integration Cost, Benefits, and Schedule information is available in Appendix C.

5.4 Relationship of Integration with Aviation Weather Programs

DSTs essentially remain outside the purview of aviation weather. While weather information drawn from the 4-D Wx SAS must be consistent—i.e., the same published forecast value for a given time and place—the uses to which that information can be put is potentially limitless. The weather may be the same, but its impact is highly variable. The Aviation Weather Office (AWO) communicates with the weather data user community ensuring that the 4-D4-D Wx Data Cube and especially the 4-D Wx SAS contains current and forecast weather data in the form and at the temporal and spatial resolution required to meet all user requirements.

The AWO operates four key programs which play a critical role in the integration of weather into DSTs.

Aviation Weather Research Program (AWRP): The program develops new technologies to provide weather observations, warnings, and forecasts that are accurate, accessible, and efficient. It works to enable flight deck weather information technologies that allow pilots and aircrews to engage in shared situational awareness and shared responsibilities with controllers, dispatchers, Flight Service Station specialists, and others, pertaining to safe and efficient preflight, en route, and post flight aviation safety decisions involving weather. As the Integration effort works with NextGen decision process designers, it will uncover more information about specific user weather requirements. AWRP is addressing those requirements which were identified in preliminary analyses. If additional weather capabilities are identified through the Integration process as new or refined requirements, they will be forwarded through RWI for AWRP to address.

Reduce Weather Impact (RWI): RWI is the primary funding and implementation program for Integration activities. It addresses the need to enable better weather decision making and use of weather information in the transformed NAS. User requirements for weather observations and forecasts identified by the Integration process will be relayed to RWI to ensure that the weather infrastructure can support them. RWI addresses providing improved forecasts and observations, and providing weather forecast information tailored for integration into traffic management decision support systems. RWI will conduct planning, prototyping, demonstrations, engineering evaluation and investment readiness activities leading to an implementation of operational capabilities throughout NextGen near, mid and far terms.

Weather Technology in the Cockpit (WTIC): The Weather Technology in the Cockpit (WTIC) is a research and development program which seeks to ensure the adoption of cockpit, ground, and communication technologies, practices, and procedures that will:

- Provide pilots with shared and consistent weather information to enhance common situational awareness
- Provide airborne tools to exploit the common weather picture

- Utilize the "aircraft as a node", functions to autonomously exchange weather information with surrounding aircraft and ground systems
- Facilitate integration of weather information into cockpit NextGen capabilities (e.g. Trajectory Based Operations)
- Result from WTIC R&D supporting certification and operational approvals.

WTIC is essentially an Integration effort--one dimension of the overall Integration Plan. WTIC efforts will be applied to cockpit weather integration.

NextGen Network Enabled Weather (NNEW): The NextGen Network Enabled Weather (NNEW) develops the standards necessary to support universal user access to needed weather information. It enables the seamless access to standard weather data sets by all NextGen users by establishing the 4-D Wx Data Cube. There will be demonstration efforts to resolve key technical questions and reduce implementation risk of a network-enabled weather environment to the FAA and external system users. This will include assurance that NNEW is fully compatible and consistent with the evolved System-Wide Information Management (SWIM) infrastructure. This will also serve to define open standards and requirements necessary for overall NextGen weather dissemination compatibility. NNEW is the delivery mechanism by which weather information will be provided from weather sources to decision makers. The Integration Team will ensure that the user systems are informed about applicable network-centric standards so that they can obtain and apply the weather information from NNEW capabilities.

The AWRP will fill the technology gap when observing and forecast techniques are not sufficient either in time/space resolution or quality to enable TFM DSTs to have the weather information required to make automated decisions. The RWI program provides a programmatic platform for the AWO to test prototype applications of weather techniques in order to demonstrate that they offer the accuracy and quality for direct application into DSTs. NNEW will provide the means for direct access by DSTs to appropriate weather data.

The key interaction for success in weather integration will be the relationships established between the AWO and the ATM tool development community. The AWO role is to ensure proper use and application of weather data and techniques in development of specific DSTs. During development, the AWO will fund demonstrations for specific technologies in order to demonstrate both the quality and usability of weather information in the decision process. As DST development proceeds, weather data for specific DSTs will transition from a testing scenario to inclusion of production data directly from the 4D Wx Data Cube.

6 ALIGNING THE WEATHER INTEGRATION PLAN WITH PREVIOUS FINDINGS AND RECOMMENDATIONS

There is a need for a multi-agency, synchronized plan to achieve solutions to the problem of weather integration into ATM operations and decisions. As articulated in the NextGen vision, the solution must enable decision makers to identify areas where and when aircraft can fly safely with weather assimilated into the decision making process in order to optimize the entire national airspace system. The NextGen Weather Integration Plan provides the initial requirements, scope and implementation roadmap to achieve the NextGen vision. It also addresses agency roles and responsibilities and includes resource requirements.

6.1 Weather – ATM Integration Working Group (WAIWG) of the National Airspace System Operations Subcommittee of the FAA's Research, Engineering and Development Advisory Committee (REDAC)

The Weather – ATM Integration Working Group (WAIWG) of the National Airspace System Operations Subcommittee of the FAA's Research, Engineering and Development Advisory Committee (REDAC) conducted a twelve-month study to examine the potential benefits of integrating weather and air traffic management.

The group, with members from airlines, general aviation, NASA, the National Weather Service, national research centers and academia, gathered information during visits to airline operations centers terminals and en route air traffic facilities and research centers. The following key findings and recommendation were reported back to the FAA:

- Few instances of integrated tools exist: time-of-flight estimates incorporating winds aloft; storm free departure times at one airport, and winter deicing timing. All other NAS decision tools use weather manually, as traffic display overlays or on separate displays.
- Aviation weather forecasts have much more accuracy in 0-2 hour, tactical time frame, than the 2-10 hour, strategic time frame. However, the size and shape of the 0-2 hour solution space is much smaller and with increasing congestion, more decisions will have to be made in the latter. Conversely the more the tactical solution space can be expanded, the more decisions can be delayed adaptively and traffic optimized to meet business objectives.
- A risk management approach with adaptive, incremental decision making, based on automatically translating weather forecasts into air traffic impacts, presents a major new opportunity for reducing weather related delays in the future NAS.
- The key recommendation is that a cross cutting research program, involving public and private sector air traffic management and aviation weather experts, is needed to exploit these key findings.

6.2 NextGen Conference on Integrating Weather, Airports, and Air Navigation Services

Over 200 aviation professionals – user, agency and industry stakeholders – converged on Washington, DC for two days in February 2008 to discuss the challenges of meeting NextGen with regards to weather and weather integration. Several of the plenary speakers urged participants to "think outside the current ways of doing business" - be novel and non-traditional. The group broke into relatively small working groups to address the issues of policy, research, planning, simulations, demonstrations and metrics with regard to weather integration within each of the four major pillars of NextGen – Trajectory Based Operations, Super Density Operations, Surface Airport Operations, and Net-Centric availability and access to common weather information.

A common theme that prevailed across the working groups was that while the language in the NextGen Concept of Operations (ConOps) has been embraced by all National Airspace System (NAS) stakeholders, there are several considerations towards the reduction of weather impact that must be taken into account before many of the envisioned operational (non-weather) benefits are realized. These involve operational constructs and nuances as perceived by the intended user of the information. Such considerations (i.e., where the rubber meets the road) go beyond any specific scientific improvements in weather understanding and behavior, airborne or ground-based weather sensor density, weather forecast skill or modeling and ultimate weather integration. These considerations include how and when the information is presented, the consistency of the information among differing operators, common interpretation of the information in terms that are relevant to the operation, and the risks or consequences (real or perceived) of the use of the information. There was general agreement that the most important considerations of all will be the policies that facilitate change, the regulations that dictate change, and the transitional stages in operations that will enable operational evolution (e.g., continuity of services/conservation of functionality) while providing perceived benefits and safety. The general consensus of the participants in the NextGen Weather work group determined that while network enabled digital data is a key to success, there was a lack of clarity and messaging (outside the Joint Planning and Development Office (JPDO)) regarding government and industry roles for populating and operating the weather 4D Wx Data Cube. Weather dissemination to, and access by, aircraft is also vital to satisfying the 'aircraft as nodes on the net' concept. Industry is prepared to join the government in identifying options to make NextGen Weather a reality.

6.3 Integration Teams Approach to Tracking the Status on the Previous Findings and Recommendations

The Weather Integration Team has developed a spread sheet to track the stat of the major findings and recommendations from these two groups. The spreadsheet is contained in Appendix D.

6.4 Agency Approaches to Implementing the Findings and Recommendations

In the NextGen concept, weather information used by ATM decision-makers will come from a net-centric, virtual, data repository of aviation weather data, referred to as the "four-dimensional weather data cube." This concept allows each Federal agency to leverage and merge their existing agency-specific efforts and aviation-weather requirements into a mutually supportable national and eventually global, construct. This Federal effort addresses a way to combine public and private sector aviation weather needs into the ATM process as well as allowing each agency to maintain various independent capabilities consistent with their own weather needs. The weather communities within NOAA, FAA, DoD have developed a plan to ensure accessible, network-enabled weather information will be available to meet the user's integration/operation needs.

Currently, the FAA is the lead agency charged with developing integration tools. The FAA's NextGen Implementation Plan (NIP) includes the Reduce Weather Impact (RWI) Program.

Activities in the near term will focus on: developing a concept of use and initial requirements for weather dissemination; preparing for and conducting a weather dissemination interoperability demonstration; developing a concept of use and requirements for weather information needed by manual and automated traffic management and cockpit decision-support tools; assessing gaps and redundancies in the current aviation weather observation networks; development of a pre-prototype multifunction phased array radar; and development of improved forecasts (e.g., convection, turbulence, icing).

APPENDICES

A. NEXTGEN WEATHER INTEGRATION: DECISION SUPPORT TOOLS, DECISION IMPLEMENTATION PLAN AND COST PROCESSES

An analysis of the current state of weather integration was performed and this plan was developed for weather integration in six of the NextGen solution sets: Initiate Trajectory Based Operations (TBO), Increase Arrivals/Departures at High density Airports (High Density), Increase Flexibility in the Terminal Environment (Flex Term), Improved Collaborative Air Traffic Management (CATM), Increase Safety, Security and Environmental Performance (SSE), and Transform Facilities (Facilities).

For this first draft, each solution set was broken down into the strategic timeline components of Separation Management, Trajectory Management, Capacity Management, and Flight Data Management, and then further into capabilities, also identified as Operational Improvements (OIs). Each capability fell within either the near-, mid- or far-term timeframe. Capabilities in the mid-term were the focus of this effort. For reference, current TFM tools are described in Appendix E.

The expected weather and weather integration requirements of the mid-term capabilities were extracted from several different sources, including the REDAC Weather/ATM Integration report, the JPDO Weather Integration Conference report, the MITRE Initial Evolution Analysis for Achieving NAS Mid-term Operations and Capabilities report, the MIT/LL Roadmap for Weather integration into Traffic Flow Management Modernization report, the FAA Traffic Flow Management Concept Engineering Plan FY09 and the FAA Infrastructure Roadmap – Mid-term Integration Worksheets.

Beyond this, each of the writing groups added additional commentary, analysis or planning information. Interviews with JPDO WG Subject Matter Experts and FAA Solution Set Coordinators helped to extract additional capability/weather information. Assumptions were written based on viewpoints of the three Collaborative Decision Making (CDM) participants (Aircraft [PIC], AOC/FOC and Air Traffic Control [ATC]). In some cases, scenarios were created in which the use of weather information in support of the mid-term capability was explored

A-1. Initiate Trajectory Based Operations (TBO)

A-1.1 Introduction

A-1 is a work in-progress intended to help communicate and refine the developing mid-term weather integration story for the Initiate Trajectory Based Operation (TBO) solution set.

Mid-term Operational Improvement (OI) descriptions, contained here, go somewhat beyond what current NextGen and Federal Aviation Administration (FAA) documentation provide. The reason for this is to develop a more complete understanding of these OIs, so mid-term weather integration candidates can be more easily identified. The mechanism used to arrive at these extended descriptions is recorded in Section A-1.1.4. Although these extensions to mid-term capability descriptions have not yet received review and vetting, this paper provides a vehicle by which these 'assumptions' can obtain needed feedback, thereby furthering our understanding of mid-term OIs. These mid-term OIs begin the journey towards a full NextGen capability. This document describes these initial steps and their future evolution.

Graphics used herein are sourced from the Initiate TBO solution set smart sheet, as well as the scenarios developed by MITRE's Center for Advanced Aviation System Development (CAASD), as a product of the FAA Implementation and Integration (I&I) team. Additionally, the Flexible Airspace Management scenarios in Section A-1.8 are derived from the FAA's I&I scenarios. Future versions of the Joint Planning and Development Office's (JPDO) Air Traffic Management (ATM) Weather Integration Plan will benefit from increased synergy with the FAA's I&I scenario work.

A-1.1.1 Purpose

The purpose of this discussion is to support drafting of the JPDO's ATM Weather Integration Plan by:

- Identifying and describing likely TBO weather integration opportunities based on the mid-term OIs contained in the Initiate TBO solution set and
- Developing weather integration scenarios to help identify potential mid-term functional weather requirements.

This may also be useful in supporting other activities such as the:

- Refinement of OI descriptions in the Initiate TBO solution set,
- Scenario development by the FAA I&I team,
- Drafting of TBO white papers by the JPDO's Air Navigation Services (ANS) Working Group (WG), and
- Drafting of TBO Concept of Operations (ConOps) and Concept of Use (ConUse) documents.

A-1.1.2 Background

"TBO represents a shift from clearance-based to trajectory-based control. Aircraft will fly negotiated trajectories and air traffic control moves to trajectory management. The traditional responsibilities and practices of pilots/controllers will evolve due to the increase in automation support and integration inherent in management by trajectory.

This solution set focuses primarily on en route cruise operations, although the effects of the trajectory-based operations will be felt in all phases of flight planning and execution.

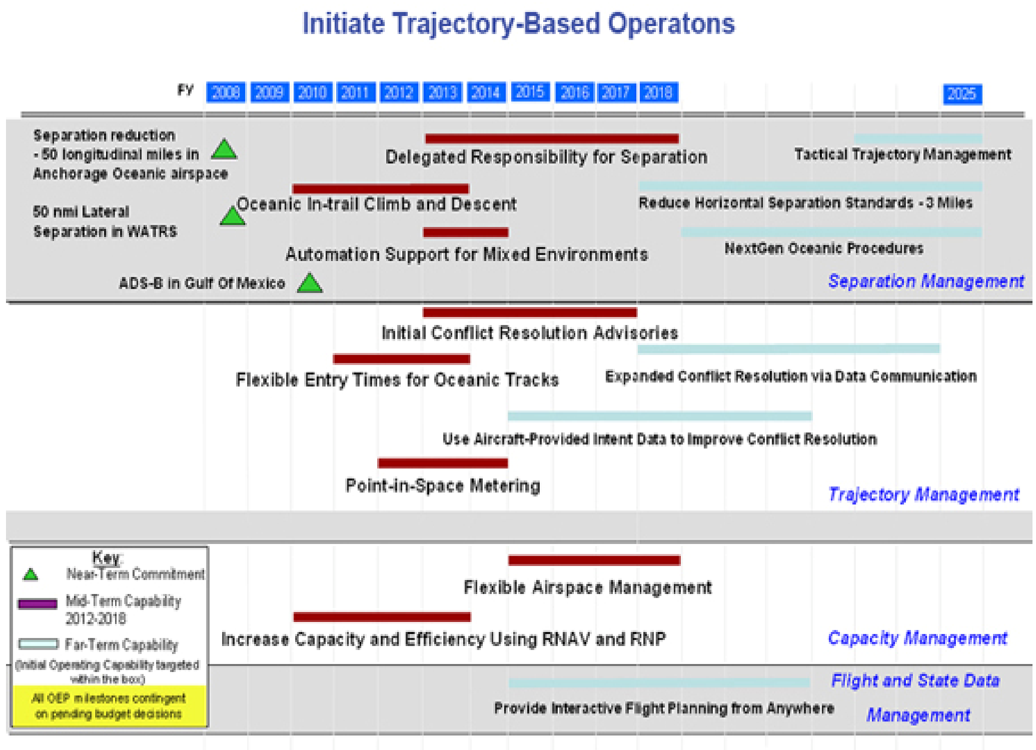
TBO is a critical NextGen capability that addresses performance gaps in the areas of capacity, productivity, efficiency, and safety. A major advantage of TBO is the ability to integrate trajectory planning, management, and execution from strategic planning to tactical decision-making. Strategic aspects of trajectory management include the planning and scheduling of flights and the corresponding planning and allocation of NextGen resources to meet demand.

Overall flows are managed strategically and tactically to ensure safety, security, and efficiency of operations. Tactical components of trajectory management include the evaluation and adjustment of individual trajectories to provide appropriate access to airspace system assets (depending on aircraft capabilities) and separation assurance to ensure safe separation among all aircraft. The flexible management of aggregate trajectories enabled by TBO allows maximum access for all traffic, while giving advantage to those aircraft with advanced capabilities that support the ATM system.

TBO represents a shift from clearance-based control to trajectory-based control. In the new high-performance ATM environment, aircraft will transmit and receive precise digital data to include aircraft routes and the times aircraft will cross key points in the airspace." [Initiate TBO Solution Set Smart Sheet, 2008]

The OIs of interest here are listed here and appear in the Initiate TBO roadmap figure below:

- Delegated Responsibility for Separation
- Oceanic In-trail Climb and Descent
- Automation Support for Mixed Environments
- Initial Conflict Resolution Advisories
- Flexible Entry Times for Oceanic Tracks
- Point-in-Space Metering
- Flexible Airspace Management
- Increase Capacity and Efficiency Using Area Navigation (RNAV) and Required Navigational Performance (RNP)



A-1.1.3 Definitions

This section defines key processes and terms used in this section.

<u>Concepts</u>

"**Trajectory Operations** is the concept of an air traffic management system in which every aircraft that is operating in and managed by the system is represented in the system via a four dimensional trajectory (4DT). Every managed aircraft known to the system has a 4DT either provided by the user or derived from a flight plan or the type of operation. Increasingly, the trajectories used are much more accurate than those in use today. High performing aircraft are flying the trajectory via their Flight Management System (FMS), using more precise navigation capabilities. The nature of the aircraft's adherence to the trajectory is based on the aircraft's capabilities and the type of operation being conducted. In this way, operations are performance based; meaning that improved services are available to better equipped aircraft.

The trajectories, from initial flight plans through subsequent changes, are managed, to the extent possible, through negotiations among the users and the Air Navigation Service Provider (ANSP). Trajectories are used for advisory services, airspace security, and separation and congestion management. Any changes to the flight (aside from time critical safety clearances) are communicated through or to the trajectory. To be effective, the trajectory must be maintained and updated at all times to reflect the latest flight plan, intent information, or clearance. During pre-flight, the users share trajectory intent information with the ANSP and have improved awareness of current and predicted availability of National Airspace System (NAS) resources, including expected constraint information. The ANSP aggregates the trajectory intent information across all user classes for improved planning. The resulting negotiated trajectory reflects user intent and provides a common basis for access to resources and knowledge of system constraints. In flight, the trajectory is used to manage separation by problem detection/resolution automation (either flight deck or ground-based). Throughout the day, the trajectories are aggregated by ANSP flow management automation to assess potential congestion problems, evaluate alternatives collaboratively, and then implement strategies with aircraft specific clearances. After flight completion, trajectories are used for post analysis and monitoring of system performance by the ANSP and by the users. At the end of the mid-term, initial applications such as paired approaches, pair-wise delegated separation, and Required Time of Arrival (RTA) clearances will be available.

Trajectory Operations are enabled by improved utilization of current and emerging aircraft capabilities (for example, Area Navigation/Required Navigation Performance [RNAV/RNP], FMS, Automatic Dependent Surveillance - Broadcast mode [ADS-B], and data communications), and improvements in ground automation/infrastructure (for example, data communications, surveillance, net-centric data operations, and ANSP and Flight Operations Center [FOC] automation). These enablers result in increased accuracy of the aircraft surveillance information, increased accuracy in navigation of the intended path, increased accuracy and reduced workload for communication, and increased accuracy in executing an Air Traffic Control (ATC) clearance or meeting an aircraft specific flow constraint. As a result, the trajectory is more accurate in execution and more predictable in time and position. These improvements are leveraged through system-wide sharing of information with all authorized users via net-centric data operations and data communications with the aircraft through ATC or AOC/FOCs. Better information and seamless information access provide the users and operators of the NAS with common awareness, a more accurate view of the system, and improved decision making." [Draft definition prepared by MITRE/CAASD staff in support of Trajectory Operations (TOps) concept development]

Processes

Identification of candidate weather integration into Decision Support Tools (DST) involves linking an aviation decision making process, algorithm, or decision aid with an operational need for weather information, for example:

- Operational air traffic recommendations such as airport configuration change options are associated with changing weather conditions (e.g., wind shifts),
- Calculations such as trajectory estimation need to incorporate the impacts of weather on flight performance and speed,
- Airspace and airport capacity prediction are impacted by both severe and routine weather (e.g., thunderstorms, obstructions to vision, winds), and
- Visual aids to decision making such as traffic displays require weather information be overlaid to identify constraints to flights and traffic flows.

Description of candidate weather integration goes on to describe in more detail the role weather plays in these decisions, for example with respect to high density airports:

- From historical Aviation System Performance Metrics (ASPM) data, empirical analysis can identify weather-parameter thresholds (e.g., winds) that identify historical runway configuration usage. These thresholds can then be used by DST algorithms to identify and recommend operational runway configurations based on current weather conditions;
- Integration of weather information into sophisticated trajectory estimation algorithms can be used to recommend a Controlled Time of Arrival (CTA) to a metering fix in support of high density airport operations:
  - Detailed "Big Airspace" terminal wind fields (particularly near merge points and the jet stream's edge),
  - Temperature and barometric pressure profiles (used to calculate geometric altitude), and
  - Icing and turbulence (because of their impact on aircraft performance).

Terms

- 4 Dimensional Trajectory (4DT) is a series of points from departure to arrival representing the aircrafts' path in four dimensions: lateral (latitude and longitude), vertical (altitude), and time.
- Trajectory Based Operations (TBO) is the set of NextGen capabilities for Traffic Flow Management (TFM) by trajectory, which may exist at many levels of complexity from today's flight plans through NextGen's high density operations. TBO capabilities are present in multiple FAA Solution Sets, including Initiate TBO, Increase Arrivals/Departures at High-Density Airports, Increase Flexibility in the
- Terminal Environment, and Improved Collaborative ATM (C-ATM).
- Initiate TBO Solution Set refers to the FAA organization that is responsible for implementing the en route portion of TBO. This should not be confused with the total set of NextGen OIs that in some way involve TBO. TBO-related OIs are also found in other Solution Sets (e.g., Increase Arrivals/Departures at High-Density Airports, Increase Flexibility in the Terminal Environment, and Improved Collaborative Air Traffic Management).
- 4-dimensional (4-D) Weather (Wx) Single Authoritative Source (SAS) is one or more 4-D grid(s) of the 'best' representation of ATM aviation-specific observations, analyses, and forecasts (including probability) and climatology organized by 3-Dimensional (3-D) spatial and time components (x, y, z, t) that supports NextGen ATM aviation decision making.
- 4-D Wx Data Cube is a 4-D grid of aviation-specific weather observations, analyses, and forecasts organized by 3-D spatial and time components (x, y, z, and t). The data

in the cube is used to develop the 4-D Wx SAS that supports NextGen air traffic management decision making. The 4-D Wx Data Cube is the distributed collection of all relevant aviation weather information formed from the merger of observations, automated gridded products, models, climatological data, and human forecasters input from both public and private sources. The production of the 4-D Wx Data Cube, and its utilization by NAS users' applications in an integrated, operational manner, is the essence of NextGen weather capabilities.

A-1.1.4 Methodology

In order for the JPDO to identify and describe potential candidates for mid-term weather integration into DSTs, it is essential that the corresponding OIs are first clearly and thoroughly understood. Therefore, the first step in ATM-weather integration planning is to study the descriptions of the eight Initiate TBO mid-term OIs listed in Section A-1.1.2. Our examination found these descriptions did not provide sufficient detail to support our purpose. Additionally, we found instances in which the descriptions were somewhat ambiguous and/or confusing. A subsequent review of a broad range of NextGen documentation added little to our knowledge of these eight OIs. It should be noted, later this year, the JPDO ANS WG may draft white papers for the mid-term OIs in the Initiate TBO, Increase Arrivals/Departures at High-Density Airports, Increase Flexibility in the Terminal Environment, and Improved Collaborative Air Traffic Management solution sets. This would probably provide the JPDO ATM-weather integration team with the correct level of understanding of the Initiate TBO mid-term OIs, but it would come too late to meet our work schedule for FY09 (i.e., v1.0 by September 30, 2009). Having discovered the information we require to perform our task did not yet exist, we set out to expand upon our understanding of the existing OI descriptions through discussions with TBO Subject Matter Experts (SME). Our first step was to form a discussion group of these SME to clarify and extend our understanding of the TBO mid-term OIs. This group included: key JPDO ANS and Weather WG members, JPDO ATM Weather Integration Plan writing staff, the coordinator of the Initiate TBO solution set, and MITRE staff developing scenarios for the FAA I&I team. Over several months, we discussed each of the eight mid-term TBO OIs to enhance the OI descriptions to a point where weather-related decisions became more obvious, and we could proceed to identify and describe potential weather integration candidates.

A-1.1.5 Outline

Sections A-1.2 through A-1.9 apply this methodology to each of the eight mid-term OIs listed above for the Initiate TBO solution set. These sections document OI goals, needs/shortfalls, descriptions, and design/architecture; develop assumptions as to what these OIs really intend; identify and describe 'potential' candidates for weather integration; develop scenarios; and identify weather needs. Section A-1.10 provides weather integration findings, conclusions and recommendations across the Initiate TBO solution set.

A-1.2 Delegated Responsibility for Separation (OI-0355, NAS OI-102118)

A-1.2.1 Major Mid-term Goals

The goal of Delegated Responsibility for Separation is to extend today's visual flight rules capabilities for clear weather, pair-wise, "in sight" delegated separation to operations conducted in Instrument Meteorological Conditions (IMC) leveraging ADS-B, Cockpit Display of Traffic Information (CDTI), and improved avionics.

A-1.2.2 Mid-term Operational Needs/Shortfalls

"Controllers are responsible for maintaining radar separation of aircraft based on established standards. Delegating separation responsibility may increase capacity through the use of more precise surveillance and shorter reaction times." [Initiate TBO Solution Set Smart Sheet, 2008]

A-1.2.3 Mid-term Planned Capabilities

The mid-term capabilities described in Section A-1.2.3.1 are direct quotes from NextGen documents and those in Section A-1.2.3.2 are clarifications developed via the methodology described in Section A-1.1.4. At this point in time, the clarified capabilities in Section A-1.2.3.2 are only assumptions.

A-1.2.3.1 Documented Capabilities

"Enhanced surveillance and new procedures enable the ANSP to delegate aircraft-to-aircraft separation. Improved display avionics and broadcast positional data provide detailed traffic situational awareness to the flight deck. When authorized by the controller, pilots will implement delegated separation between equipped aircraft using established procedures. Broadcast surveillance sources and improved avionics capabilities provide ANSP and the flight deck with accurate position and trajectory data. Aircraft that are equipped to receive the broadcasts and have the associated displays, avionics, and crew training are authorized to perform delegated separation when recommended by the controller. Delegated separation operations include separation authority for a specific maneuver (e.g., in-trail arrival). For aircraft not delegated separation authority, ANSP automation still manages separation. Aircraft performing delegated separation procedures separate themselves from one another." [Initiate TBO Solution Set Smart Sheet, 2008]

A-1.2.3.2 Capabilities Clarified

It is assumed the mid-term OI, Delegated Responsibility for Separation, is a first step towards NextGen delegated separation responsibility and is limited to pair-wise separation. The controller will be responsible for determining when to delegate, and there are a limited number of geometries for which they may do so. The pilot may decline delegated separation responsibility.

Today, in clear weather, once an aircraft has a target aircraft in sight, a controller may delegate pair-wise separation to that aircraft during the performance of a single maneuver, such as station-keeping or passing, or conducting a visual approach, etc.

It is assumed this mid-term OI would allow an aircraft in IMC, either on approach or en route, to be "in sight" on the CDTI instead of out the window. However, Delegated Responsibility for Separation is still in the concept definition phase, so the scope of this capability is not known precisely.

Some stakeholders advocate taking advantage of onboard weather radar, such as having a ‘pathfinder’ aircraft pick a route through a line of thunderstorms and then delegate separation responsibility to another aircraft following the ‘pathfinder’. This potential application of this capability would be limited to pair-wise separation for limited periods of time. For this scenario, onboard weather radar becomes an enabler and a Common Weather Picture between the aircraft and the ANSP, provided by the 4-D Wx SAS, could enhance weather situational awareness and therefore assist the delegated separation process to proceed more smoothly.

A-1.2.4 Mid-term Design/Architecture

“New procedures permit air traffic controllers to authorize separation responsibility to pilots when it is operationally beneficial. Decision support tools are available to manage delegated separation. Key Enabling Programs include:

- En Route Automation Modernization Mid-Term work package (2013-2017).

To participate in this limited delegated separation, the lead aircraft must be equipped with ADS-B (Out), in compliance with the FAA’s Notice of Proposed Rulemaking. The secondary aircraft must be equipped with an ADS-B (In) capability on the same frequency. The following aircraft must also be equipped with a CDTI and a display of the distance to the lead aircraft in the primary field of view.” [Initiate TBO Solution Set Smart Sheet, 2008]

A-1.2.5 Mid-term Candidate Weather Integration

It is thought that Delegated Responsibility for Separation will not include any direct weather integration. Although, in the case of delegated separation for an aircraft following a ‘pathfinder’ through an area of convective weather, providing the flight deck and ANSP with a common weather picture (i.e., the 4-D Wx SAS) would be a useful, although perhaps not an essential enabler.

A-1.2.6 Linkage to Near- and Far-term

The mid-term OI, Delegated Responsibility for Separation, is a first step towards a full NextGen capability. Table A-1.2.6 describes this initial step, links it back to today’s capabilities and commitments, and describes its future evolution. Section A-1.2.7 then develops scenarios, based on this mid-term capability, which are subsequently used in Section A-1.2.8 to assist us in identifying mid-term weather needs.

Table A-1.2.6 Delegated Responsibility for Separation – Linkage to Near- and Far-term
<u>Near –Term</u> a) TBD
<u>Mid-Term (Transition to NextGen)</u>

a) Extend today's clear weather, pair-wise, 'in-sight' delegated separation operations to IMC, for example, allow delegated pair-wise separation to an aircraft following a 'pathfinder' through an area of convective weather

b) Weather common situational awareness is available to all aviation stakeholders and automation capabilities (i.e., 4-D Wx SAS).

Far-Term (Full NextGen)

a) OI-0363: Delegated Separation - Complex Procedures

b) OI-0343: Reduced Separation – High Density En Route, 3-mile

c) OI-0362: Self-Separation Airspace Operations

d) OI-0348: Reduce Separation – High Density Terminal, Less Than 3-miles

e) By breaking this complex implementation into more manageable steps, benefits are realized sooner and implementation risks are reduced.

f) Weather OIs also evolve in the far-term to include:

- NAS OI-103121: Full (2016-2025) Improved Weather Information and Dissemination
  - Improved common weather situational awareness between the ground and air may become even more important as delegated separation procedures extend duration in the far-term.

A-1.2.7 Mid-term Operational Scenarios

This section contains the following scenarios:

- Delegated Responsibility for Pair-Wise Separation in Cloud
- Delegated Responsibility for Pair-Wise Separation in Airspace Impacted by Convective Weather

A-1.2.7.1 Delegated Responsibility for Pair-Wise Separation in Cloud

Step 0: Pilot files a flight plan, which includes flight plan parameters related to aircraft performance levels and operational capabilities (e.g., aircraft certification, crew training and currency, ADS-B, CDTI, avionics)

Step 1: Controller delegates responsibility for separation to the appropriately equipped aircraft (as determined from its flight plan) to perform a specific pair-wise delegated separation maneuver (aircraft is in cloud and does not have a visual on the other pair-wise aircraft)

Step 2: Pilot of the 'delegated separation' aircraft accepts responsibility for separation

Step 3: Pilot of the 'other pair-wise' aircraft flies its cleared flight plan

Step 4: Pilot of the 'delegated separation' aircraft maintains separation from the 'other pair-wise' aircraft using aircraft systems (ADS-B, CDTI, avionics) until maneuver is complete

Step 5: Controller monitors both pair-wise flights to separate them from all other traffic during the maneuver and to determine when the maneuver is complete

Step 6: Controller, when the maneuver is complete, terminates the pilot delegated separation responsibility and assumes separation responsibility

A-1.2.7.2 Delegated Responsibility for Pair-Wise Separation in Airspace Impacted by Convective Weather

Step 0: Pilot files a flight plan, which includes flight plan parameters related to aircraft performance levels and operational capabilities (e.g., aircraft certification, crew training and currency, ADS-B, CDTI, avionics)

Step 1: Controller delegates separation responsibility to the appropriately equipped aircraft (as determined from its flight plan) to perform a specific pair-wise delegated separation maneuver (i.e., follow a 'pathfinder' aircraft through a convective weather area)

Step 2: Pilot of the 'delegated separation' aircraft accepts responsibility for separation

Step 3: Pilot of 'pathfinder' aircraft finds a path through the convective weather with the aid of his onboard radar and a Common Weather Picture shared with the ANSP

Step 4: Pilot of the 'delegated separation' aircraft maintains separation from the 'pathfinder' aircraft using aircraft systems (ADS-B, CDTI, avionics) and monitors the convective weather using his onboard weather radar and a Common Weather Picture shared with the ANSP and the 'pathfinder' aircraft

Step 5: Controller monitors both pair-wise flights to separate them from all other traffic during the maneuver and to determine when the maneuver is complete

Step 6: Controller, after the paired aircraft emerge from the convective weather area, terminates the pilot delegated separation responsibility and assumes separation responsibility

A-1.2.8 Mid-term Weather Needs Analysis

Based on the scenarios developed in the previous section, weather needs are analyzed in Table A-1.2.8. The 1st column identifies the weather integration need (i.e., the operational decision that will be supported by a DST), the 2nd column attempts to identify the functional weather needs of that DST, the 3rd column identifies the weather information that will be available in the mid-term (according to current plans), and the 4th column identifies gaps, and the 5th column provides recommendations.

Work on this table has only just begun. The next immediate steps are to focus on and complete columns 2 and 3, so that columns 4 and 5 can be addressed. Please note that in its final form, column 3 will not reference weather 'products', rather it will identify the characteristics of the weather 'information' available in the mid-term.

Table A-1.2.8 *Delegated Responsibility for Separation* – Mid-term Weather Needs Analysis

Mid-Term Wx Integration Need	Mid-Term Wx Information Need	Mid-Term 4-D Wx Data Cube Capability	Mid-Term Wx Information Gap	Recommendations
None	4-D Wx SAS disseminated to pathfinder, following aircraft, and controller (desired), including current convective weather conditions and forecasts out 20 minutes *Accuracy TBD* *Resolution TBD* *Forecast Update Rate TBD* *Latency TBD*	4-D Wx SAS Initial Operating Capability (IOC), including current convective weather conditions and deterministic forecasts out 20 minutes	None	N/A

A-1.3 Oceanic In-trail Climb and Descent (NAS OI-102108)

A-1.3.1 Major Mid-term Goals

The goal of Oceanic In-trail Climb and Descent is to take advantage of improved communication, navigation, and surveillance coverage in the oceanic domain to allow participating aircraft to fly more advantageous trajectories.

A-1.3.2 Mid-term Operational Needs/Shortfalls

"The current system optimizes user efficiency subject to constraints of the current system, including the very large (tens of miles) procedural separation standards. These standards often constrain aircraft to inefficient altitudes and undesirable speeds, as other aircraft are within the separation standard and block the aircraft from its desired operating profile." [Initiate TBO Solution Set Smart Sheet, 2008]

A-1.3.3 Mid-term Planned Capabilities

The mid-term capabilities described in Section A-1.3.3.1 are direct quotes from NextGen documents and those in Section A-1.3.3.2 are clarifications developed via the methodology described in Section A-1.1.4. At this point in time, the clarified capabilities in Section A-1.3.3.2 are only assumptions.

A-1.3.3.1 Documented Capabilities

"ANSP automation enhancements will take advantage of improved communication, navigation, and surveillance coverage in the oceanic domain. When authorized by the controller, pilots of equipped aircraft use established procedures for climbs and descents.

Improved ANSP automation provides the opportunity to use new procedures and reduce longitudinal spacing. Aircraft are able to fly the most advantageous trajectories with climb and descent maneuvers.

These procedures are intended for aircraft with existing Future Air Navigation System (FANS)-1/A capabilities." [Initiate TBO Solution Set Smart Sheet, 2008]

A-1.3.3.2 Capabilities Clarified

The mid-term OI, Oceanic In-trail Climb and Descent, is a capability that is already at a fairly high level of development maturity and is nearly ready for demonstration. The assumption is that there is no weather integration involved in this OI, nor any new weather information required.

A-1.3.4 Mid-term Design/Architecture

"Tools and procedures, for both aircrew and ground-based system will be needed to assist the controller in managing the delegation process. Procedures will be developed for the controllers that use surveillance information and Controller Pilot Data Link Communications (CPDLC) capability. Key Enabling Programs include:

- Advanced Technologies and Oceanic Procedures Technical Refresh (2008–2010)." [Initiate TBO Solution Set Smart Sheet, 2008]

A-1.3.5 Mid-term Candidate Weather Integration

It is thought that Oceanic In-trail Climb and Descent will neither include any weather integration nor any new weather requirements.

A-1.3.6 Linkage to Near- and Far-term

The mid-term OI, Oceanic In-trail Climb and Descent, is a first step towards a full NextGen capability. Table A-1.3.6 describes this initial step, links it back to today's capabilities and commitments, and describes its future evolution. Section A-1.3.7 then develops scenarios, based on this mid-term capability, which are subsequently used in Section A-1.3.8 to assist us in identifying mid-term weather needs.

Table A-1.3.6 *Oceanic In-trail Climb and Descent* – Linkage to Near- and Far-term
Near –Term a) Separation reduction – 50 longitudinal miles in Anchorage Oceanic airspace b) 50 nm lateral separation in West Atlantic Route System (WATRS)
Mid-Term (Transition to NextGen) p) Take advantage of improved communication, navigation, and surveillance coverage in the oceanic domain to allow participating aircraft to fly more advantageous trajectories with in-trail climb and descent maneuvers
Far-Term (Full NextGen)

a) OI-0359: *Self-Separation Airspace - Oceanic*

A-1.3.7 Mid-term Operational Scenarios

There are no applicable weather-related scenarios for *Oceanic In-trail Climb and Descent*.

A-1.3.8 Mid-term Weather Needs Analysis

Based on the scenarios developed in the previous section, weather needs are analyzed in Table A-1.3.8. The 1st column identifies the weather integration need (i.e., the operational decision that will be supported by a DST), the 2nd column attempts to identify the functional weather needs of that DST, the 3rd column identifies the weather information that will be available in the mid-term (according to current plans), and the 4th column identifies gaps, and the 5th column provides recommendations.

We have yet to identify any weather integration or weather information needs for *Oceanic In-trail Climb and Descent*.

Table A-1.3.8 *Oceanic In-trail Climb and Descent* – Mid-term Weather Needs Analysis

Mid-Term Wx Integration Need	Mid-Term Wx Information Need	Mid-Term 4-D Wx Data Cube Capability	Mid-Term Wx Information Gap	Recommendations
None	None	N/A	N/A	N/A

A-1.4 Automation Support for Mixed Environments (OI-0349, NAS OI-102137)

A-1.4.1 Major Mid-term Goals

The goal of Automation Support for Mixed Environments is to allow the controller to better manage aircraft in an environment with mixed navigation equipage and aircraft with varying wake performance characteristics.

A-1.4.2 Mid-term Operational Needs/Shortfalls

"Automation enhancements are needed in the en route airspace to manage operations in a mixed separation environment and improve controllers' situational awareness of advanced capabilities. Controllers need to have tools that assist them in coordinating with other facilities or positions when aircraft are performing delegated separation maneuvers, parallel RNAV and RNP routes, identifying equipped vs. non-equipped aircraft, and trajectory flight data management." [Initiate TBO Solution Set Smart Sheet, 2008]

A-1.4.3 Mid-term Planned Capabilities

The mid-term capabilities described in Section A-1.4.3.1 are direct quotes from NextGen documents and those in Section A-1.4.3.2 are clarifications developed via the methodology described in Section A-1.1.4. At this point in time, the clarified capabilities in Section A-1.4.3.2 are only assumptions.

A-1.4.3.1 Documented Capabilities

"The ANSP automation provides the controller with tools to manage aircraft in a mixed navigation and wake performance environment. Aircraft with various operating and performance characteristics will be operating within the same volume of airspace. Controllers will use ANSP automation enhancements to provide situational awareness of aircraft with advanced capabilities (e.g., delegated self-separation maneuvers, equipped vs. non-equipped aircraft, RNAV, RNP, and trajectory flight data management). These enhancements enable ANSP to manage the anticipated increase in complexity and volume of air traffic." [Initiate TBO Solution Set Smart Sheet, 2008]

"The separation standards used in mixed use airspace will be enhanced to accommodate new larger aircraft and Unmanned Aircraft Systems (UASs). The separation standards including wake turbulence requirements will be incorporated into ANSP automation providing support for efficiently managing parameter-driven separation, and requires development of standards and procedures." [NextGen Integrated Work Plan (IWP) v1.0, 2008]

A-1.4.3.2 Capabilities Clarified

The supporting documentation for both the NAS and IWP OIs listed above specifically refers to separation assurance and enhanced separation standards, and the IWP OI additionally includes separation standards for wake turbulence. However, the first requirement for the automation should be that it enables the controller to safely and efficiently manage aircraft of differing capability, including those controlled solely through voice communication and those with datalink capability, while allowing the more equipped aircraft to take advantage of their advanced capabilities. This implies the automation is aware of, and is tracking, all the aircraft for which the controller has responsibility. The automation must additionally be aware of aircraft performance characteristics, including any degraded capability, so it can calculate the appropriate separation standard to use.

Today's use of vectors to control traffic results in large uncertainties in the aircraft's future path because of the wide range of normal pilot and aircraft response characteristics. To usefully enhance separation standards, such uncertainty will need to be substantially reduced. As these OIs are intended for mixed aircraft capability environments, a means must be found to control aircraft with voice instructions that, when accepted, are fed back into the automation which then tracks compliance with the instruction. The JPDO Aircraft and ANS Working Groups have suggested that this could be achieved through the automation generating 3-D Path clearances for voice-controlled aircraft, which the controller then relays to the aircraft, but this is still under discussion. Boeing originally proposed the 3-D Path concept.

Once automation has been developed that can assist the controller in managing traffic of differing capabilities, then it might be possible to enhance separation standards. However, voice controlled aircraft will generate more workload for the controller than datalink aircraft, even if a means of providing closed-loop trajectory changes is implemented as suggested above. Controller workload, together with the reduced flexibility and precision inherent in voice control, will limit the complexity and density of traffic in a mixed equipage environment. Wake avoidance for new very large aircraft such as the Airbus A-380 could be accommodated through a larger separation standard. UAS's might be similarly treated. The automation will also be required to track both delegation of separation responsibility and whether the aircraft remains within the limits delegated.

A-1.4.4 Mid-term Design/Architecture

"En route decision support tools will be enhanced and the Human-Computer Interface designed to provide the ANSP with situational awareness to manage traffic with mixed equipage environment. The En Route Automation Modernization (ERAM) conflict alert and problem prediction capabilities will be augmented with additional algorithms to account for mixed equipage capabilities. Key Enabling Programs include:

- En Route Automation Modernization Mid-Term Work Package 2013-2017 and
- Key Decision #31 En Route Automation Modernization Mid-Term Work Package final investment decision (2011)."

[Initiate TBO Solution Set Smart Sheet, 2008]

A-1.4.5 Mid-term Candidate Weather Integration

The new capability represented by Automation Support for Mixed Environments (i.e., to handle and to take advantage of mixed equipage) does not appear to have any weather decisions associated with it directly. The tools to implement this capability will clearly be integrated with tools that do need weather information, but those weather information needs should be captured in other OIs, not this one.

A-1.4.6 Linkage to Near- and Far-term

The mid-term OI, Automation Support for Mixed Environments, is a first step towards a full NextGen capability. Table A-1.4.6 describes this initial step, links it back to today's capabilities and commitments, and describes its future evolution. Section A-1.4.7 then develops scenarios, based on this mid-term capability, which are subsequently used in Section A-1.4.8 to assist us in identifying mid-term weather needs.

Table A-1.4.6 *Automation Support for Mixed Environments* – Linkage to Near- and Far-term
<u>Near –Term</u> a) TBD
<u>Mid-Term (Transition to NextGen)</u> a) Automation enhancements provide ANSP with situational awareness of aircraft with advanced capabilities (e.g., delegated self-separation maneuvers, equipped vs. non-equipped aircraft, RNAV, RNP, and trajectory flight data management) b) Automation provides the controller with tools to manage aircraft in a mixed navigation and wake performance environment.
<u>Far-Term (Full NextGen)</u> a) None

A-1.4.7 Mid-term Operational Scenarios

There are no applicable weather-related scenarios for Automation Support for Mixed Environments.

A-1.4.8 Mid-term Weather Needs Analysis

Based on the scenarios developed in the previous section, weather needs are analyzed in Table A-1.4.8. The 1st column identifies the weather integration need (i.e., the operational decision that will be supported by a DST), the 2nd column attempts to identify the functional weather needs of that DST, the 3rd column identifies the weather information that will be available in the mid-term (according to current plans), and the 4th column identifies gaps, and the 5th column provides recommendations.

We have yet to identify any weather integration or weather information needs for Automation Support for Mixed Environments

Table A-1.4.8 *Automation Support for Mixed Environments* – Mid-term Weather Needs Analysis

Mid-Term Wx Integration Need	Mid-Term Wx Information Need	Mid-Term 4-D Wx Data Cube Capability	Mid-Term Wx Information Gap	Recommendations
None	None	N/A	N/A	N/A

A-1.5 Initial Conflict Resolution Advisories (NAS OI-102114)

A-1.5.1 Major Mid-term Goals

The goal of Initial Conflict Resolution Advisories is to reduce sector controller workload by: integrating existing conflict detection and trial flight planning capabilities with those for conflict resolution advisory and ranking, and introducing data link clearances.

A-1.5.2 Mid-term Operational Needs/Shortfalls

"Traffic is expected to increase in volume and complexity. ANSP will require additional automation support to help identify problems and provide efficient resolutions to those problems in order to safely manage the expected traffic levels. Controllers need automation support to help evaluate resolutions of conflicts. Today, the User Request Evaluation Tool (URET) notifies the en route controller of predicted problems, but trial planning for developing resolutions is workload intensive." [Initiate TBO Solution Set Smart Sheet, 2008]

A-1.5.3 Mid-term Planned Capabilities

The mid-term capabilities described in Section A-1.5.3.1 are direct quotes from NextGen documents and those in Section A-1.5.3.2 are clarifications developed via the methodology described in Section A-1.1.4. At this point in time, the clarified capabilities in Section A-1.5.3.2 are only assumptions.

A-1.5.3.1 Documented Capabilities

"The ANSP conflict probe is enhanced not only to recognize conflicts but to provide rank-ordered resolution advisories to the provider. The provider may select one of the resolutions to issue to the aircraft. Automation enables ANSP to better accommodate pilot requests for trajectory changes by providing conflict detection, trial flight planning, and development of resolutions, as well as an optimal ranking of resolutions.

ANSP resolves tactical trajectory management conflicts using en route automation. The resolution will be tailored to the communication medium (voice or data communication). In the mid-term, voice communication between ANSP and flight operators is expected to be the dominant communication medium; in the far-term, the role of voice communication will diminish. As a result, this capability will support integration with data communications. Automation provides problem prediction and resolution support to the controller position." [Initiate TBO Solution Set Smart Sheet, 2008]

A-1.5.3.2 Capabilities Clarified

The documented description of Initial Conflict Resolution Advisories, cited above in A-1.5.3.1, makes no mention of weather. Therefore, it appears this operational improvement is limited to expanding current aircraft-to-aircraft conflict capabilities and will not include weather integration. However, since aircraft-to-aircraft conflict resolution is a fairly mature concept, there may be an opportunity to expand the scope of this capability to also include an initial weather problem detection capability and possibly one for weather problem resolution advisories. Some research has been done in developing a concept for a weather problem detection and resolution advisory capability and it is possible that such an initial capability could be ready for implementation in the mid-term. The following discussion makes a case for these weather integration capabilities.

There appears to be a need for at least an automated weather problem detection capability, for sectors adjoining convective weather, to evaluate aircraft-to-aircraft conflict resolutions, ensuring they do not inadvertently direct aircraft into the weather. Moreover, one could make the case that a weather problem detection capability is essential, when employed in sectors near convective weather, to provide both the controller and pilot with confidence in the automated aircraft-to-aircraft conflict resolution advisories. As stated in A-1.5.1, the goal of Initial Conflict Resolution Advisories is to reduce workload. However, it would significantly reduce the benefit of this capability, if it could not be used near convective weather, where workloads are especially high and it is needed the most. Similarly, a weather problem detection capability could be employed to evaluate a pilot requested maneuver around a convective area to ensure the proposed trajectory would not result in the aircraft encountering another convection weather problem just beyond the range of the aircraft's airborne radar.

There also may be a need for an automated weather problem resolution capability to address tactical weather problems resulting from highly dynamic weather that rapidly and unexpectedly closes a TFM initiated flow through or around a convective weather area. In this case, such a capability could assist the sector controller in responding to pilot requests for assistance in identifying alternate routes around the weather. This case should not be construed to mean the sector controller's decision support would provide resolution advisories that would either 'thread' an aircraft through convective weather cells or would extend the sector controller's responsibility to include separating aircraft from weather. Rather this case would provide resolution advisories around the weather, similar to those provided by TFM, and it would be utilized only in response to a pilot's request for assistance, which otherwise the controller would perform cognitively without the assistance of automation. While the sector controller is assisting flights within the impacted sector to negotiate the changing weather constraint, TFM would address upstream flows so that the impacted sector would quickly return to more manageable traffic loads.

Rapidly improving weather is another case for an automated weather problem resolution capability. In this case, airspace previously impacted by weather suddenly and unexpectedly becomes available, allowing aircraft previously rerouted to request maneuvers returning them to their original flight plans. While TFM adjusts upstream flows of aircraft to take advantage of the newly opening airspace, a weather problem resolution capability would allow the sector controller to better respond to a request, from a pilot within the impacted sector, for a more efficient trajectory back to the aircraft's original flight path.

A-1.5.4 Mid-term Design/Architecture

"A problem resolution capability based on the ERAM trajectory modeler will be added. Problem prediction will have migrated from the URET display to the display at the Radar Controller position. If air-ground data communication is available during this timeframe, it will be integrated with this capability to allow the ANSP to transmit the clearance (based on the resolution advisory) to capable aircraft. Key Enabling Programs include:

- En Route Automation Modernization mid-term work package (2013-2017)."

[Initiate TBO Solution Set Smart Sheet, 2008]

A-1.5.5 Mid-term Candidate Weather Integration

A weather integration opportunity for Initial Conflict Resolution Advisories is dependent on expanding the scope of this capability to include weather problem detection and possibly resolution. The following weather-related capabilities have been identified as 'potential' candidates for inclusion into Initial Conflict Resolution Advisories:

- Controller weather problem detection decision support to:
  - Prevent directing aircraft into hazardous weather inadvertently when resolving aircraft-to-aircraft conflicts
  - Evaluate a pilot requested maneuver around the weather to ensure it would not send the aircraft into another area of convection not yet visible on the aircraft's airborne radar
- Controller weather problem resolution decision support to respond to pilot requests for assistance to:

  – Route around significant areas of convective weather that are rapidly and unexpectedly worsening

  – Return to aircraft's original flight plan when convective weather rapidly and unexpectedly improves

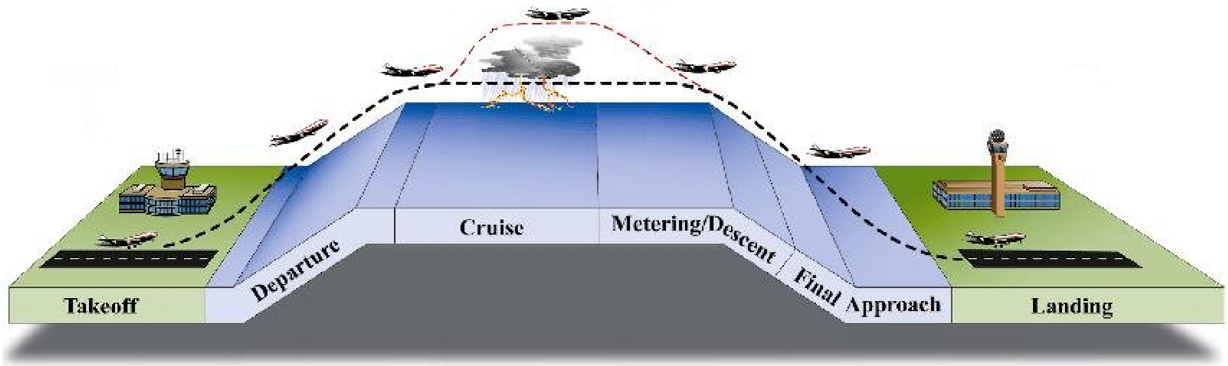
A-1.5.6 Linkage to Near- and Far-term

The mid-term OI, Initial Conflict Resolution Advisories, is a first step towards a full NextGen capability. Table A-1.5.6 describes this initial step, links it back to today's capabilities and commitments, and describes its future evolution. Section A-1.5.7 then develops scenarios, based on this mid-term capability, which are subsequently used in Section A-1.5.8 to assist us in identifying mid-term weather needs.

Table A-1.5.6 ***Initial Conflict Resolution Advisories*** **– Linkage to Near- and Far-term**
Near –Term a) UAS- 4-D Trajectory-based Demonstration
Mid-Term (Transition to NextGen) a) Integrate existing aircraft-to-aircraft conflict detection and trial flight planning capabilities with those for conflict resolution advisory and ranking, and introduce data link clearances b) Suggest expanding the scope of this capability to include aircraft-to-weather problem detection and resolution advisory and ranking
Far-Term (Full NextGen) a) NAS OI-xxxxxx: *Use of Aircraft-Provided Intent Data to Improve Conflict Resolution* b) NAS OI-xxxxxx: *Expanded Conflict Resolution via data Communic*ations c) OI-0360: *Automation-Assisted Trajectory Negotiation* d) OI-0358: *Trajectory Flight Data Management* e) OI-0370: *Trajectory-Based Management- Full Gate-to-Gate* f) OI-0369: *Automated Negotiation/Separation Management* g) By breaking this complex implementation into more manageable steps, benefits are realized sooner and implementation risks are reduced. h) Weather OIs also evolve in the far-term to include: • NAS OI-103119a: *Full (2016-2025) Integration of Weather Information into NAS Automation and Decision Making* • NAS OI-103121: *Full (2016-2025) Improved Weather Information and Dissemination*

A-1.5.7 Mid-term Operational Scenarios

As Initial Conflict Resolution Advisories is currently described in the NextGen Implementation Plan (NGIP), there are no applicable weather-related scenarios. However, if the scope of the description is extended to include a weather problem detection and possibly resolution advisory capability, then the following scenarios may be applicable. Also, included in this section are scenarios that would not require an automated weather problem capability, to better clarify where an automated capability is and is not needed.



Weather Problem Detection Capability

- Controller uses aircraft-to-aircraft conflict resolution decision support, combined with a weather problem detection capability, to avoid inadvertent aircraft-to-aircraft conflict resolution into hazardous weather
- Controller uses weather problem detection decision support to evaluate a pilot requested maneuver around the weather to ensure it would not send the aircraft into another area of convection not yet visible on the aircraft's airborne radar

Weather Problem Resolution Capability

- Controller uses weather problem resolution decision support to respond to pilot requests for assistance in routing around significant areas of convective weather that are rapidly and unexpectedly worsening
- Controller uses weather problem resolution decision support to respond to pilot requests for assistance in returning to aircraft's original flight plan when convective weather rapidly and unexpectedly improves

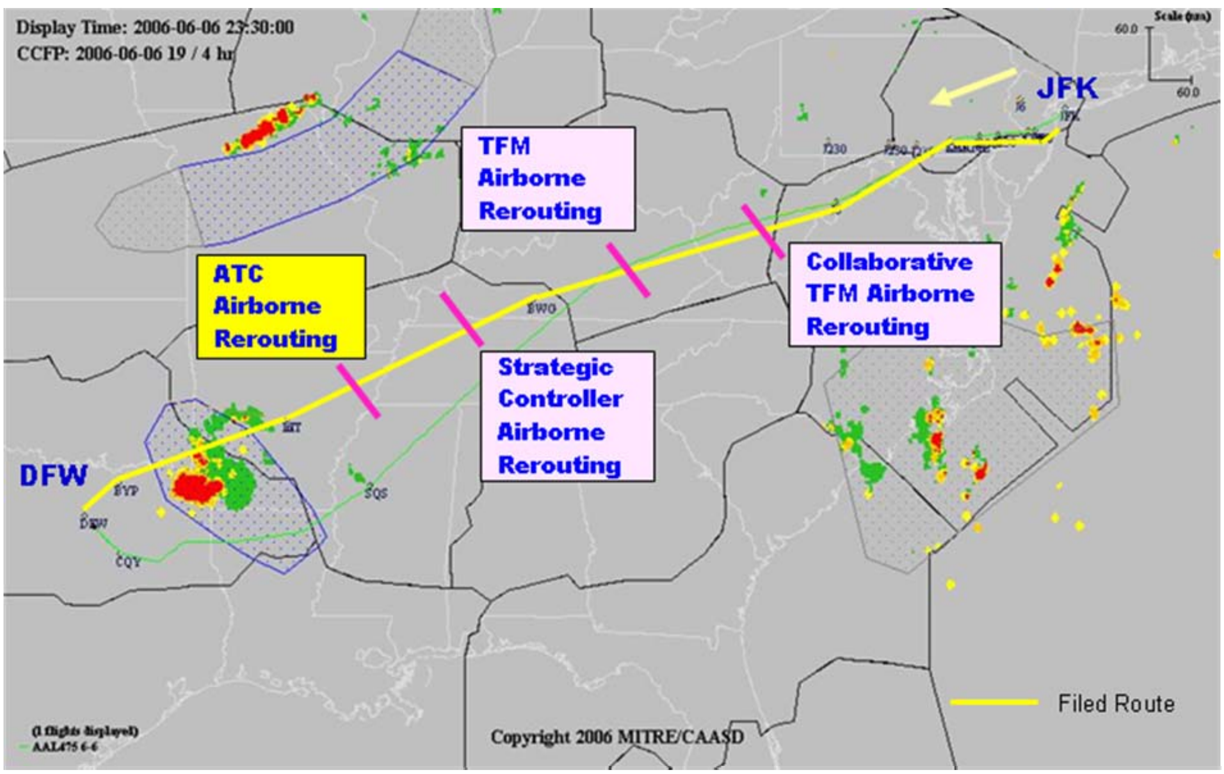
No Weather Problem Capability

- Controller monitors the traffic on a TFM flow around weather on a day when the convective weather forecast 20-40 minutes out is accurate and the weather is stable, without the need for weather problem detection or resolution decision support
- Controller vectors an aircraft around an individual convective weather cell with an open-loop clearance, without the need for weather problem detection or resolution decision support

As the figure below indicates, the NextGen concept for addressing weather problems begins strategically in the TFM domain (from 20 minutes out to several hours prior to an aircraft's encountering of the weather) and ends in the ATC domain (0-20 minutes out). In the mid-term, the Traffic Management Coordinator (TMC) collaborates with FOCs 2-6 hours out to plan flows through or around the weather. 1-2 hours out, when there is sufficient confidence in the weather forecasts, planned flows around the weather are implemented. 20-40 minutes out, the strategic controller in coordination with the TMC adjusts the flows, as weather forecast updates require. 0-20 minutes out, the sector controllers monitor traffic on these flows to maintain aircraft separation.

By 2025, the concept suggests that TFM will resolve the 'majority' of weather problems. However, as indicated above, there are instances in which the dynamic nature of weather would require ATC to tactically address some weather problems. Providing sector controllers with an automated weather problem detection/resolution capability would assist them in working these problems in a safe, timely, and efficient manner, at a time when controller workloads are high.

In the following mid-term scenarios, it is assumed that the controller is not responsible for separating aircraft from weather, but will assist the pilot, to the extent possible, when a request is made. In the far-term, it is possible that the sector controller's role in separating aircraft from weather may change, but these scenarios do not consider this potential outcome.



A-1.5.7.1 Controller Uses Aircraft-to-Aircraft Conflict Resolution Decision Support, Combined with a Weather Problem Detection Capability, to Avoid Inadvertent Aircraft-to-Aircraft Conflict Resolution into Hazardous Weather

Step 0: The 4-D Wx SAS provides ATC automation and pilots with a common weather picture. The pilot also has on-board weather radar and may have access to commercially obtained weather forecasts. The pilot is responsible for keeping his aircraft a safe distance from the weather. The controller is responsible for separating aircraft from other aircraft and, to the extent possible, assisting pilots in avoiding weather hazards. The aircraft is 15 minutes out from an area of convective weather.

Step 1: ATC aircraft-to-aircraft conflict detection Decision Support (DS) determines the flight paths of two aircraft will come into conflict 10 minutes out.

Step 2: ATC aircraft-to-aircraft conflict resolution DS, integrated with a weather problem detection capability and utilizing the weather's impact (rather than the weather forecast alone), generates multiple ranked (weather free) resolutions for the aircraft-to-aircraft conflict.

Step 3: ATC aircraft-to-aircraft conflict DS notifies the controller of the aircraft-to-aircraft conflict and provides ranked resolutions that will keep the aircraft free of weather's impact.

Step 4: The sector controller selects an operationally acceptable resolution from the ranked resolution or uses the ATC aircraft-to-aircraft conflict DS to create and evaluate a trial plan.

Step 5: The sector controller, using voice or data communications, contacts the flight deck to provide the change in trajectory, thereby alerting the pilot of the conflict.

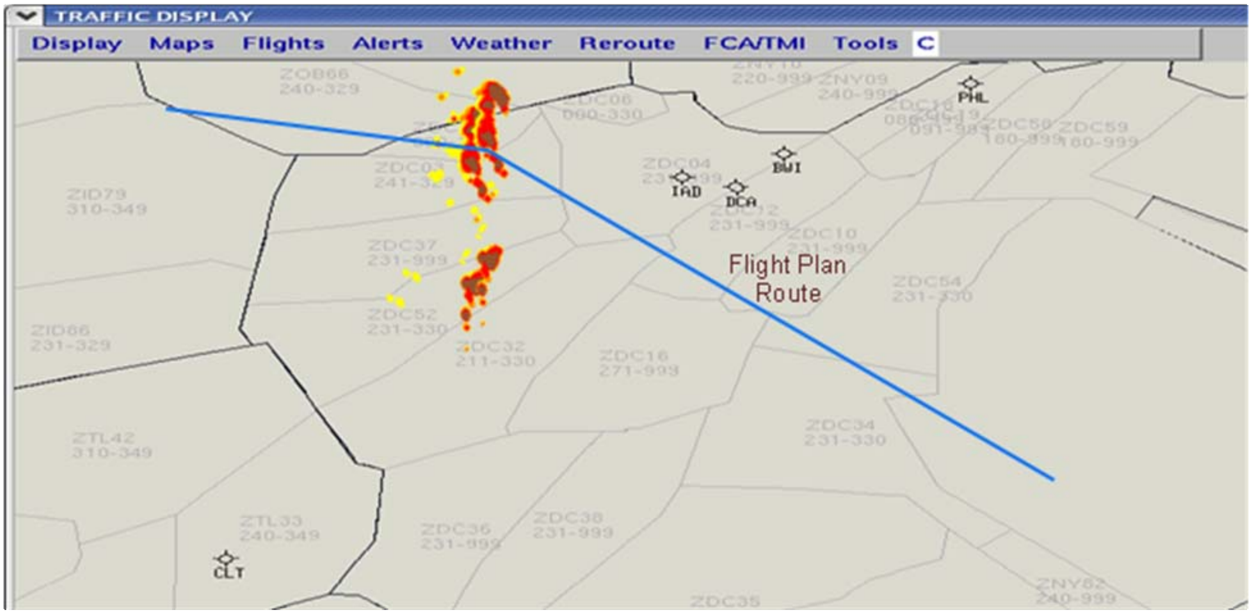
Step 6: The pilot accepts the controller's aircraft-to-aircraft conflict resolution.

Step 7: The pilot enters the new trajectory into the FMS. Or, in the case of low-end General Aviation (GA), executes each leg of the trajectory as it's cleared or flies direct to a designated fix.

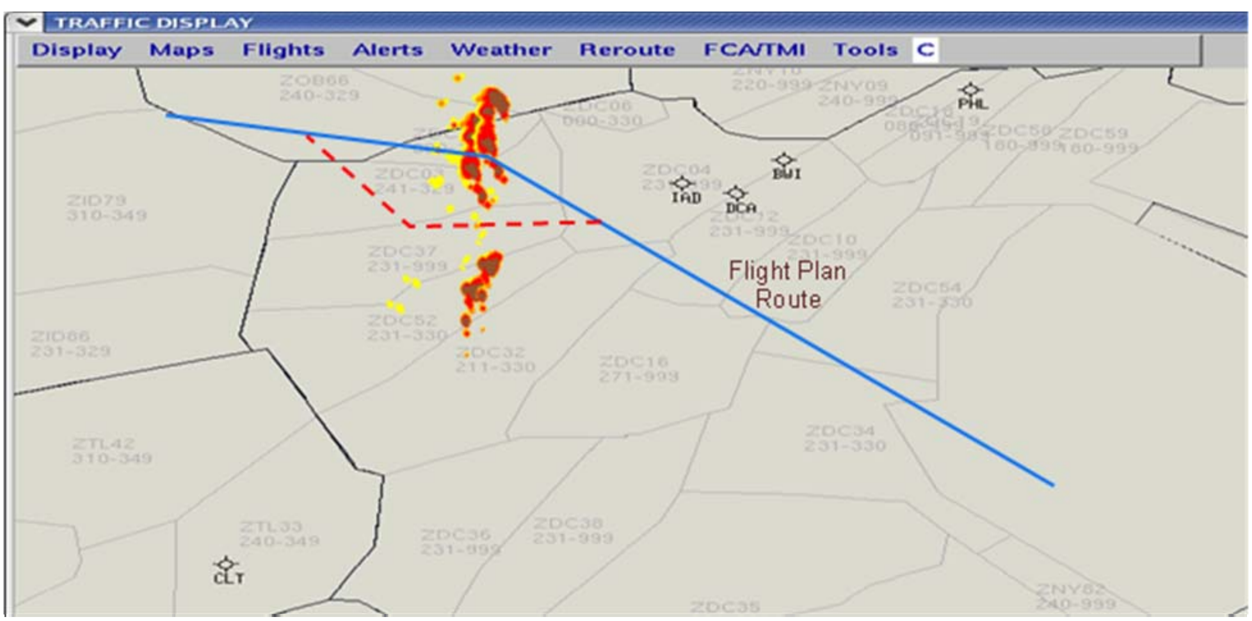
A-1.5.7.2 Controller uses weather problem detection decision support to evaluate a pilot requested maneuver around the weather to ensure it will not send the aircraft into another area of convection not yet visible on the aircraft's airborne radar

Step 0: The 4-D Wx SAS provides ATC automation and pilots with a common weather picture. The pilot also has on-board weather radar and may have access to commercially obtained weather forecasts; additionally the aircraft has data link. The pilot is responsible for keeping his aircraft a safe distance from the weather. The controller is responsible for separating aircraft from other aircraft and to the extent possible assisting pilots in avoiding weather hazards. The aircraft is 15 minutes out from an area of convective weather.

Step 1: The pilot detects convective weather directly in the aircraft's path.



Step 2: The pilot, using all the weather information at his disposal, cognitively determines a weather problem resolution option and communicates a maneuver request to the sector controller via data communications.



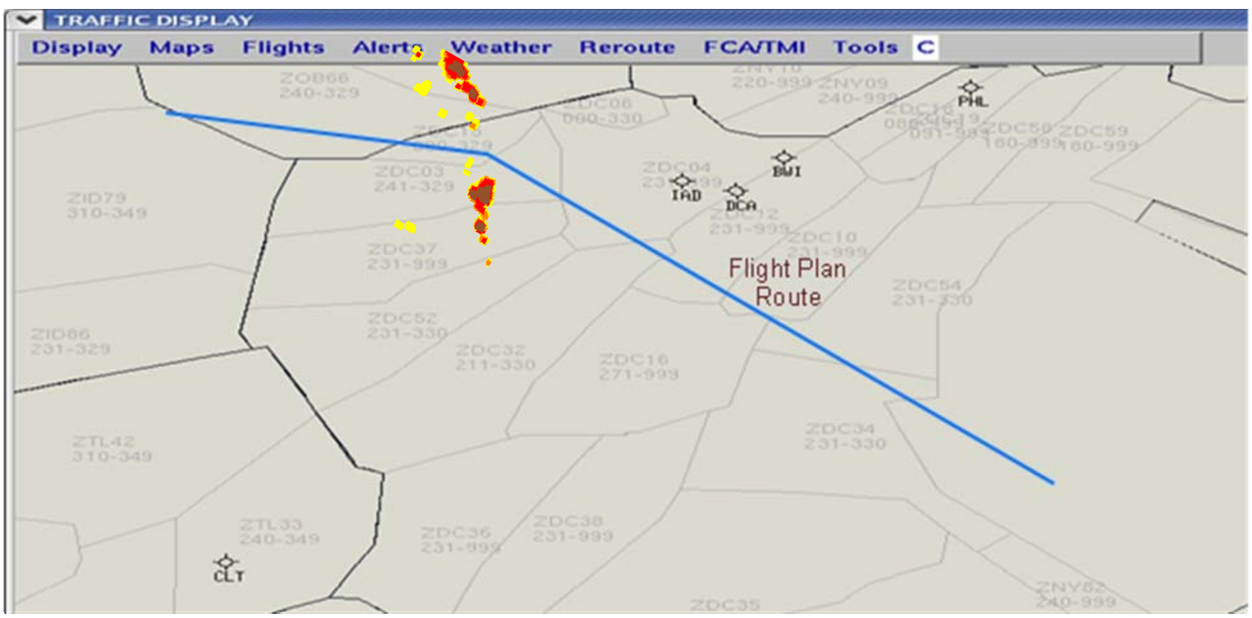
Step 3: ATC DS, integrated with a weather problem detection capability, assesses the pilot's data link requested maneuver to identify potential aircraft-to-aircraft conflicts, as well as any aircraft-to-weather problems; none are found.

Step 4: The sector controller, via data communications, issues a clearance for the pilot's requested maneuver.

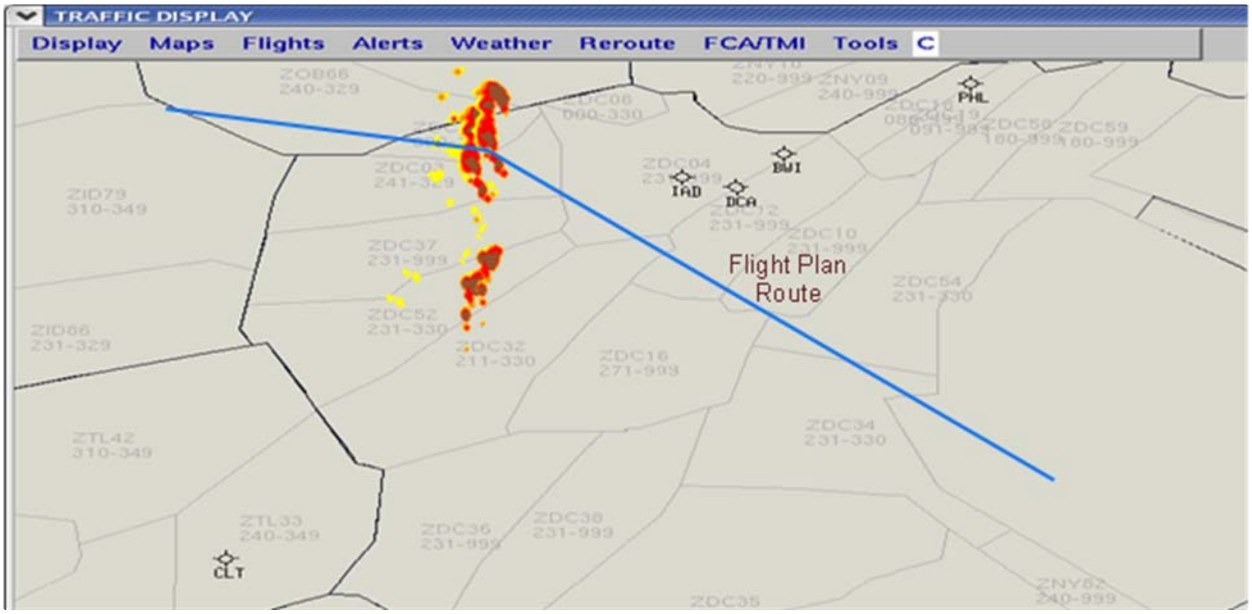
Step 5: The pilot accepts the clearance and enters the new trajectory into the aircraft's FMS.

A-1.5.7.3 Controller uses weather problem resolution decision support to respond to pilot requests for assistance in routing around significant areas of convective weather that are rapidly and unexpectedly worsening

Step 0: The 4-D Wx SAS provides ANSP, ATM automation, and users with a common weather picture. The pilot is responsible for keeping his aircraft a safe distance from the weather. The controller is responsible for separating aircraft from other aircraft and to the extent possible assisting pilots in avoiding weather hazards. One hour prior to an aircraft's encountering of the weather, the TMC, using 4-D Wx SAS integrated with TFM DS, initiates a flow of aircraft through a gap in the forecasted convective weather. 30 minutes prior to an aircraft's encountering of the weather, the strategic controller, using the 4-D Wx SAS integrated with TFM DS, adjusts the flow to compensate for changes in the forecast.



Step 1: 20 minutes out from the weather, the weather rapidly and unexpectedly intensifies deviating from the forecasts used to setup the flow of traffic around the weather. The gap in the weather still exists, but is now further to the South.



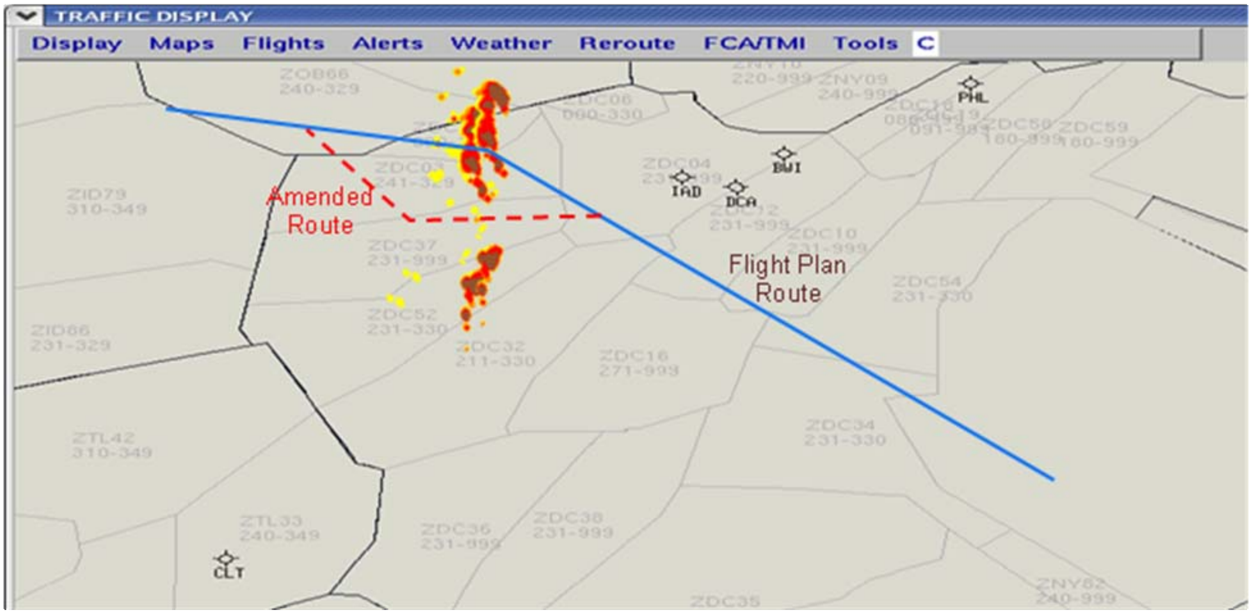
Step 2: TFM DS identifies the weather problem and alerts the appropriate TMC and strategic controller, providing them with assistance in adjusting the flow for upstream aircraft towards the new gap in the weather.

Step 3: 15 minutes out from the weather, the pilot of an aircraft detects convective weather directly in his path and requests assistance from the sector controller to find a route around it.

Step 4: ATC DS translates 4-D Wx SAS convective weather forecast information into operational impact, taking weather uncertainty into account. Using this impact information, ATC DS generates and assesses multiple weather problem resolution options and notifies the sector controller of the highest ranked resolutions.

Step 5: The sector controller selects an operationally acceptable weather problem resolution and suggests it to the pilot via voice or data communications.

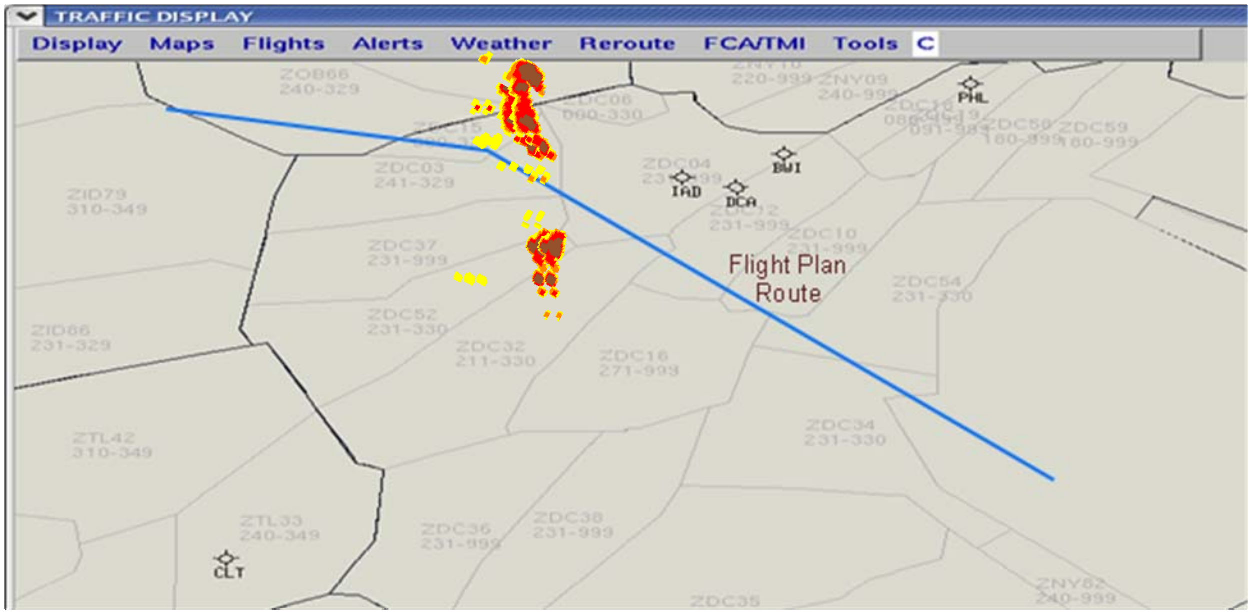
Step 6: The pilot accepts controller's suggested weather problem resolution.



Step 7: The pilot enters the new trajectory into the aircraft's FMS. Or, in the case of low-end GA, executes each leg of the trajectory as it's cleared or flies direct to a designated fix.

A-1.5.7.4 Controller uses weather problem resolution decision support to respond to pilot requests for assistance in returning aircraft to original flight plan when convective weather rapidly and unexpectedly improves

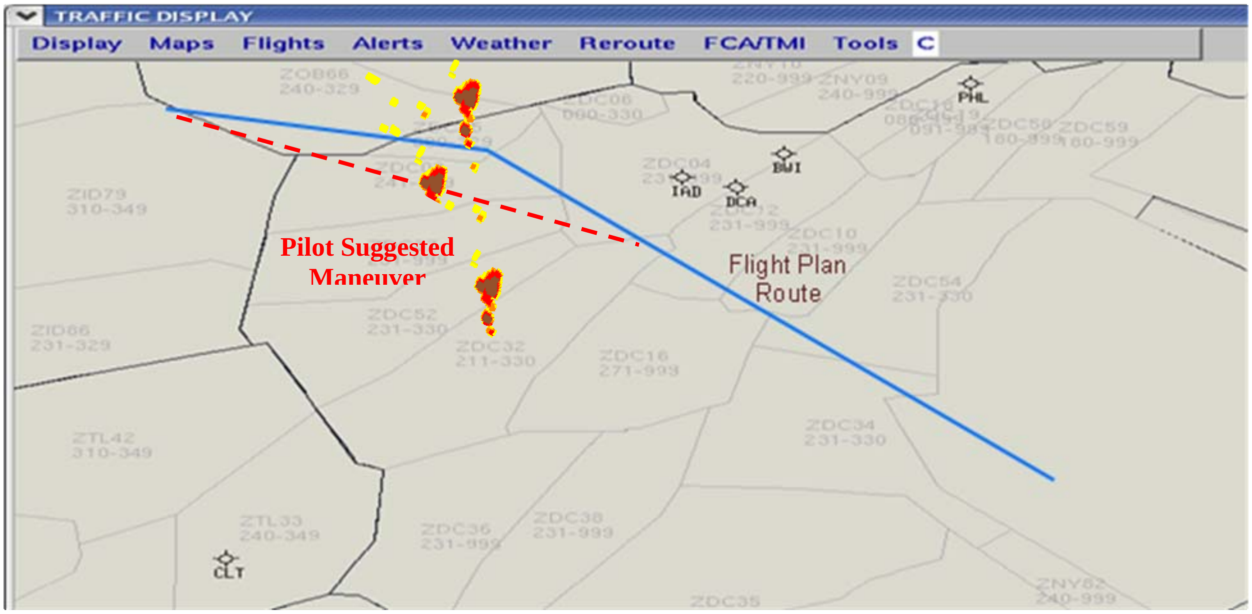
Step 0: The 4-D Wx SAS provides ANSP, ATM automation, and users with a common weather picture. The pilot also has on-board weather radar and may have access to commercially obtained weather forecasts; additionally the aircraft has data link. The pilot is responsible for keeping his aircraft a safe distance from the weather. The controller is responsible for separating the aircraft from other aircraft and to the extent possible assisting pilots in avoiding weather hazards. One hour prior to an aircraft's encountering of the weather, the TMC, using 4-D Wx SAS integrated with TFM DS, initiates a flow of aircraft through a gap in the forecasted convective weather. 30 minutes prior to an aircraft's encountering of the weather, the strategic controller, using 4-D Wx SAS integrated with TFM DS, adjusts the flow to compensate for changes in the forecast.



Step 1: 20 minutes out from the weather, the weather unexpectedly and rapidly improves making a return to the originally filed flight plan an option to consider.

Step 2: TFM DS alerts the appropriate TMC and strategic controller of the improving weather and provides them with assistance in returning upstream aircraft to their original flight paths.

Step 3: The pilot, using all the weather information at his disposal, cognitively detects the weather improvement, determines a maneuver option to return to his original flight plan, and communicates the maneuver request to the sector controller via data communications.

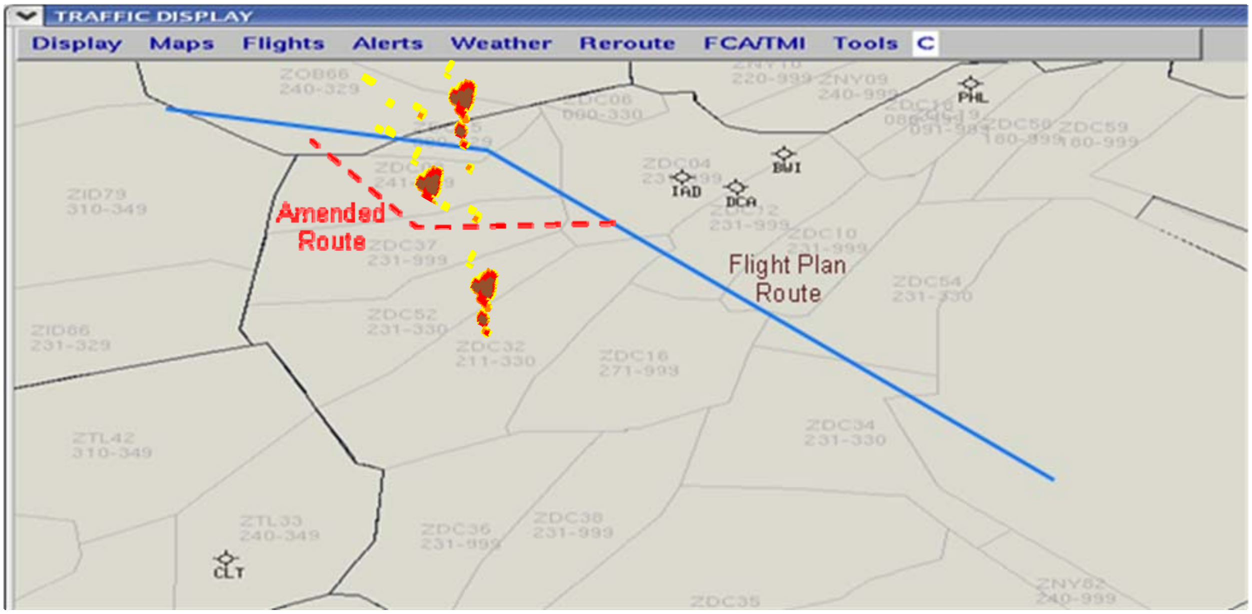


Step 4: ATC DS, integrated with a weather problem detection capability, assesses the pilot data link requested maneuver to identify potential aircraft-to-aircraft conflicts, as well as any aircraft-to-weather problems; a weather problem is found.

Step 5: ATC DS, using a weather problem resolution capability, generates and assesses multiple resolution options and notifies the sector controller of the highest ranked resolutions.

Step 6: The sector controller selects an operationally acceptable weather problem resolution and suggests it to the pilot via data communications.

Step 7: The pilot accepts the controller’s suggested weather problem resolution.



Step 8: The pilot enters the new trajectory into the FMS.

A-1.5.7.5 Controller monitors the traffic on a TFM flow around weather on a day when the convective weather forecast 20-40 minutes out is accurate and the weather is stable, without the need for weather problem detection/resolution decision support

Step 0: The 4-D Wx SAS provides the sector controller and the pilot with a common weather picture. The pilot may also use on-board weather radar, as well as commercially obtained weather forecasts. An aircraft is 10 minutes out from convective weather, which is stable and conforming well to the forecast.

Step 1: The pilot, using available weather information, cognitively determines that his trajectory on the TFM initiated flow is clear of weather.

Step 2: The sector controller monitors aircraft separation and maintains weather situational awareness.

Step 3: The pilot clears the weather and proceeds normally on his flight plan.

A-1.5.7.6 Controller Vectors an Aircraft Around a Convective Weather Cell with an Open-loop Clearance, without the need for automated decision support

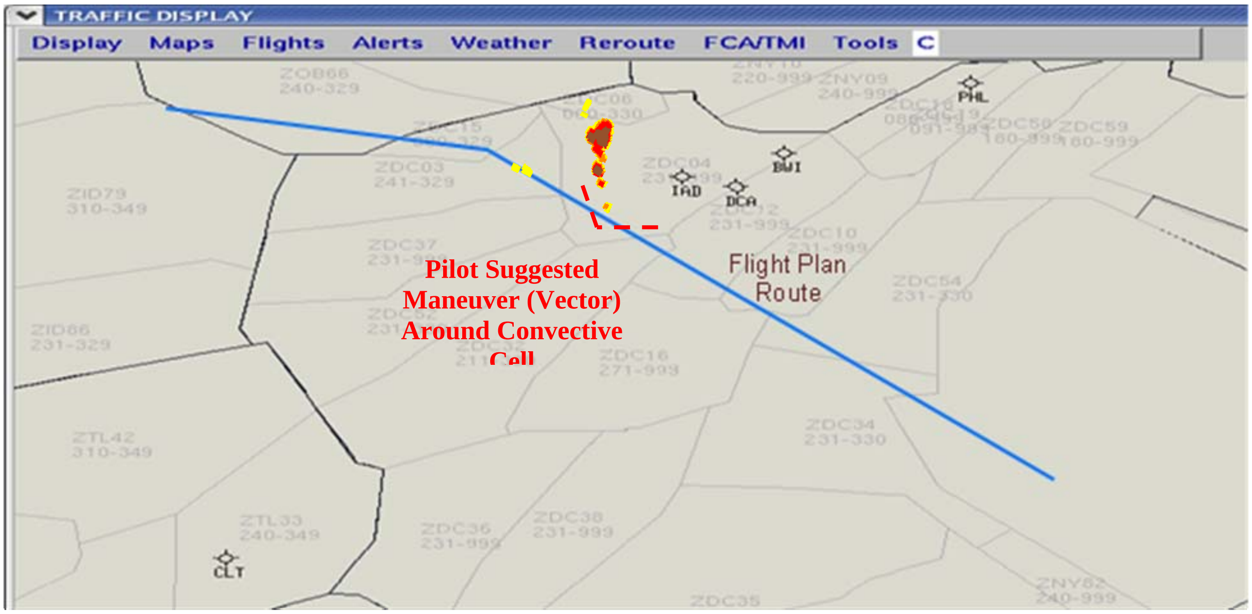
Step 0: The 4-D Wx SAS provides the sector controller and the pilot with a common weather picture. The pilot may also use on-board weather radar, as well as commercially obtained weather forecasts. An aircraft is 10 minutes out from encountering an isolated convective weather cell on its filed flight plan.

Step 1: The pilot cognitively detects the weather problem, using his airborne weather radar, and determines a maneuver option (vector) around the cell.

Step 2: The pilot contacts the sector controller, using voice communications, and requests this maneuver option (vector).

Step 3: The sector controller issues a clearance for the maneuver.

Step 4: Pilot accepts the clearance and executes the maneuver.



A-1.5.8 Mid-term Weather Needs Analysis

Based on the scenarios developed in the previous section, weather needs are analyzed in Table A-1.5.8. The 1st column identifies the weather integration need (i.e., the operational decision that will be supported by a DST), the 2nd column attempts to identify the functional weather needs of that DST, the 3rd column identifies the weather information that will be available in the mid-term (according to current plans), and the 4th column identifies gaps, and the 5th column provides recommendations.

Work on this table has only just begun. The next immediate steps are to focus on and complete columns 2 and 3, so that columns 4 and 5 can be addressed. Please note that in its final form, column 3 will not reference weather 'products', rather it will identify the characteristics of the weather 'information' available in the mid-term. Please note that in its final form, column 3 will not reference weather 'products', rather it will identify the characteristics of the weather 'information' available in the mid-term.

Table A-1.5.8 *Initial Conflict Resolution Advisories* – Mid-term Weather Needs Analysis

Mid-Term Wx Integration Need	**Mid-Term Wx Information Need**	**Mid-Term 4-D Wx Data Cube Capability**	**Mid-Term Wx Information Gap**	**Recommendations**
None - for the aircraft-to-aircraft capability currently described	None	N/A	N/A	N/A
Suggested weather	NextGen shall provide	TBD	TBD	TBD

integration candidate Weather problem detection and resolution including: 1) NextGen shall provide ATC DS to determine the impact of weather (i.e., determine when airspace is useable and by which aircraft classes) based on pilot behavior and deterministic/probabilistic weather forecasts. This translation shall be standardized and use a common weather picture (i.e., 4-D Wx SAS). 2) NextGen shall provide ATC DS (e.g., algorithms) to proactively determine which aircraft have a weather problem. 3) NextGen shall provide ATC DS for weather problem resolution (e.g., algorithms) to generate resolution options around the weather based initially on deterministic weather forecasts (supplemented with other methodologies to address weather uncertainty) and later using probabilistic forecasts. This capability needs to be standardized and must use a common weather picture (i.e., 4-D Wx SAS). 4) NextGen shall provide a weather-related rationale along with clearances.	ATC DS with a convective weather analysis (current time weather) and 10-minute interval forecasts, out to 20 minutes, with an update rate of 5 minutes. NextGen shall provide enhanced convective weather observations (e.g., weather radar mosaic), with improved tops altitude information (e.g., tops at each grid point or multiple tops per polygon) and reduced observation data latency. NextGen shall provide convective weather forecast information that can be readily translated into impact for NextGen en route operations including: • Horizontal extent of the weather • Vertical extent of the weather (e.g., improved tops information) • Weather severity (e.g., Video Integrator and Processor [VIP] Level) • Begin/end time • Storm speed and direction • Standardized weather forecast elements (e.g., map projections, underlying forecast rules, grid projections, hazard levels) NextGen shall provide a net-centric, 4-D Wx SAS of convective weather information (i.e., current and			

	forecast weather) available to all stakeholders. NextGen shall develop methodologies to address ever increasing volumes of data, as weather forecast information content and resolutions increase. For example, improved weather data compression techniques or tailored weather information that more exactly meets the needs of users (e.g., weather along 4-D trajectory). NextGen shall provide a common framework (e.g., reference grid) of convective weather information and other constraints (e.g., environment, security, traffic levels, equipment outages, and military needs), so ATC DS can easily ingest constraint information, translate it into an integrated NAS impact, and proactively and agilely address the resulting impact. NextGen shall (in the mid-term) provide deterministic convective weather area information (also requires adding buffers around weather area or other methodology to allow for forecast uncertainty) and (in the far-term) shall provide probabilistic forecasts. Further forecast improvements to reduce forecast			

	uncertainty shall also be needed. *Accuracy TBD* *Resolution TBD* *Forecast Update Rate TBD* *Latency TBD*			

A-1.6 Flexible Entry Times for Oceanic Tracks (OI-0304, NAS OI-104102)

A-1.6.1 Major Mid-term Goals

The goal of Flexible Entry Times for Oceanic Tracks is to allow greater use of user-preferred trajectories, by looking ahead to plan near-term climbs when loading oceanic tracks.

A-1.6.2 Mid-term Operational Needs/Shortfalls

"The current system optimizes user efficiency subject to constraints of the current system. As fuel costs increase and as traffic increases, constraints need to be removed and traffic flows need to be improved to achieve further efficiencies (e.g., flight efficiency and system performance)." [Initiate TBO Solution Set Smart Sheet, 2008]

A-1.6.3 Mid-term Planned Capabilities

The mid-term capabilities described in Section A-1.6.3.1 are direct quotes from NextGen documents and those in Section A-1.6.3.2 are clarifications developed via the methodology described in Section A-1.1.4. At this point in time, the clarified capabilities in Section A-1.6.3.2 are only assumptions.

A-1.6.3.1 Documented Capabilities

"Flexible entry times into oceanic tracks or flows allow greater use of user-preferred trajectories. Under the Oceanic Trajectory Management Four Dimensional (OTM4D) pre-departure concept, flexible entry times into oceanic tracks allow aircraft to fly minimum time/fuel paths. ANSP automation reviews the request and negotiates adjustments to entry time requests. By incorporating entry optimization algorithms within the request review process, flights trade-off some near-term suboptimal profiles to achieve more optimal oceanic profiles." [Initiate TBO Solution Set Smart Sheet, 2008]

"Oceanic route efficiency is improved through collaborative negotiation of entry times and track loading and oceanic traffic handling is improved through comparison of current routes against desired profiles to identify beneficial control actions. The negotiation for entry times includes looking ahead to plan near-term climbs when loading tracks. Oceanic 4-D profiles of active flights are continually examined to determine control actions that enhance oceanic capacity while providing improved efficiency within traffic flows." [NextGen IWP v1.0, 2008]

A-1.6.3.2 Capabilities Clarified

This concept provides initial profile de-confliction and enhanced sequencing optimization (using wind direction and speed), resulting in flexible (or negotiated) entry times, rather than the current

RTA at oceanic entry points. Airspace users will supply initial optimal trajectories via their submitted flight plans. Analysis tools will use this information to calculate oceanic entry solutions to optimize airspace usage. To arrive at a preferred trajectory, the pilot request will be used to specify an initial flight level. Trajectory planning tools will then be used to match the new request against other planned trajectories to achieve a preferred achievable trajectory.

A-1.6.4 Mid-term Design/Architecture

"Ground-based automation develops trajectory information for each aircraft and determines opportunities for increased efficiencies. Decision support tools help the controllers ensure the accuracy of the trajectories and their implications on traffic and separation. They also help identify suggested control actions to satisfy the requested 4-D trajectory and/or identify the emerging opportunities. Key Enabling Programs include:

- Advanced Technologies and Oceanic Procedures Enhancements (2013-2014)."

[Initiate TBO Solution Set Smart Sheet, 2008]

A-1.6.5 Mid-term Candidate Weather Integration

This OI needs to integrate oceanic wind forecast information with the calculation of flexible entry times for oceanic tracks. During concept development at MITRE/CAASD, it was determined there may be a need for more frequent oceanic weather forecasts, perhaps every 3 hours instead of 6, to support more efficient pre-departure planning for Flexible Entry Times for Oceanic Tracks. Another possible need is for better real-time weather information to the flight crew, possibly from the leading aircraft. These potential weather needs will be further explored in future releases of this document.

A-1.6.6 Linkage to Near- and Far-term

The mid-term OI, Flexible Entry Times for Oceanic Tracks, is a first step towards a full NextGen capability. Table A-1.6.6 describes this initial step, links it back to today's capabilities and commitments, and describes its future evolution. Section A-1.6.7 then develops scenarios, based on this mid-term capability, which are subsequently used in Section A-1.6.8 to assist us in identifying mid-term weather needs.

Table A-1.6.6 ***Flexible Entry Times for Oceanic Tracks*** **– Linkage to Near- and Far-term**
<u>Near –Term</u> a) Oceanic Trajectory Management 4-D Pre-departure Tool Specification
<u>Mid-Term (Transition to NextGen)</u> a) Integrate oceanic wind forecast information with the calculation of flexible entry times for oceanic tracks
<u>Far-Term (Full NextGen)</u> a) OI-0359: *Self-Separation Airspace - Oceanic* b) By breaking this complex implementation into more manageable steps, benefits are realized sooner and implementation risks are reduced.

c) Weather OIs also evolve in the far-term to include:
- NAS OI-103119a: *Full (2016-2025) Integration of Weather Information into NAS Automation and Decision Making*
- NAS OI-103121: *Full (2016-2025) Improved Weather Information and Dissemination*

A-1.6.7 Mid-term Operational Scenarios

This section contains the following scenario:

Calculate flexible entry times for oceanic tracks, using forecasted oceanic winds

A-1.6.7.1 Calculate Flexible Entry Times for Oceanic Tracks, Using Forecasted Oceanic Winds

Step 0: TBD

Step 1: TBD

A-1.6.8 Mid-term Weather Needs Analysis

Based on the scenarios developed in the previous section, weather needs are analyzed in Table A-1.6.8. The 1st column identifies the weather integration need (i.e., the operational decision that will be supported by a DST), the 2nd column attempts to identify the functional weather needs of that DST, the 3rd column identifies the weather information that will be available in the mid-term (according to current plans), and the 4th column identifies gaps, and the 5th column provides recommendations.

Work on this table has only just begun. The next immediate steps are to focus on and complete columns 2 and 3, so that columns 4 and 5 can be addressed. Please note that in its final form, column 3 will not reference weather 'products', rather it will identify the characteristics of the weather 'information' available in the mid-term. Please note that in its final form, column 3 will not reference weather 'products', rather it will identify the characteristics of the weather 'information' available in the mid-term.

Table A-1.6.8 ***Flexible Entry Times for Oceanic Tracks*** – Mid**-term Weather Needs Analysis**

Mid-Term Wx Integration Need	Mid-Term Wx Information Need	Mid-Term 4-D Wx Data Cube Capability	Mid-Term Wx Information Gap	Recommendations
Integrate oceanic wind forecast information with the calculation of flexible entry times for oceanic tracks	Forecasted Oceanic winds, perhaps updated more frequently (e.g., 3 hours). Real-time weather observations, perhaps supplied by lead aircraft. *Accuracy TBD* *Resolution TBD* *Forecast Update Rate*	TBD	TBD	TBD

	TBD *Latency TBD*			

A-1.7 Point-in-Space Metering (NAS OI-104120)

A-1.7.1 Major Mid-term Goals

The goal of Point-in-Space Metering is to provide smooth metering of traffic to a downstream capacity-constrained point by providing an automated sequence of upstream CTAs, at various airspace boundaries along a flight path, to meter traffic rather than imposing Miles-in-Trail (MIT) constraints.

A-1.7.2 Mid-term Operational Needs/Shortfalls

"As air traffic increases, flows into constrained resources must be strategically managed to minimize individual flight as well as system delays. Currently, a common way to do this is by using MIT restrictions. However, MIT restrictions are controller-workload intensive and are often overly restrictive and not integrated. There is a need to manage flows into constrained resources in order to maximize the use of those resources, as well as minimize additional controller workload." [Initiate TBO Solution Set Smart Sheet, 2008]

A-1.7.3 Mid-term Planned Capabilities

The mid-term capabilities described in Section A-1.7.3.1 are direct quotes from NextGen documents and those in Section A-1.7.3.2 are clarifications developed via the methodology described in Section 1.4. At this point in time, the clarified capabilities in Section A-1.7.3.2 are only assumptions.

A-1.7.3.1 Documented Capabilities

"ANSP uses scheduling tools and trajectory-based operations to assure smooth flow of traffic and increase the efficient use of airspace.

Point-in-space metering can be associated with a departure fix, arrival fix, en route airspace volume or boundary, or point-in-space. Decision support tools will allow traffic managers to develop scheduled arrival times for constrained resources and allow controllers to manage aircraft trajectories to meet the scheduled meter times." [Initiate TBO Solution Set Smart Sheet, 2008]

A-1.7.3.2 Capabilities Clarified

This capability allows the ANSP to manage the flow of traffic across multiple sectors to help ensure operational efficiency. Rather than using today's MIT restrictions, the ANSP, supported by decision-support automation, establishes a series of upstream metering points and uses CTAs to smooth out the traffic and establish a uniform flow at the appropriate acceptance rate for a downstream resource. This procedure is transparent to the user; the CTAs are not transmitted to the aircraft but rather are used internally by the ANSP to determine the desired 4-D trajectory of the aircraft, which is then translated into speed clearances and transmitted to the aircraft.

Before this OI capability is applied to the current traffic, C-ATM traffic flow management processes would have been applied to the traffic to ensure that the overall traffic loads are manageable within the acceptance rate of the downstream resource and to facilitate user prioritization of aircraft within the stream for fleet management.

Although it is transparent to the aircraft, this OI represents a significant step toward the ANSP managing traffic by 4-D trajectories, which is a change that must be accomplished before air/ground trajectory negotiation and full trajectory-based operations can be employed.

A-1.7.4 Mid-term Design/Architecture

"Ground-based systems using system-wide shared trajectory-based operations information will create and maintain schedules at metering points and will disseminate the schedules to both air traffic controllers and to flight operators. Decisions need to be made on the allocation of functions among ERAM and Traffic Flow Management System (TFMS). Key Enabling Programs include:

- Traffic Management Advisor – NextGen,
- Key Decision #44 Implementation of Mid-term Traffic Management Advisor (TMA) (2010)
- Traffic Flight Management System Work Package (WP) 1 (2009-2011), and
- En Route Automation Modernization Release 4 (2013-2014)."

[Initiate TBO Solution Set Smart Sheet, 2008]

A-1.7.5 Mid-term Candidate Weather Integration

C-ATM traffic flow management uses strategic weather information to calculate the future acceptance rate at the downstream resource and to route aircraft around major convective weather areas. Once those C-ATM processes are applied, the weather information needed for Point-in-Space Metering would be more tactical in nature, similar to what is described for the High Density Airports time-based metering OI: Time-Based Metering Using RNP and RNAV Route Assignments.

The CTAs generated by Point-in-Space Metering, which are used by the ANSP to provide speed clearances, must reflect what an aircraft can and will actually fly, given the weather conditions along its trajectory. Weather, such as turbulence and winds, impact an aircraft's en route speed.

A-1.7.6 Linkage to Near- and Far-term

The mid-term OI, Point-in-Space Metering, is a first step towards a full NextGen capability. Table A-1.7.6 describes this initial step, links it back to today's capabilities and commitments, and describes its future evolution. Section A-1.7.7 then develops scenarios, based on this mid-term capability, which are subsequently used in Section A-1.7.8 to assist us in identifying mid-term weather needs.

Table A-1.7.6 *Point-in-Space Metering* – Linkage to Near- and Far-term

Near –Term

a) Point-in-Space Metering (TMA En Route) Demonstration

Mid-Term (Transition to NextGen)

a) Weather common situational awareness is available to all aviation stakeholders and automation capabilities (i.e., 4-D Wx SAS).
b) ANSP automation calculates a sequence of ‘attainable’ upstream CTAs for an aircraft, at various airspace boundaries along a flight path, to provide smooth metering of traffic to a downstream capacity-constrained point, taking weather’s impact on aircraft speed into account.
c) ANSP automation calculates the airspeed required to meet the next CTA, using weather impact information (i.e., impact on aircraft ground speed).
d) The ANSP manages the aircraft by issuing speed changes, rather than employing MIT

Far-Term (Full NextGen)

a) OI-0360/NAS OI 104105: A*utomation-Assisted Trajectory Negotiation and Conflict Resolution*
b) OI-0369/NAS OI 104121: *Automated Negotiation/Separation Management*
c) OI-0370: *Trajectory-Based Management – Gate-To-Gate*
d) By breaking this complex implementation into more manageable steps, benefits are realized sooner and implementation risks are reduced.
e) Weather OIs also evolve in the far-term to include:
    - NAS OI-103119a: *Full (2016-2025) Integration of Weather Information into NAS Automation and Decision Making*
    - NAS OI-103121: *Full (2016-2025) Improved Weather Information and Dissemination*

A-1.7.7 Mid-term Operational Scenarios

This section contains the following scenario:

Calculate a sequence of recommended upstream CTAs to a downstream capacity-constrained point, integrating weather and aircraft performance information, and convert these CTAs into desired airspeed changes

A-1.7.7.1 Calculate a Sequence of Recommended Upstream CTAs to a Downstream Capacity-Constrained Point, Integrating Weather and Aircraft Performance Information, and Convert These CTAs into Desired Airspeed Changes

Step 0: Weather information is made available by the NextGen net-centric 4-D Wx Data Cube and its initial 4-D Wx SAS. C-ATM Traffic Flow Management processes are used collaboratively (ANSP, AOC, FOC, and pilot) to determine aircraft’s CTA at a downstream capacity-constrained point.

Step 1: Point-in-Space Metering DS recommends a sequence of CTAs for the aircraft, at various airspace boundaries, to ensure that this aircraft can be smoothly incorporated into the traffic converging on the downstream capacity-constrained point. These CTAs also manage the number of aircraft in each section of airspace over time to stay within traffic density/complexity constraints for current weather conditions. While the downstream CTA will have precise timing and position requirements, these upstream CTAs will probably have less precise timing and lateral position requirements. The Point-in-Space Metering calculations of the upstream CTAs incorporate aircraft performance and weather information that may impact the flight trajectory of the aircraft, such as wind information.

Step 2: As the aircraft flies its route towards the downstream capacity-constrained point and encounters various weather changes (e.g., winds), Point-in-Space Metering DS uses this weather information to calculate the desired airspeed for the aircraft to meet the next CTA in the series and provides recommendations to the ANSP. The ANSP uses this information to manage the aircraft by issuing speed changes.

A-1.7.8 Mid-term Weather Needs Analysis

Based on the scenarios developed in the previous section, weather needs are analyzed in Table A-1.7.8. The 1st column identifies the weather integration need (i.e., the operational decision that will be supported by a DST), the 2nd column attempts to identify the functional weather needs of that DST, the 3rd column identifies the weather information that will be available in the mid-term (according to current plans), and the 4th column identifies gaps, and the 5th column provides recommendations.

Work on this table has only just begun. The next immediate steps are to focus on and complete columns 2 and 3, so that columns 4 and 5 can be addressed. Please note that in its final form, column 3 will not reference weather ‘products’, rather it will identify the characteristics of the weather ‘information’ available in the mid-term. Please note that in its final form, column 3 will not reference weather ‘products’, rather it will identify the characteristics of the weather ‘information’ available in the mid-term.

Table A-1.7.8 *Point-in-Space Metering* – Mid-term Weather Needs Analysis

Mid-Term Wx Integration Need	Mid-Term Wx Information Need	Mid-Term 4-D Wx Data Cube Capability	Mid-Term Wx Information Gap	Recommendations
q) Calculation of a set of ‘attainable’ CTAs to a metering point in en route airspace (e.g., merge point), taking weather’s impact on	Forecasts out ~1 hr: • Winds aloft because of their impact on aircraft speed, with detail particularly near merge points and areas of hard to predict winds near the jet	Winds Aloft • Hi-Res Rapid Refresh (HRRR) a) 3 km horizontal, hourly update, 15 min resolution, Continental United States (CONUS) • Rapid Update	TBD	TBD

aircraft speed and performance into account	stream's edge • In-flight turbulence because of its impact on aircraft performance *Accuracy TBD* *Resolution TBD* *Forecast Update Rate TBD* *Latency TBD*	Cycle (RUC) a) 13 km horizontal, 50 vertical levels, hourly update, 0-12 hr forecasts, CONUS • Weather Research and Forecasting - Rapid Refresh (WRF-RR) Turbulence • Analysis and 1-12hr Graphical Turbulence Guidance (GTG)		

A-1.8 Flexible Airspace Management (OI-0351, NAS OI-108206)

A-1.8.1 Major Mid-term Goals

The goal of Flexible Airspace Management is to allow ANSP automation to support the assessment of alternate configurations; and to reallocate resources, trajectory information, surveillance, and communications information to different positions or different facilities.

A-1.8.2 Mid-term Operational Needs/Shortfalls

"Today's airspace configurations and sector boundaries are pre-determined based on historical flows and pre-defined boundaries. This imposes a capacity constraint on the system during periods of peak demand, airspace use restrictions, and convective weather. Currently, airspace management techniques are implemented by degrees; for example: flight data, other automation functions (e.g., automated handoff), and the controller's map displaying changes when the airspace is reconfigured. In another example, only the map would display changes. Each of these implementations requires adaptation in advance of their use. They will be used to varying degrees by different facilities and individuals, according to standard and/or individual practices." [Initiate TBO Solution Set Smart Sheet, 2008]

A-1.8.3 Mid-term Planned Capabilities

The mid-term capabilities described in Section A-1.8.3.1 are direct quotes from NextGen documents and those in Section A-1.8.3.2 are clarifications developed via the methodology described in Section A-1.1.4. At this point in time, the clarified capabilities in Section A-1.8.3.2 are only assumptions.

A-1.8.3.1 Documented Capabilities

"ANSP automation supports reallocation of trajectory information, surveillance, communications, and display information to different positions or different facilities. The ANSP moves controller capacity to meet demand. Automation enhancements enable increased flexibility to change sector boundaries and airspace volume definitions in accordance with pre-defined configurations. The extent of flexibility has been limited due to limitations of automation, surveillance, and communication capabilities, such as primary and secondary radar coverage, availability of radio frequencies, and ground-communication lines. New automated tools will define and support the assessment of alternate configurations as well as re-mapping of information (e.g., flight and radar) to the appropriate positions." [Initiate TBO Solution Set Smart Sheet, 2008]

A-1.8.3.2 Capabilities Clarified

Automation enhancements enable increased flexibility to change sector boundaries and airspace volume definitions in accordance with pre-defined configurations, as well as allowing assets to be shared across facility boundaries. These flexible configurations would be developed based on historical climate and traffic patterns. Identification of airspace needs and development of a baseline plan for the given flight day would occur 1 to 5 days in advance. The determination of alternative day of flight configurations and the selection of the actual configuration to be employed (along with the timing of the reconfiguration) would be based on predicting weather and traffic demand 1-24 hours out. Configurations should be fairly static. It would not be desirable to change configurations during operations unless something significant is predicted to impact the system (e.g., convective weather moving through an area, large movement of the jet stream, icing). For these occasions, a capability is needed to predict the timing of the triggering event, determine the appropriate change in predefined airspace configuration, and plan accordingly.

There appears to be a significant interaction between the Initiate TBO OI, Flexible Airspace Management, and the Improved C-ATM OI, Continuous Flight Day Evaluation. At this time, it is not clear how the potential weather integration candidate discussed in this section may be distributed across these two OIs. After more discussion, it is entirely possible (all or part of) the weather integration discussed here could be moved over to Continuous Flight Day Evaluation.

A-1.8.4 Mid-term Design/Architecture

"Tools will be developed to define and support the assessment of alternate configurations as well as re-mapping of flight information, radar information, etc., to the appropriate positions. Key Enabling Programs include:

- En Route Automation Modernization Release 3 (2011-2012),
  - Key Decision #43 En Route Automation Modernization Release 3 Package Contents (2009)
- Traffic Flow Management System WP 2 (2011-2016),
- En Route Automation Mid-term WP (2013-2017), and
- National Voice Switch (2013-2015). "

[Initiate TBO Solution Set Smart Sheet, 2008]

A-1.8.5 Mid-term Candidate Weather Integration

Weather integration for Flexible Airspace Management includes:

- Determination of pre-defined airspace configurations, using existing traffic patterns and climatological weather
- Identification of airspace needs and development of a baseline plan for the given flight day, 1 to 5 days in advance, using forecasted weather information
- Establishment of a baseline airspace configuration for the day, 8-24 hours in advance, using forecasted weather information
- Determination of alternative airspace configurations, 4-8 hours in advance, using forecasted weather information
- Selection and implementation of specific alternatives, 1- 4 hours in advance, using forecasted weather information

A-1.8.6 Linkage to Near- and Far-term

The mid-term OI, Flexible Airspace Management, is a first step towards a full NextGen capability. Table A-1.8.6 describes this initial step, links it back to today's capabilities and commitments, and describes its future evolution. Section A-1.8.7 then develops scenarios, based on this mid-term capability, which are subsequently used in Section A-1.8.8 to assist us in identifying mid-term weather needs.

Table A-1.8.6 ***Flexible Airspace Management*** **– Linkage to Near- and Far-term**
<u>Near –Term</u> a) TBD
<u>Mid-Term (Transition to NextGen)</u> a) Weather common situational awareness is available to all aviation stakeholders and automation capabilities (i.e., 4-D Wx SAS). b) En Route airspace designers use existing traffic patterns and climatological weather studies to generate pre-defined airspace configuration c) Traffic management Specialist (TMS), TMC, and Front Line Manager (FLM) identify airspace needs and develop baseline plan for the given flight day 1 to 5 days ahead using forecasted weather information d) TMS, TMC, strategic controller & FLM establish baseline airspace configuration of the day 8-24 hours in advance using forecasted weather information e) Strategic controller & FLM determine alternative airspace configurations 4-8 hours in advance using forecasted weather information f) TMC, strategic controller and FLM select and implement specific alternatives 1- 4 hours in advance using forecasted weather information
<u>Far-Term (Full NextGen)</u>

a) OI-0366: *Dynamic Airspace Performance Designation*
b) By breaking this complex implementation into more manageable steps, benefits are realized sooner and implementation risks are reduced.
c) Weather OIs also evolve in the far-term to include:
   - NAS OI-103119a: *Full (2016-2025) Initial* Integration of Weather Information into NAS Automation and Decision Making
   - NAS OI-103121: *Full (2016-2025) Improved Weather Information and Dissemination*

A-1.8.7 Mid-term Operational Scenarios

This section contains the following four scenarios:

- Identify airspace needs and develop baseline plan for the given flight day, 1 to 5 days in advance, using forecasted weather information
- Establish baseline airspace configuration of the day, 8-24 hours in advance, using forecasted weather information
- Determine alternative airspace configurations, 4-8 hours in advance, using forecasted weather information
- Select and implement specific alternatives, 1- 4 hours in advance, using forecasted weather information

A-1.8.7.1 Identify Airspace Needs and Develop Baseline Plan for the Given Flight Day, 1 to 5 Days in Advance, Using Forecasted Weather Information

Step 0: Months in advance, based on historical traffic patterns and climatological weather, pre-defined routes (including RNAV and RNP routes) and pre-defined airspace configurations are defined, along with rules for their usage. At least 4 weeks in advance of a given flight day, FLM at the facilities establish a first-cut facility staffing schedule.

Step 1: The TMS (1-5 days out) collaborating with TMCs, reviews available flight intent information, historical traffic patterns, controller staffing resources, and long-range forecast weather information to select a baseline configuration.

Step 2: The TMS identifies potential airspace capacity needs where congestion may become a problem (i.e., “Hot spots”).

Step 3: The TMC proposes a first-cut set of RNAV and RNP routes.

Step 4: The above route selection refines the plan for use of Generic Sectors and pre-canned configurations.

Step 5: The FLM establishes a preliminary schedule for configuration changes.

A-1.8.7.2 Establish Baseline Airspace Configuration of the Day, 8-24 Hours in Advance, Using Forecasted Weather Information

Step 0: Days in advance, updated airspace needs are identified and a baseline plan is developed.

Step 1: 8 to 24 hours in advance, and before each shift change, primary responsibility shifts from the Air Traffic Control System Command Center (ATCSCC) to local facilities.

Step 2: The TMS prioritizes the hot spots across the NAS and identifies conditions that warrant alternative “plays”.

Step 3: The Center Team (TMC, strategic controller & FLM), in collaboration with other affected facilities, identifies airspace configurations, and route structures.

Step 4: The Center Team develops a rough schedule for planned transitions in configuration and staffing to move capacity to where it is needed including: designating performance-based access and identifying Special Activity Airspace (SAA) that may need to be traversed.

Step 5: TMCs negotiate use of SAA with appropriate agency.

A-1.8.7.3 Determine Alternative Airspace Configurations, 4-8 Hours in Advance, Using Forecasted Weather Information

Step 0: 8-24 hours out, congestion issues are prioritized and the baseline plan is updated

Step 1: TMCs (4-8 hours out) set up prioritized configuration contingencies (i.e., “watch list”) using the following information: updated flight intent information (including users’ prioritized alternatives), weather information, SAA status, and current and planned Traffic Management initiatives (TMIs). For example: if thunderstorms arrive between 2 and 4 pm, use airspace configuration A, if they arrive after 4 pm, use airspace configuration B, if they move farther north, continue to use current airspace configuration C.

A-1.8.7.4 Select and Implement Specific Alternatives, 1- 4 Hours in Advance, Using Forecasted Weather Information

Step 0: 4-8 hours out, alternative “Plays” are developed, the baseline is fine-tuned, and a “watch list” is created.

Step 1: The FLM and/or sector controller (1-4 hours out) monitor the “watch list”.

Step 2: When “watch list” parameters indicates a change will be required, the TMC, strategic controller and FLM agree on when to transition to the new airspace configuration. The TMC coordinates the change with adjacent facilities.

A-1.8.8 Mid-term Weather Needs Analysis

Based on the scenarios developed in the previous section, weather needs are analyzed in Table A-1.8.8. The 1st column identifies the weather integration need (i.e., the operational decision that will be supported by a DST), the 2nd column attempts to identify the functional weather needs of that DST, the 3rd column identifies the weather information that will be available in the mid-term (according to current plans), and the 4th column identifies gaps, and the 5th column provides recommendations.

Work on this table has only just begun. The next immediate steps are to focus on and complete columns 2 and 3, so that columns 4 and 5 can be addressed. Please note that in its final form, column 3 will not reference weather 'products', rather it will identify the characteristics of the weather 'information' available in the mid-term. Please note that in its final form, column 3 will not reference weather 'products', rather it will identify the characteristics of the weather 'information' available in the mid-term.

Table A-1.8.8 *Flexible Airspace Management* **– Mid-term Weather Needs Analysis**

Mid-Term Wx Integration Need	Mid-Term Wx Information Need	Mid-Term 4-D Wx Data Cube Capability	Mid-Term Wx Information Gap	Recommendations
Determine pre-defined airspace configuration using existing traffic patterns and climatological weather	NAS-wide climatological weather information	No climatological weather information planned for IOC	Gaps • NAS-wide climatological weather information	TBD
Identify airspace needs and develop baseline plan for the given flight day 1 to 5 days ahead using forecasted weather information	Multi-hour forecasts (e.g., 3 hourly) of winds aloft, icing, turbulence and convection 1 to 5 days out *Accuracy TBD* *Resolution TBD*	Currently, no plans for 5 day forecasts of winds aloft, icing, turbulence and convection	Gaps • Multi-hour forecasts (e.g., 3, 6 hourly) of winds aloft, icing, turbulence and convection 1 to 5 days out	TBD
Establish baseline airspace configuration of the day 8-24 hours in advance using forecasted weather information	Hourly forecasts of winds aloft, icing, turbulence and convection 8-24 hours out *Accuracy TBD* *Resolution TBD* *Forecast Update Rate TBD*	Winds Aloft • RUC a) 13 km horizontal, 50 vertical levels, hourly update, 0-12 hr forecasts, CONUS Convection • Corridor Integrated Weather System (CIWS) (0-2 hr) • Consolidated Storm Prediction for Aviation (CoSPA) (2-8 hr) Turbulence • Analysis and 1-12hr GTG	Gaps • 12-24 Turbulence Forecast	TBD

Determine alternative airspace configurations 4-8 hours in advance using forecasted weather information	Hourly forecasts of winds aloft, icing, turbulence and convection 4-8 hours out *Accuracy TBD* *Resolution TBD* *Forecast Update Rate TBD*	Winds Aloft • HRRR a) 3 km horizontal, hourly update, 15 min resolution, CONUS • RUC a) 13 km horizontal, 50 vertical levels, hourly update, 0-12 hr forecasts, CONUS • WRF-RR Convection • CIWS (0-2 hr) • CoSPA (2-8 hr) Turbulence • Analysis and 1-12hr GTG	TBD	TBD
Select and implement specific alternatives 1- 4 hours in advance using forecasted weather information	Hourly forecasts of winds aloft, icing, turbulence and convection 1-4 hours out *Accuracy TBD* *Resolution TBD* *Forecast Update Rate TBD* *Latency TBD*	Winds Aloft • HRRR a) 3 km horizontal, hourly update, 15 min resolution, CONUS • RUC a) 13 km horizontal, 50 vertical levels, hourly update, 0-12 hr forecasts, CONUS • WRF-RR Convection • CIWS (0-2 hr) • CoSPA (2-8 hr) Turbulence • Analysis and 1-12hr GTG	TBD	TBD

A-1.9 Increase Capacity and Efficiency Using Area Navigation (RNAV) and Required Navigational Performance (RNP) (OI-0311, NAS OI-108209)

A-1.9.1 Major Mid-term Goals

The goal of Increase Capacity and Efficiency Using RNAV and RNP is to create more en route structured routes, taking advantage of both RNAV and RNP to enable more efficient aircraft trajectories. RNAV and RNP combined with airspace changes, increase airspace efficiency and capacity.

A-1.9.2 Mid-term Operational Needs/Shortfalls

"Traditional airways are based on a system of routes among ground-based navigational aids (NAVAIDS). These routes require significant separation buffers. The constraint of flying from one navigational aid to another generally increases user distance and time. It can also create choke points and limit access to NAS resources, for example, when severe weather forces the closure of some airport arrival routes. Terminal operations today are also constrained by ground-based arrival and departure procedures and airspace design. This limits terminal ingress/egress and access to and from the overhead streams. Additionally, terminal operations are constrained by terrain, environmental requirements/restrictions, special use airspace, and adjacent airport traffic flows." [Initiate TBO Solution Set Smart Sheet, 2008]

A-1.9.3 Mid-term Planned Capabilities

The mid-term capabilities described in Section A-1.9.3.1 are direct quotes from NextGen documents and those in Section A-1.9.3.2 are clarifications developed via the methodology described in Section A-1.1.4. At this point in time, the clarified capabilities in Section A-1.9.3.2 are only assumptions.

A-1.9.3.1 Documented Capabilities

"Both RNAV and RNP will enable more efficient aircraft trajectories. RNAV and RNP combined with airspace changes, increase airspace efficiency and capacity. RNAV and RNP will permit the flexibility of point-to-point operations and allow for the development of routes, procedures, and approaches that are more efficient and free from the constraints and inefficiencies of the ground-based NAVAIDS. This capability can also be combined with an Instrument Landing System (ILS), to improve the transition onto an ILS final approach and to provide a guided missed approach. Consequently, RNAV and RNP will enable safe and efficient procedures and airspace that address the complexities of the terminal operation through repeatable and predictable navigation. These will include the ability to implement curved path procedures that can address terrain, and noise-sensitive and/or special-use airspace. Terminal and en route procedures will be designed for more efficient spacing and will address complex operations." [Initiate TBO Solution Set Smart Sheet, 2008]

"Performance-based RNAV and RNP will help to increase access and options for airport utilization as well as reduce overall environmental impact by addressing noise, emissions and fuel use in the development and use of routes and procedures." [NextGen IWP v1.0, 2008]

A-1.9.3.2 Capabilities Clarified

RNAV capability allows an aircraft to fly directly point-to-point rather than following the inefficient zig-zag fixed route structure based on ground-based NAVAIDS, resulting in distance, time and cost saving for the aircraft. RNP capability allows aircraft to fly the RNAV route with a defined level of precision. Currently, only lateral (or cross track) precision is defined and implemented, and is referred to as 2D RNP. To support full 4-D TBO, 3-D RNP including altitude, and 4-D RNP including both altitude and timing (or along track) conformance bounds will be developed. The combination of RNAV and RNP (also referred to as Performance-Based Navigation) allows more routes to be defined for a given airspace because the separation buffers between routes can safely be reduced, resulting in greater capacity or throughput. The capability defined in this section appears to refer to 2D RNP for en-route airspace.

RNAV/RNP capability is already implemented in some busy en-route airspace as "Q Routes" and in terminal airspace as "T Routes". Most air transport category aircraft are already RNAV equipped, and many have the RNP 2 or (RNAV 2) capability required to fly these routes. As noted in Section A-1.9.3.1, airspace design changes are needed in addition to aircraft capabilities to implement RNAV/RNP, and this appears to be the focus of this capability.

In the mid-term (2018) RNAV/RNP routes would still be fixed, and would not have the capability to be moved to avoid en-route convective weather, so mid-term weather integration needs would include determining whether a particular route would be available (i.e., free of hazardous weather).

A-1.9.4 Mid-term Design/Architecture

"RNAV will be implemented at and above flight level 180 by the end of the mid-term. RNP-2 will be implemented at and above flight level 290 by the end of the mid-term. A decision on mandating these capabilities will be made in the near-term. [Initiate TBO Solution Set Smart Sheet, 2008]

Key Enabling Programs include:

- En Route Automation Modernization Release 2 (2010-2011) and
- En Route Automation Modernization Release 3 (2011-2012)
  - Key Decision #43 En Route Automation Modernization Release 3 Package Contents (2009) " [Initiate TBO Solution Set Smart Sheet (2008)]

A-1.9.5 Mid-term Candidate Weather Integration

Identify whether fixed RNAV/RNP routes are or soon will be blocked by convective weather.

A-1.9.6 Linkage to Near- and Far-term

The mid-term OI, Increase Capacity and Efficiency Using RNAV and RNP, is a first step towards a full NextGen capability. Table A-1.9.6 describes this initial step, links it back to today's capabilities and commitments, and describes its future evolution. Section A-1.9.7 then develops scenarios, based on this mid-term capability, which are subsequently used in Section A-1.9.8 to assist us in identifying mid-term weather needs.

Table A-1.9.6 ***Increase Capacity and Efficiency Using RNAV and RNP*** – **Linkage to Near- and Far-term**
Near –Term a) TBD

<u>Mid-Term (Transition to NextGen)</u>

a) Identify whether fixed RNAV/RNP routes are or soon will be blocked by convective weather

<u>Far-Term (Full NextGen)</u>

a) OI-0338: *Efficient Metroplex Merging and Spacing (assuming RNAV)*
b) By breaking this complex implementation into more manageable steps, benefits are realized sooner and implementation risks are reduced.
c) Weather OIs also evolve in the far-term to include:
   - NAS OI-103119a: *Full (2016-2025) Initial Integration of Weather Information into NAS Automation and Decision Making*
   - NAS OI-103121: *Full (2016-2025) Improved Weather Information and Dissemination*

A-1.9.7 Mid-term Operational Scenarios

This section contains the following scenario:

- Use weather information to determine availability of predefined RNAV/RNP routes

A-1.9.7.1 Use Weather Information to Determine Availability of Predefined RNAV/RNP Routes

Step 0: Weather information is made available by the NextGen net-centric 4-D Wx Data Cube and its initial 4-D Wx SAS. A network of RNAV and RNP routes has been predefined for high density en route airspace. These RNP/RNAV routes are not limited to aligning with ground-based NAVAIDS. The RNP routes can be spaced more closely than today's airways because the aircraft flying on them are constrained to tighter RNP.

Step 1: Increase Capacity and Efficiency Using RNAV and RNP DS identifies whether the predefined RNAV/RNP routes are or soon will be blocked by convective weather and provides a route blockage advisory to the ANSP. En route ANSP managing high-density traffic assigns each aircraft to a structured airway. ANSP accesses information on equipage levels for each aircraft from its flight plan, assigning properly equipped aircraft to RNAV or RNP routes. Aircraft flying on an RNP route are issued an RNP constraint.

Step 2: Aircraft follow assigned structured routes. The use of these additional routes enables higher airspace capacity and the RNP/RNAV routes may involve less distance flown and hence more fuel efficient for users.

A-1.9.8 Mid-term Weather Needs Analysis

Based on the scenarios developed in the previous section, weather needs are analyzed in Table A-1.9.8. The 1st column identifies the weather integration need (i.e., the operational decision that will be supported by a DST), the 2nd column attempts to identify the functional weather needs of that DST, the 3rd column identifies the weather information that will be available in the mid-term (according to current plans), and the 4th column identifies gaps, and the 5th column provides recommendations.

Work on this table has only just begun. The next immediate steps are to focus on and complete columns 2 and 3, so that columns 4 and 5 can be addressed. Please note that in its final form, column 3 will not reference weather 'products', rather it will identify the characteristics of the weather 'information' available in the mid-term. Please note that in its final form, column 3 will not reference weather 'products', rather it will identify the characteristics of the weather 'information' available in the mid-term.

Table A-1.9.8 *Increase Capacity and Efficiency Using RNAV and RNP* – Mid-term Weather Needs Analysis

Mid-Term Wx Integration Need	Mid-Term Wx Information Need	Mid-Term 4-D Wx Data Cube Capability	Mid-Term Wx Information Gap	Recommendations
TBD	TBD	TBD	TBD	TBD

A-1.10 Findings, Conclusions, and Recommendations

Much analysis and discussion are required before a final set of mid-term, Initiate TBO, weather integration candidates can be identified. From among the 'potential' weather integration candidates listed below, some may be incorporated into TBO ConOps documents, forming the basis for NextGen weather integration requirements.

A-1.10.1 Findings

To-date, the following mid-term, Initiate TBO, weather-related, operational capabilities have been identified as 'potential' candidates for inclusion into DSTs.

Initial Conflict Resolution Advisories

- Controller weather problem detection decision support to:
  - Prevent directing aircraft into hazardous weather inadvertently when resolving aircraft-to-aircraft conflicts
  - Evaluate a pilot requested maneuver around the weather to ensure it will not send the aircraft into another area of convection not yet visible on the aircraft's airborne radar
- Controller weather problem resolution decision support to respond to pilot requests for assistance to:
  - Route around significant areas of convective weather that are rapidly and unexpectedly worsening
  - Return aircraft to original flight plan when convective weather rapidly and unexpectedly improves

Flexible Entry Times for Oceanic Tracks

- Integrate oceanic wind forecast information with the calculation of flexible entry times for oceanic tracks

Point-in-Space Metering

- Calculation of a sequence of recommended upstream CTAs to a downstream capacity-constrained point, integrating weather and aircraft performance information, and conversion of these CTAs into desired airspeed changes

Flexible Airspace Management

- Determination of pre-defined airspace configurations, using existing traffic patterns and climatological weather
- Identification of airspace needs and development of a baseline plan for the given flight day, 1 to 5 days ahead, using forecasted weather information
- Establishment of a baseline airspace configuration for the day, 8-24 hours in advance, using forecasted weather information
- Determination of alternative airspace configurations, 4-8 hours in advance, using forecasted weather information
- Selection and implementation of specific airspace configuration alternatives, 1- 4 hours in advance, using forecasted weather information

Increase Capacity and Efficiency Using Area Navigation (RNAV) and Required Navigational Performance (RNP)

- Determination of whether fixed RNAV/RNP routes are or soon will be blocked by convective weather

Additionally, the following mid-term, en route TBO, weather-related, operational decisions have been identified as 'potential' candidates for common weather situational awareness among decision makers:

Delegated Responsibility for Separation

- Delegated responsibility for pair-wise separation in convective weather (i.e., aircraft following a 'pathfinder')

Initial Conflict Resolution Advisories

- Controller vectors an aircraft around a convective weather cell with an open-loop clearance

A-1.10.2 Conclusions

The authors of this document need to perform more analysis and receive more feedback on this initial version, before conclusions can be reached.

A-1.10.3 Recommendations

The authors of this document need to perform more analysis and receive more feedback on this initial version, before recommendations can be made.

A-2. Increase Arrivals/Departures at High Density Airports

A-2.1 Introduction

This Section is a work in-progress intended to help communicate and refine the developing mid-term weather integration story for the Increase Arrivals/Departures at High Density Airport solution set. Mid-term Operational Improvement (OI) descriptions, contained in this section, go somewhat beyond what current NextGen and Federal Aviation Administration (FAA) documentation provide. The reason for this is to develop a more complete understanding of these OIs, so mid-term weather integration candidates can be more easily identified. The mechanism used to arrive at these extended descriptions is documented in Section A-2.1.4. Although these extensions to mid-term capability descriptions have not yet received review and vetting, this paper provides a vehicle by which these 'assumptions' can obtain needed feedback, thereby furthering our understanding of mid-term OIs. These mid-term OIs begin the journey towards a full NextGen capability. This document describes these initial steps and their future evolution.

Graphics in this paper are sourced from the Increase Arrivals/Departures at High-Density Airports solution set smart sheet, as well as the Terminal Airspace Reconfiguration scenarios developed by MITRE's Center for Advanced Aviation System Development (CAASD), as a product of the FAA's Implementation and Integration (I&I) team.

A-2.1.1 Purpose

The purpose of this paper is to support drafting of the Joint Planning and Development Office's (JPDO) Air Traffic Management (ATM) Weather Integration Plan by:

- Identifying and describing likely high density airport weather integration opportunities based on the mid-term OIs contained in the Increase Arrivals/Departures at High Density Airports solution set and
- Developing weather integration scenarios to help identify mid-term functional weather requirements.

This section may also be useful in supporting other activities such as the:

- Refinement of OI descriptions in the Increase Arrivals/Departures at High Density Airports solution set,
- Scenario development by the FAA I&I team,
- Drafting of high density airport white papers by the JPDO's Air Navigation Services (ANS) Working Group (WG), and
- Drafting of Increase Arrivals/Departures at High Density Airports Concept of Operations (ConOps) and Concept of Use (ConUse) documents.

A-2.1.2 Background

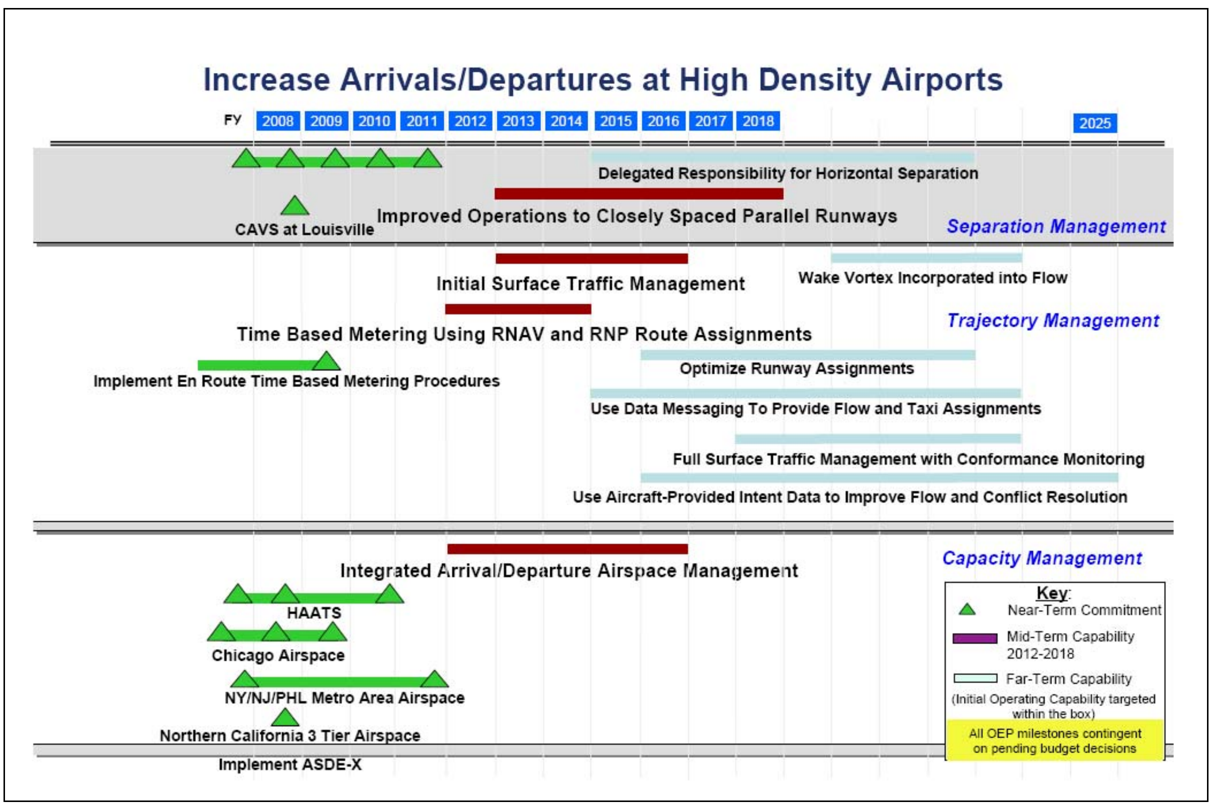
"The Increase Arrivals/Departures at High-Density Airports solution set involves airports (and the airspaces that access those airports) in which:

- Demand for runway capacity is high,
- There are multiple runways with both airspace and taxiing interactions, or
- There are close-proximity airports with the potential for airspace or approach interference.

The above defined airports require all the capabilities of the flexible terminals and airspace plus integrated tactical and strategic flow capabilities. They may require higher performance navigation and communications capabilities for ANS providers and the aircraft to support these additional operational requirements." [Increase Arrivals/ Departures at High-Density Airports Solution Set Smart Sheet, 2008]

The OIs of interest for this white paper are listed here and appear in the Increase Arrivals/ Departures at High-Density Airports roadmap figure below:

- Integrated Arrival/Departure Airspace Management
- Time-Based Metering Using RNAV and RNP Route Assignments
- Improved Operations to Closely Spaced Parallel Runways
- Initial Surface Traffic Management



A-2.1.3 Definitions

This section defines key processes and terms used in this paper.

Processes

- Identification of candidate weather integration into Decision Support Tools (DST) involves linking an aviation decision making process, algorithm, or decision aid with an operational need for weather information, for example:
  - Operational air traffic recommendations such as airport configuration change options are associated with changing weather conditions (e.g., wind shifts),
  - Calculations such as trajectory estimation need to incorporate the impacts of weather on flight performance and speed,
  - Airspace and airport capacity prediction are impacted by both severe and routine weather (e.g., thunderstorms, obstructions to vision, winds), and
  - Visual aids to decision making such as traffic displays require weather information be overlaid to identify constraints to flights and traffic flows.
- Description of candidate weather integration goes on to describe in more detail the role weather plays in these decisions, for example:
  - From historical Aviation System Performance Metrics (ASPM) data, empirical analysis can identify weather-parameter thresholds (e.g., winds) that identify historical runway configuration usage. These thresholds can then be used by DST algorithms to identify and recommend operational runway configurations based on current weather conditions;
  - Integration of weather information into sophisticated trajectory estimation algorithms can be used to recommend a Controlled Time of Arrival (CTA) to a metering fix in support of high density airport operations:

    Detailed “Big Airspace” terminal wind fields (particularly near merge points and the jet stream’s edge),

    Temperature and barometric pressure profiles (used to calculate geometric altitude), and

    Icing and turbulence (because of their impact on aircraft performance).

Terms

- **4-Dimensional (4-D) Weather (Wx) Single Authoritative Source (SAS)** is one or more 4-D grid(s) of the ‘best’ representation of ATM aviation-specific observations, analyses, and forecasts (including probability) and climatology organized by 3-dimensional (3-D) spatial and time components (x, y, z, t) that supports NextGen ATM aviation decision making.
- **4-D Wx Data Cube** is a 4-D grid of aviation-specific weather observations, analyses, and forecasts organized by 3-D spatial and time components (x, y, z, and t). The data in the cube is used to develop the 4-D Wx SAS that supports NextGen air traffic management decision making. The 4-D Wx Data Cube is the distributed collection of

all relevant aviation weather information formed from the merger of observations, automated gridded products, models, climatological data, and human forecasters input from both public and private sources. The production of the 4-D Wx Data Cube, and its utilization by National Airspace System (NAS) users' applications in an integrated, operational manner, is the essence of NextGen weather capabilities.

A-2.1.4 Methodology

In order for the JPDO to identify and describe potential candidates for mid-term weather integration into DSTs, it is essential that the corresponding OIs are first clearly and thoroughly understood. Therefore, the first step in ATM-weather integration planning is to study the descriptions of the four Increase Arrivals/Departures at High Density Airports mid-term OIs listed in Section A-2.1.2. Our examination found these descriptions did not provide sufficient detail to support our purpose. Additionally, we found instances in which the descriptions were somewhat ambiguous and/or confusing. A subsequent review of a broad range of NextGen documentation added little to our knowledge of these four OIs. It should be noted that later this year the JPDO ANS WG may draft white papers for their mid-term OIs in the Trajectory Based Operations (TBO), Increase Arrivals/Departures at High Density Airports, Flexible Terminal, and Collaborative-ATM (C-ATM) solution sets. This would probably provide the JPDO ATM-weather integration team with the correct level of understanding of the Increase Arrivals/ Departures at High Density Airport mid-term OIs, but it would come too late to meet our work schedule (i.e., v1.0 by September 30, 2009). Having discovered the information we require to perform our task did not yet exist, we set out to expand upon our understanding of the existing OI descriptions through discussions with high density airport Subject Matter Experts (SME). Our first step was to form a discussion group of these SME to clarify and extend our understanding of the Increase Arrivals/Departures at High Density Airport mid-term OIs. This group included: key JPDO ANS and Weather WG members, JPDO ATM Weather Integration Plan writing staff, the coordinator of the Increase Arrivals/Departures at High-Density Airports solution set, ATO-T (both headquarters and operations), and MITRE staff developing scenarios for the FAA I&I team. Over several months, we discussed each of the four mid-term Increase Arrivals/Departures at High Density Airports OIs to enhance the OI descriptions to a point where weather-related decisions became more obvious, and we could proceed to identify and describe weather integration candidates.

A-2.1.5 Outline

SectionsA-2. 2 through A-2.5 apply this methodology to each of the four mid-term OIs listed above for the Increase Arrivals/Departures at High-Density Airports solution set. These sections document OI goals, needs/shortfalls, descriptions, and design/architecture; develop assumptions as to what these OIs really intend; identify and describe 'potential' candidates for weather integration; develop scenarios; and identify weather needs. Section 6 provides weather integration findings, conclusions and recommendations across the Increase Arrivals/Departures at High Density Airport solution set.

A-2.2 Integrated Arrival/Departure Airspace Management (OI-0307, OI-104122)

A-2.2.1 Major Mid-term Goals

Support optimal terminal area configuration management by tailoring capacity to meet demand, managing delay, giving consideration to environmental factors, and better addressing metroplex inter-dependencies.

A-2.2.2 Mid-term Operational Needs/Shortfalls

"Current airspace structure in high-density terminal areas is complex and inefficient and does not provide the structure to support the demands for increased capacity. Complexity is created by the closeness and interaction between arrival/departure flow of several major airports, satellite airports, and over flight flow." [Increase Arrivals/ Departures at High-Density Airports Solution Set Smart Sheet, 2008]

A-2.2.3 Mid-term Planned Capabilities

The mid-term capabilities described in Section A-2.2.3.1 are direct quotes from NextGen documents and those in Section A-2.2.3.2 are clarifications developed via the methodology described in Section 1.4. At this point in time, the clarified capabilities in Section A-2.2.3.2 are only assumptions.

A-2.2.3.1 Documented Capabilities

"New airspace design takes advantage of expanded use of terminal procedures and separation standards. This is particularly applicable in major metropolitan areas supporting multiple high-volume airports. This increases aircraft flow and introduces additional routes and flexibility to reduce delays. Air Navigation Service Provider (ANSP) DSTs are instrumental in scheduling and staging arrivals and departures based on airport demand, aircraft capabilities, and gate assignments. This capability expands the use of terminal separation standards and procedures (e.g., 3 nm, degrees divergence, and visual separation) within the newly defined transition airspace. It extends further into current en route airspace (horizontally and vertically). A redesign of the airspace will permit a greater number of Area Navigation (RNAV) and Required Navigation Performance (RNP) procedures within the transition airspace to allow for increased throughput." [NextGen Integrated Work Plan (IWP) v1.0, 2008]

"Departure performance will be improved by implementing multiple precise departure paths from each runway end. This will allow each departing aircraft to be placed on its own, separate path, keeping the aircraft safely separated from other aircraft and wake vortices. These multiple paths also will be an important aid to circumnavigating thunderstorms and other severe weather in the airport vicinity. Precise departure paths will optimize system operations for entire metropolitan areas, reducing delays by allowing each airport to operate more independently. This will provide for better balance of arrivals and departure flow to airports within close proximity. These precise departures can also be designed to support airports that are now limited by terrain and other obstacles or during periods of reduced visibility. Precise paths will reduce flight time, fuel burn and emissions. They may also decrease the impact of aircraft noise to surrounding communities.

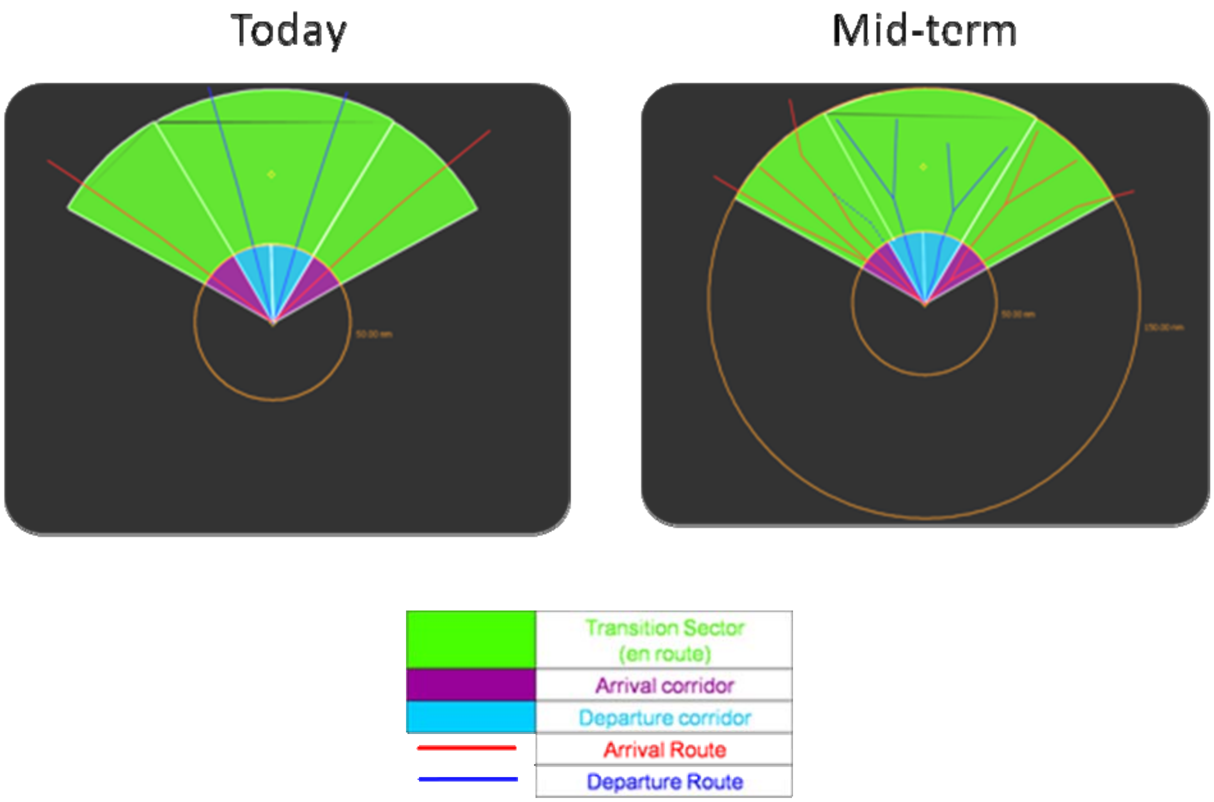
Enhanced traffic management tools will analyze flights approaching an airport from hundreds of miles away, across the facility boundaries that limit the capability today, and will calculate scheduled arrival times to maximize arrival capacity. This will provide controllers with automated information on airport arrival demand and available capacity to improve sequencing and better balance arrival and departure rates. With the improved precision of NextGen systems, separation between aircraft can be safely reduced. This will allow for more efficient transitions to the approach phase of flight to high density airports because controllers will have access to more usable airspace. Therefore, descending aircraft can be managed as a unified operation and the airspace can be structured to have multiple precision paths that maintain individual flows to each runway.

Today, the structure of arrival and departure routes does not allow for the most efficient use of the airspace. By redesigning airspace, precision 3-D paths can be used in combination to provide integrated arrival and departure operations. More importantly, this more flexible airspace will give controllers better options to safely manage departure and arrival operations during adverse weather, restoring capacity that is currently lost in inclement conditions. Poor visibility conditions dramatically reduce capacity for closely spaced runways. These capacity losses ripple as delays throughout the system. NextGen capabilities will allow us to continue using those runways safely by providing precise path assignments and appropriate safe separation between aircraft assigned on parallel paths, restoring capacity and reducing delays throughout the NAS." [NextGen Implementation Plan (NGIP), 2009]

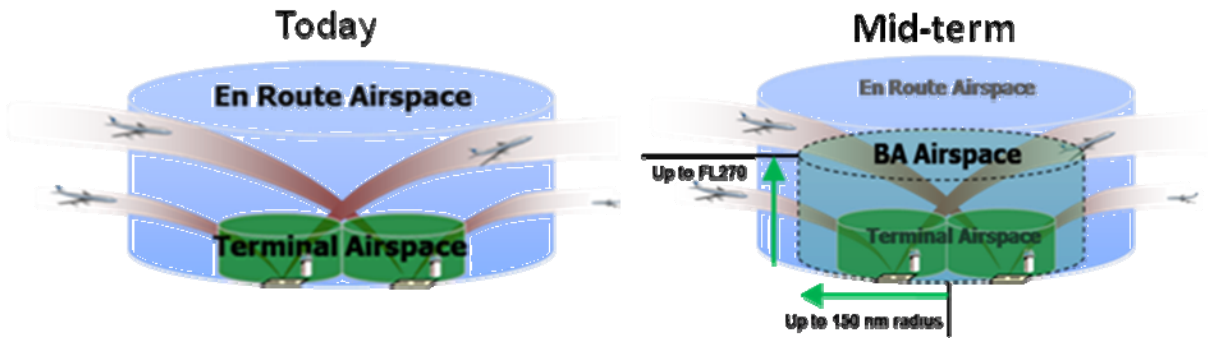
A-2.2.3.2 Capabilities Clarified

Mid-term capabilities for Integrated Arrival/Departure Airspace Management operations may include:

- Increased number and complexity of static arrival and departure configurations supported by Decision Support (DS) automation (see figure below) including:
  - More diverse configurations
  - RNP routes closer to one another allowing additional static arrival and departure routes
  - More complex merging
  - Bi-directional routes (180 degree switching of routes between configurations)
- More timely arrival/departure configuration changes, using weather information to better predict the timing of such changes



- Extension, further into today's en route airspace, of terminal procedures and separation standards (e.g., 3 nautical mile separation, visual separation), allowing for more efficient use of airspace to support higher capacity flows of traffic into high-density airports. The Figure below depicts this Big Airspace (BA) concept.
  - The 3 nautical mile spacing reference may involve separation between aircraft merging into one or more streams before they reach the merge point or separation between streams of aircraft; this would require sophisticated DS automation and use of Required Time of Arrival (RTAs)/CTAs, rather than vectoring for spacing
  - The visual separation reference relates to the NextGen goal to augment/replace visual separation with airborne separation maneuvers (based on Automatic Dependent Surveillance – Broadcast mode [ADS-B] signals), including Cockpit Display of Traffic Information (CDTI) Assisted Visual Separation (CAVS) that enable aircraft briefly passing through a thin cloud layer to maintain visual separation augmented by CDTI



A-2.2.4 Mid-term Design/Architecture

"The integrated arrival/departure airspace structure and supporting infrastructure is primarily applicable to high-density, complex metropolitan areas. RNAV-equipped aircraft and trained crew and controllers (on new RNAV procedures) are essential. In order to take full advantage of these capabilities and to increase flexibility over time, terminal separation procedures are linked to a required surveillance performance for the positional information, rather than an equipment-specific requirement. Key enabling programs include:

- En Route Automation Modernization (ERAM) Release 3 (2011-2012) and
- Traffic Management Advisor (TMA) Upgrades (2008-2011)."

[Increase Arrivals/ Departures at High-Density Airports Solution Set Smart Sheet, 2008]

A-2.2.5 Mid-term Candidate Weather Integration

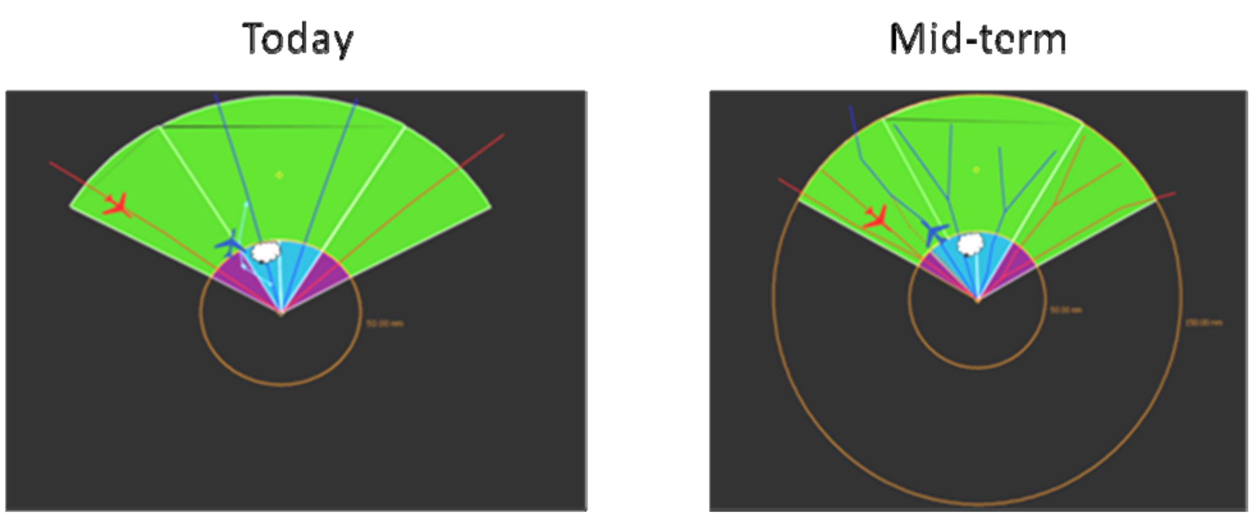
Integrated Arrival/Departure Airspace Management retrieves/subscribes to updates of weather information to support planning/re-planning. In particular, the 4-D Wx Data Cube and the 4-D Wx SAS support enhanced volumetric extractions, by time frame of interest, of weather information to quickly filter the enhanced weather content to the region of interest for impact analysis. Subscriptions provide weather information updates, when Integrated Arrival/Departure Airspace Management provided weather parameter thresholds are met.

Integration of weather information into Integrated Arrival/Departure Airspace Management may be both tactical and strategic. From a strategic standpoint, Integrated Arrival/Departure Airspace Management may support/recommend an optimal airport configuration plan for the flight day plus one or 2 alternates, from among the increased number and complexity of mid-term arrival/departure configurations, based on an analysis of

- Traffic density,
- Performance capabilities of the aircraft types involved,
- Environmental considerations in effect, plus
- Numerous weather factors at various points around the airport, including terminal area winds, winds aloft, convection, and ceiling/visibility.

Weather conditions, whether they are adverse or routine, always are a major factor in the selection of an optimal arrival/departure configuration. From a tactical perspective, Integrated Arrival/Departure Airspace Management receives weather information updates, from the 4-D Wx Data Cube when weather parameter thresholds are reached, so it can continually evaluate the timing of upcoming meteorological conditions (e.g., wind shifts, ceiling and visibility) to better predict when a change in arrival/departure configuration would be required. Integrated Arrival/Departure Airspace Management works closely with Initial Surface Traffic Management, which is responsible for airport configuration changes. Similarly, Integrated Arrival/Departure Airspace Management may also monitor rapidly changing and highly localized weather conditions (e.g., pop-up thunderstorms on arrival/departure routes) to determine when an arrival/departure configuration needs to be dynamically altered (e.g., routing an arrival route around a weather cell).

The figures below represent the difference between today's and the mid-term's arrival/departure configurations. The rings represent the mid-term's expansion of terminal separation standards and procedures usage into today's en route airspace (e.g., from 50 nm today, out to 150 nm in the mid-term). The figure below and to the left demonstrates that today there is limited maneuverability and route flexibility due to airspace constraints, requiring significant coordination when airport arrival/departure configuration or tactical maneuvers occur (e.g., maneuvering into adjacent terminal areas of control to avoid a pop-up thunderstorm). The figure below and to the right demonstrates the improved mid-term flexibility of airspace, resulting from expansion of terminal separation standards and procedures farther into today's en route airspace and an increased number and complexity of arrival/departure configurations (including 180 degree switching of predefined bidirectional routes).



A-2.2.6 Linkage to Near- and Far-term

The mid-term OI, Integrated Arrival/Departure Airspace Management, is a first step towards a full NextGen capability. Table A-2.2.6 describes this initial step, links it back to today's capabilities and commitments, and describes its future evolution. Section A-2.2.7 then develops scenarios, based on this mid-term capability, which are subsequently used in Section A-2.2.8 to assist us in identifying mid-term weather needs.

Table A-2.2.6 Integrated Arrival/Departure Airspace Management – Linkage to Near- and Far-term

<u>Near –Term</u>

a) There is no common weather picture available to all users, weather information is gathered from multiple sources and individual ANSP perceptions are used to determine the "best source".
b) The number and complexity of static arrival/departure configuration options is limited.
c) Configuring the airport is reactive and the selection of an optimal configuration is a manual process, with weather impact cognitively determined.
d) ANSPs have little DS capability to assist in airport configuration changes.

<u>Mid-Term (Transition to NextGen)</u>

a) Weather common situational awareness is available to all aviation stakeholders and automation capabilities (i.e., 4-D Wx SAS).
b) Terminal airspace designers use climatological studies to generate additional, more complex, static arrival/departure configurations.
c) DS supports/recommends an optimal day of flight arrival/departure configuration plus one or 2 alternates, based on a rules based examination of traffic density, performance capabilities of associated aircraft types, environmental considerations in effect, plus numerous weather factors at various points around the airport, including terminal area winds, winds aloft, convection, and ceiling/visibility. Then, the Traffic Management Coordinator (TMC), collaborating with the facility supervisor, selects an arrival/departure configuration. This capability is closely coordinated with *Initial Surface Traffic Management*, which is responsible for establishing the baseline airport configuration for the day of flight.
d) DS supports/recommends when major changes to the arrival/departure configuration may be needed (e.g., after an examination of wind shift timing information) and proceeds to make recommendations as described in item c above. This capability is closely coordinated with *Initial Surface Traffic Management*, which is responsible for airport configuration changes.
e) DS supports/recommends a modified arrival/departure configuration plus one or 2 alternates to avoid hazardous weather, based on a rules based examination of traffic density, performance capabilities of associated aircraft types, environmental considerations in effect, plus numerous weather factors at various points around the airport, including terminal area winds, winds aloft, convection, ceiling/visibility, as well as rapidly changing and highly localized weather conditions (e.g., pop-up thunderstorms on arrival/departure routes). Then, the TMC, collaborating with the facility supervisor, selects a modified arrival/departure configuration.
f) *Integrated Arrival/Departure Airspace Management* needs to be integrated with

Initial Surface Traffic Management to coordinate airport and arrival/departure configurations.

Far-Term (Full NextGen)

a) The mid-term's *Integrated Arrival/Departure Airspace Management* is the first of three steps leading to the full NextGen arrival/departure airspace management capability; the two remaining steps, which involve integration with other OIs, are listed below:

   Integration with Other Capabilities

   a. OI-0331: *Integrated Arrival/Departure and Surface Operations*
   b. OI-0339: *Integrated Arrival/Departure and Surface Traffic Management for Metroplex*

b) By breaking this complex implementation into more manageable steps, benefits are realized sooner and implementation risks are reduced.

c) Weather OIs also evolve in the far-term to include:

   a. OI-103119a: *Full (2016-2025) Initial Integration of Weather Information into NAS Automation and Decision Making*
   b. OI-103121: *Full (2016-2025) Improved Weather Information and Dissemination*

A-2.2.7 Mid-term Operational Scenarios

This section contains the following three scenarios:

- Baseline (strategic) arrival/departure configuration plan for the flight day, using weather forecasts
- Proactive change in arrival/departure configuration due to forecasted wind shift, and
- Reactive arrival/departure configuration changes due to pop-up weather.

A-2.2.7.1 Baseline (strategic) Arrival/Departure Configuration Plan for the Flight Day, Using Weather Forecasts

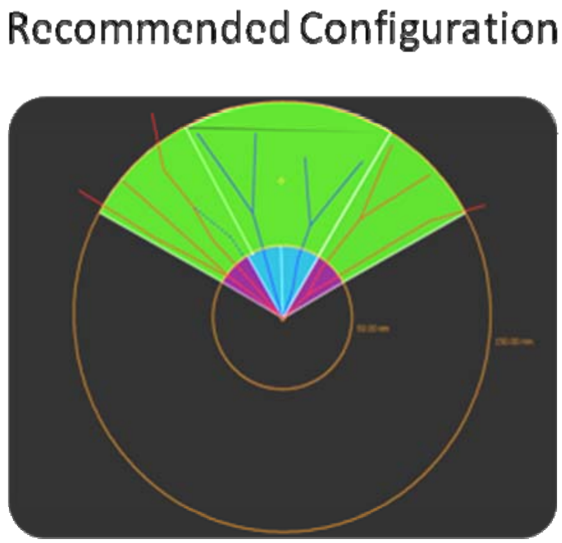
Step 0: Weather information is made available by the 4-D Wx Data Cube and its initial 4-D Wx SAS. DS subscribes to the weather information needed to plan the arrival/departure configuration for the flight day. DS also obtains information concerning traffic density, the performance capabilities of associated aircraft types, as well as environmental considerations in effect. Initial Surface Traffic Management has already supported the determination of the airport configuration for the flight day.

Step 1: DS assists with the development of or recommends an optimal arrival/departure configuration, plus one or 2 alternates, from among the increased number and complexity of predefined arrival/departure configurations. DS bases this recommendation on an analysis of traffic density, the performance capabilities of associated aircraft types, environmental considerations in effect, plus numerous weather factors at various points around the airport, including terminal area winds, winds aloft, convection, and ceiling/visibility.

Step 2: The arrival/departure configurations are coordinated within the facility, with NAS users, and with adjacent facilities, as necessary.

Step 3: The TMC, collaborating with the facility supervisor and guided by the DS and the coordination in Step 2, evaluates the options and selects an arrival/departure configuration for the flight day.

Step 4: The TMC notifies stakeholders of the arrival/departure configuration plan for the flight day and starts system-wide implementation.



A-2.2.7.2 Proactive Change in Arrival/Departure Configuration Due to Forecasted Wind Shift

Step 0: Weather information is made available by the 4-D Wx Data Cube and its initial 4-D Wx SAS. DS subscribes to the weather information needed to identify and plan for arrival/departure configuration changes. Initial Surface Traffic Management has already supported the determination of an airport configuration change for to a wind shift predicted to occur at the airport in 15 minutes.

Step 1: DS monitors Initial Surface Traffic Management communications to know when arrival/departure configuration changes would be required.

Step 2: As a wind shift approaches (i.e., far enough in advance to efficiently move traffic to a new arrival/departure configuration), DS assists with the development of or recommends an optimal arrival/departure configuration with 2 or more alternates. In addition to an arrival/departure configuration change, DS assists with the development of or recommends a set of interim changes to facilitate this major arrival/departure configuration change, such as switching some subset of the arrival/departure routes before doing the major swap, so the configuration change happens in steps and has a less drastic impact on capacity.

Step 3: The arrival/departure configurations are coordinated within the facility, with NAS users, and with adjacent facilities, as necessary.

Step 4: The TMC, collaborating with the facility supervisor and guided by the DS and the coordination in the Step 3, evaluates the options and selects the new arrival/departure configuration (as well as any interim arrival/departure configuration changes).

Step 5: The TMC notifies stakeholders of the arrival/departure configuration change and starts a proactive system-wide implementation.

A-2.2.7.3 Reactive Arrival/Departure Configuration Changes Due to Pop-Up Weather

Step 0: Weather information is made available by the 4-D Wx Data Cube and its initial 4-D Wx SAS. DS subscribes to the weather information needed to identify and plan for dynamic changes to arrival/departure configurations. DS also obtains information concerning traffic density, the performance capabilities of associated aircraft types, as well as environmental considerations in effect.

Step 1: DS, responding to rapidly changing and highly localized weather conditions (e.g., pop-up thunderstorm blocking a departure route), assists with the development of or recommends a minor arrival/departure configuration change, plus one or 2 alternates, to deal with a temporary blockage of a departure route. DS bases this recommendation on an analysis of traffic density, performance capabilities of associated aircraft types, environmental considerations in effect, plus numerous weather factors at various points around the airport, including terminal area winds, winds aloft, convection, ceiling/ visibility, as well as rapidly changing and highly localized weather conditions. For example, a pop-up thunderstorm blocking a departure route may result in the DS recommending that an arrival route be closed and opened as a departure route (see example in figure below). This option is made possible because of the mid-term capability to recommend 180 degree switching of routes between configurations.

Step 2: The arrival/departure configuration change is coordinated within the facility, with NAS users, and with adjacent facilities, as necessary.

Step 3: The TMC, collaborating with the facility supervisor and guided by the DS and the coordination in the Step 2, evaluates options and determines whether or not to perform the recommended change, for example a 180 degree switching of an arrival route to a departure route.

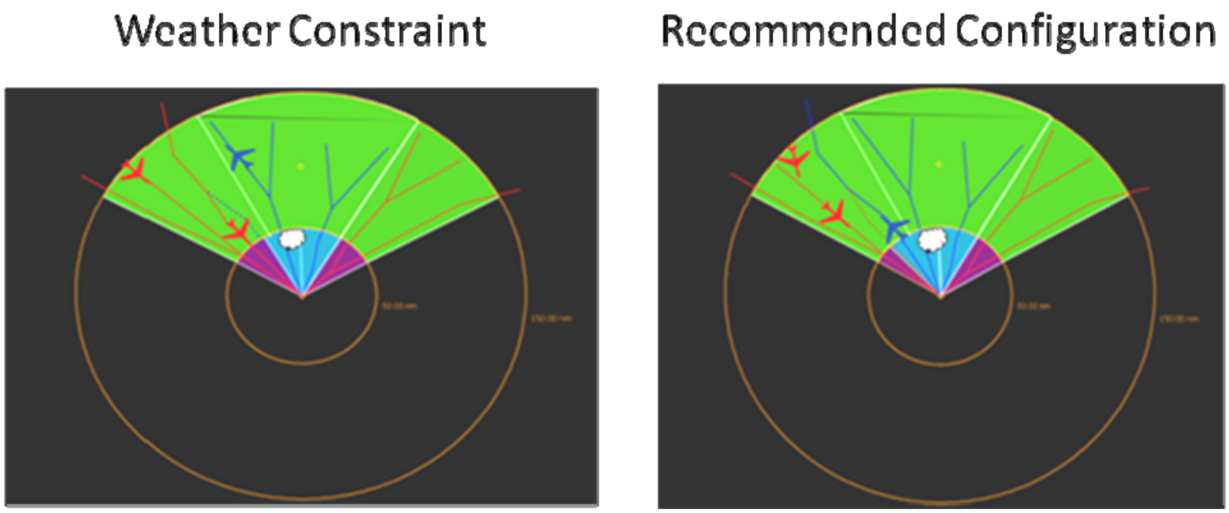
Step 4: The ANSP identifies which upstream arrival aircraft will be last to use the arrival route before it is deactivated and which aircraft is first to be routed to the alternate Standard Terminal Arrival (STAR).

Step 5: Flights allocated to use the arrival route before it is deactivated are allowed to clear the airspace. ANSP manually deactivates the arrival route, activates the departure route, and performs the predefined configuration.

Step 6: The terminal facility coordinates flight plan amendments of flights outside terminal airspace with upstream facility. Traffic Flow Management (TFM) provides amended flight plans to appropriate entities (e.g., affected users or Tower).

Step 7: Flights in en route airspace are rerouted to alternate STARs by upstream facility. The tower controller issues clearance of the alternate Standard Instrument Departures (SID) via uplink (or voice when necessary) to surface traffic in the terminal airspace.

Step 8: The controller maintains responsibility for aircraft separation and monitoring flight conformance to the RNAV procedures.



A-2.2.8 Mid-term Weather Needs Analysis

Based on the scenarios developed in the previous section, weather needs are analyzed in Table A-2.2.8. The 1st column identifies the weather integration need (i.e., the operational decision that will be supported by a DST), the 2nd column attempts to identify the functional weather needs of that DST, the 3rd column identifies the weather information that will be available in the mid-term (according to current plans), and the 4th column identifies gaps, and the 5th column provides recommendations.

Work on this table has only just begun. The next immediate steps are to focus on and complete columns 2 and 3, so that columns 4 and 5 can be addressed. Please note that in its final form, column 3 will not reference weather 'products', rather it will identify the characteristics of the weather 'information' available in the mid-term.

Table A-2.2.8 Integrated Arrival/Departure Airspace Management – Mid-term Weather Needs Analysis

Mid-Term Wx Integration Need	Mid-Term Wx Information Need	Mid-Term 4-D Wx Cube Capability	Mid-Term Wx Information Gap	Recommendations
Support/recommend a stable, baseline	Forecasts out ~8 hrs: • Terminal area winds	<u>Terminal Area Winds</u> • Integrated	TBD	TBD

arrival/departure configuration plan for flight day	(defined by a cone with a radius of 150 nm about the airport, with height up to FL270) • Convection • Ceiling/visibility *Accuracy TBD* *Resolution TBD* *Forecast Update Rate TBD* *Latency TBD*	Terminal Weather System (ITWS) Terminal Winds Diagnostic a) 10 km horizontal, 50 mb vertical, 30 min update, sfc-50,000 ft b) 2 km horizontal, 50 mb vertical, 5 min update, sfc-18,000 ft • Hi-Res Rapid Refresh (HRRR) a) 3 km horizontal, hourly update, 15 min resolution, Continental United States (CONUS) • Rapid Update Cycle (RUC) a) 13 km horizontal, 50 vertical levels, hourly update, 0-12 hr forecasts, CONUS • Weather Research and Forecasting - Rapid Refresh (WRF -RR) Convection • Corridor Integrated Weather System (CIWS) (0-2 hr) • Consolidated Storm Prediction for Aviation (CoSPA) (2-8 hr) Ceiling/Visibility • Terminal Area Forecast (TAF) • Significant Meteorological Information (SIGMET)		

		• Airman's Meteorological Information (AIRMET) • Graphical AIRMET (G-AIRMET)		
Proactively support/recommend an arrival/departure configuration change, far enough in advance of predicted weather (e.g., wind shift), to efficiently move traffic to the new arrival/departure configuration	Forecasts out ~1 hr: • Wind shift timing • Terminal area winds (defined by a cone with a radius of 150 nm about the airport, with height up to FL270) • Convection • Ceiling/visibility *Accuracy TBD* *Resolution TBD* *Forecast Update Rate TBD* *Latency TBD*	<u>Wind shift timing</u> • Derivable from ITWS Terminal Winds Diagnostic <u>Terminal area winds</u> • ITWS Terminal Winds Diagnostic a) 10 km horizontal, 50 mb vertical, 30 min update, sfc-50,000 ft b) 2 km horizontal, 50 mb vertical, 5 min update, sfc-18,000 ft • HRRR a) 3 km horizontal, hourly update, 15 min resolution, CONUS • RUC a) 13 km horizontal, 50 vertical levels, hourly update, 0-12 hr forecasts, CONUS • Weather Research and Forecasting - Rapid Refresh (WRF-RR) <u>Convection</u> • CIWS (0-2 hr) <u>Ceiling/Visibility</u> • Meteorological Aviation Report (METAR) • TAF	TBD	TBD

		• SIGMET • AIRMET • G-AIRMET		
Reactively support/recommend arrival/departure configuration modifications in response to rapidly changing and highly localized weather conditions (e.g., pop-up thunderstorms on arrival/departure routes)	Convective weather forecasts out ~1 hr: • High spatial and temporal resolution (to identify pop-up thunderstorms blocking individual arrival/ departure routes) • Initiation, growth, decay, and movement of individual storms *Accuracy TBD* *Resolution TBD* *Forecast Update Rate TBD* *Latency TBD*	Convection • CIWS (0-2 hr)	TBD	TBD

A-2.3 Time-Based Metering Using RNP and RNAV Route Assignments (OI-0325, OI-104123)

A-2.3.1 Major Mid-term Goals

Metering orderly flows of aircraft in and out of the extended terminal area of high-density airports to maximize capacity and support user-efficient operations. Arrival flows are managed via assignment of CTAs to arrival fixes, which set up streams of aircraft, sequenced and appropriately spaced to efficiently conduct airborne merging and spacing, optimal profile descents, parallel runway operations, wake-based spacing, etc. Departure routing is improved by increasing the accuracy of predicted trajectories.

A-2.3.2 Mid-term Operational Needs/Shortfalls

"The current airport environment requires additional capacity. In addition, orderly arrival-spacing of traffic is necessary if congestion, delays, and risky terminal area maneuvering are to be avoided. Currently, spacing is monitored though a series of vectors and speed changes, based on existing fixes." [Increase Arrivals/ Departures at High-Density Airports Solution Set Smart Sheet, 2008]

A-2.3.3 Mid-term Planned Capabilities

The mid-term capabilities described in Section A-2.3.3.1 are direct quotes from NextGen documents and those in Section A-2.3.3.2 are clarifications developed via the methodology described in Section A-2.1.4. At this point in time, the clarified capabilities in Section A-2.3.3.2 are only assumptions.

A-2.3.3.1 Documented Capabilities

"RNAV, RNP, and time-based metering provide efficient use of runways and airspace in high-density airport environments. RNAV and RNP provide users with more efficient and consistent arrival and departure routings and fuel-efficient operations. Metering automation will manage the flow of aircraft to meter fixes, thus permitting efficient use of runways and airspace. Building on increased capacity in terminal separation procedures, time-based metering will facilitate efficient arrival and departure flows. This will be accomplished using RNAV and RNP routings, coupled with meter fix crossing times. These will be issued to the flight crew via voice or data communications for input into the Flight Management System (FMS). Arrivals will be issued a RNAV routing to link arrival procedures to designated runways. Aircraft will navigate from en route to approach and landing phases with minimal adjustments (i.e., speed adjustments) or changes to flight trajectories by ANSP. Departures will be issued clearances that specify departure routings linked from RNAV routes into the en route phase of flight. This will reduce ANSP and flight crew workload, providing flexibility as well as maximizing arrival and departure throughput at high-density airports.

C-ATM and time-based metering replace miles in trail restrictions. This OI provides consistent delivery of aircraft into the terminal area to match runway acceptance rates, enabling efficient and high-throughput operations. Where practical, this OI enables the application of Optimized Profile Descent (OPD) operations with RNP approaches under moderate traffic conditions, with ground-based automation providing conflict-free, time-based metering solutions for En Route and transition airspace segments. OPD is also known as Continuous Descent Arrival (CDA)." [NextGen IWP v1.0, 2008]

A-2.3.3.2 Capabilities Clarified

Time-Based Metering Using RNP and RNAV Route Assignments is assumed to set up an arrival stream by providing a set of CTAs to a metering fix. This includes assigning aircraft to a runway and arrival stream, and sequencing the aircraft to maximize runway capacity based on aircraft performance (e.g., speed and descent profile) and aircraft performance level (e.g., RNP, parallel runway capability, airborne merging and spacing capability). This also includes establishing the aircraft's 4-D trajectory to the runway. Time-Based Metering Using RNP and RNAV Route Assignments will also improve departure routing, by increasing the accuracy of predicted trajectories. We are not sure what form of metering is involved with departures, but it should require the same weather information used to calculate CTAs to an arrival metering fix.

A-2.3.4 Mid-term Design/Architecture

"Additional RNAV and RNP routes will be defined that will provide longer and shorter paths. Controller tools will suggest from among the pre-defined RNAV and RNP routes those that efficiently ensure adequate spacing between aircraft. Sites will be selected based on available high levels of equipage to support this operation. Metering will occur in en route airspace in the mid-term. Key Enabling Programs include:

- Traffic Flow Management System Work Package 2 (2011-2016) and
- ERAM Mid-Term Work Package (2013-2017)."

[Increase Arrivals/ Departures at High-Density Airports Solution Set Smart Sheet, 2008]

A-2.3.5 Mid-term Candidate Weather Integration

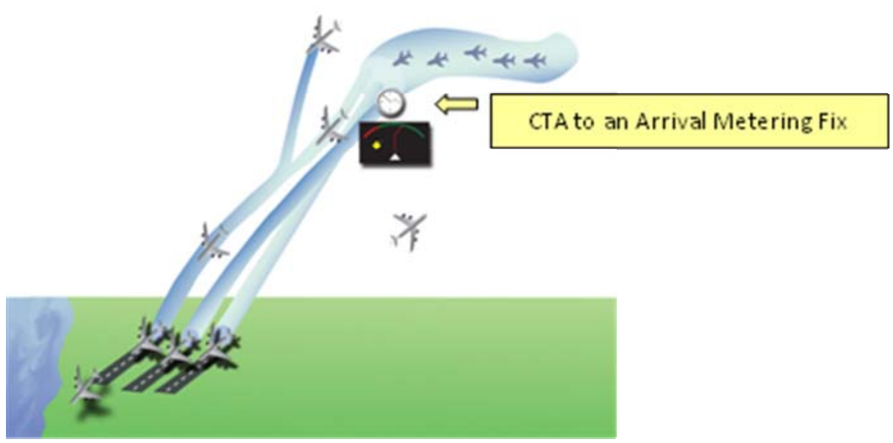
A CTA to an arrival metering fix needs to reflect all aspects of the operations from that metering fix to the runway threshold, including for example pairing for closely spaced runway operations and longitudinal spacing to enable optimal profile descents. The CTA must also reflect what an aircraft can and will actually fly, given the weather conditions along its trajectory. Weather, such as turbulence and icing, impacts aircraft performance including:

- Reduced maximum speed while flying through turbulence and
- Change in idle thrust speed on OPD when icing systems are turned on.

Winds affect the speed of an aircraft, temperature and barometric pressure profiles are needed to calculate geometric altitude, and dew point is required for kinematic modeling. An open question is how an area of convective weather between an aircraft and an arrival metering fix will impact Time-Based Metering Using RNP and RNAV Route Assignments CTAs. This more advanced form of weather integration may more appropriately be a far-term capability.

Departure routing is improved by increasing the accuracy of predicted trajectories. As we learn more regarding the scope and nature of this form of metering and its weather integration and information needs, we will update this section. For the present we assume that the weather information needed for this capability is the same that is needed for calculating CTAs to an arrival metering fix.

In order for time-based metering to work effectively in high density airspace, it is important for the FMS of participating aircraft to have a complete and accurate set of wind data so that both the air and ground can have an accurate estimate of arrival time over a downstream fix.



A-2.3.6 Linkage to Near- and Far-term

The mid-term OI, Time-Based Metering Using RNP and RNAV Route Assignments, is a first step towards a full NextGen capability. Table A-2.3.6 describes this initial step, links it back to today's capabilities and commitments, and describes its future evolution. Section A-2.3.7 then develops scenarios, based on this mid-term capability, which are subsequently used in Section A-2.3.8 to assist us in identifying mid-term weather needs.

Table A-2.3.6 Time-Based Metering Using RNP and RNAV Route Assignments – Linkage to Near- and Far-term
<u>Near –Term</u> a) There is no common weather picture available to all users, weather information is gathered from multiple sources, and individual ANSP perceptions are used to determine the “best source”. b) ANSPs do not currently have DS integrated with weather and aircraft performance information.
<u>Mid-Term (Transition to NextGen)</u> a) Common weather situational awareness is available to all aviation stakeholders and automation capabilities (i.e., 4-D Wx SAS). r) DS integrates weather values directly into algorithms to calculate CTAs to arrival metering fixes, given existing weather conditions, in order to set up streams of traffic to maximize airport capacity, while also supporting user-efficient operations and environmental constraints. s) DS improves departure routing, by increasing the accuracy of predicted trajectories.
<u>Far-Term (Full NextGen)</u> a) This capability will evolve and improve over time, but there are no follow-on OIs planned; improvements will be due to lessons learned, integration with other OIs, and availability of improved weather information. b) Weather OIs also evolve in the far-term to include: c. OI-103119a: *Full (2016-2025) Initial Integration of Weather Information into NAS Automation and Decision Making* • OI-103121: *Full (2016-2025) Improved Weather Information and Dissemination*

A-2.3.7 Mid-term Operational Scenarios

This section contains the following scenario:

- Calculate a sequence of recommended CTAs to an arrival metering fix, integrating weather, user preferences, and aircraft performance information
- Improve departure routing, by increasing the accuracy of predicted trajectories

A-2.3.7.1 Calculate a Sequence of Recommended CTAs to an Arrival Metering Fix, Integrating Weather, User Preferences, and Aircraft Performance Information

Step 0: Weather information is made available by the 4-D Wx Data Cube and its initial 4-D Wx SAS. DS subscribes to the weather information needed to calculate lists of CTAs to an arrival metering fix. Users (Airline Operations Center [AOC], Flight Operations

Center [FOC], or pilot) have a time window in which they can input their preferred arrival profile information and/or CTA preferences.

Step 1: DS supports/recommends a sequence of CTAs. The DS recommendation is based on aircraft performance and weather information that may impact the flight trajectory of the aircraft. The weather information includes: detailed wind fields (particularly near merge points), additional wind information near jet stream (if present), temperature and barometric pressure profiles used to calculate geometric altitude, dew point for kinematic modeling, and icing and turbulence because of their impact on aircraft performance. DS integrates this information into trajectory estimation to set up an efficient flow of aircraft.

Step 2: The ANSP may access a 'what if' capability to explore other options or the ANSP can accept the DS recommendations.

Step 3: The ANSP uses the CTA information to manage the aircraft arriving at the fix, either through providing the CTA to the pilot, who is then responsible for meeting it, or through issuing speed changes to non-RTA capable aircraft.

A-2.3.7.2 Improve Departure Routing, by Increasing the Accuracy of Predicted Trajectories

Step 0: TBD

Step 1: TBD

A-2.3.8 Mid-term Weather Needs Analysis

Based on the scenarios developed in the previous section, weather needs are analyzed in Table A-2.3.8. The 1st column identifies the weather integration need (i.e., the operational decision that will be supported by a DST), the 2nd column attempts to identify the functional weather needs of that DST, the 3rd column identifies the weather information that will be available in the mid-term (according to current plans), and the 4th column identifies gaps, and the 5th column provides recommendations.

Work on this table has only just begun. The next immediate steps are to focus on and complete columns 2 and 3, so that columns 4 and 5 can be addressed. Please note that in its final form, column 3 will not reference weather 'products', rather it will identify the characteristics of the weather 'information' available in the mid-term.

Table A-2.3.8 Time-Based Metering Using RNP and RNAV Route Assignments – Mid-term Weather Needs Analysis

Mid-Term Wx Integration Need	Mid-Term Wx Information Need	Mid-Term 4-D Wx Cube Capability	Mid-Term Wx Information Gap	Recommendations
t) Calculation of a set of 'attainable' CTAs to an	Forecasts out ~1 hr: • Terminal area winds because of their impact on aircraft	Terminal Area Winds • ITWS Terminal Winds	TBD	TBD

arrival metering fix, taking weather's impact on aircraft speed and performance into account	speed (defined by a cone with a radius of 150 nm about the airport, with height up to FL270), with detail particularly near merge points and areas of hard to predict winds near the jet stream's edge • Temperature and barometric pressure profiles to calculate geometric altitude • Dew point for kinematic modeling • In-flight icing and turbulence because of their impact on aircraft performance (defined by a cone with a radius of 150 nm about the airport, with height up to FL270) *Accuracy TBD* *Resolution TBD* *Forecast Update Rate TBD* *Latency TBD*	Diagnostic a) 10 km horizontal, 50 mb vertical, 30 min update, sfc-50,000 ft b) 2 km horizontal, 50 mb vertical, 5 min update, sfc-18,000 ft • HRRR a) 3 km horizontal, hourly update, 15 min resolution, CONUS • RUC a) 13 km horizontal, 50 vertical levels, hourly update, 0-12 hr forecasts, CONUS • WRF-RR <u>Terminal Area Temperatures</u> • HRRR a) 3 km horizontal, hourly update, 15 min resolution, CONUS • RUC a) 13 km horizontal, 50 vertical levels, hourly update, 0-12 hr forecasts, CONUS		

		• WRF Rapid Refresh Barometric Pressure • RUC In-flight Icing • Current Icing Products (CIP) & 1-9hr Forecast Icing Products (FIP) (Severity, probability, super-cooled large droplets) Turbulence • Analysis and 1-12hr Graphical Turbulence Guidance (GTG)		
u) Improve departure routing, by increasing the accuracy of predicted trajectories	Forecasts out ~1 hr: • Terminal area winds because of their impact on aircraft speed (defined by a cone with a radius of 150 nm about the airport, with height up to FL270), with detail particularly near merge points and areas of hard to predict winds near the jet stream's edge • Temperature and barometric pressure profiles to calculate geometric altitude	Terminal Area Winds • ITWS Terminal Winds Diagnostic a) 10 km horizontal, 50 mb vertical, 30 min update, sfc-50,000 ft b) 2 km horizontal, 50 mb vertical, 5 min update, sfc-18,000 ft • HRRR a) 3 km horizontal, hourly update, 15 min	TBD	TBD

	• Dew point for kinematic modeling • In-flight icing and turbulence because of their impact on aircraft performance (defined by a cone with a radius of 150 nm about the airport, with height up to FL270) *Accuracy TBD* *Resolution TBD* *Forecast Update Rate TBD* *Latency TBD*	resolution, CONUS • RUC a) 13 km horizontal, 50 vertical levels, hourly update, 0-12 hr forecasts, CONUS • WRF-RR <u>Terminal Area Temperatures</u> • HRRR a) 3 km horizontal, hourly update, 15 min resolution, CONUS • RUC a) 13 km horizontal, 50 vertical levels, hourly update, 0-12 hr forecasts, CONUS • WRF Rapid Refresh <u>Barometric Pressure</u> • RUC <u>In-flight Icing</u> • CIP & 1-9hr FIP (Severity, probability, super-cooled large droplets) <u>Turbulence</u> Analysis and 1-12hr GTG		

A-2.4 Improve Operations to Closely Spaced Parallel Runways (OI-0333, OI-102141)

A-2.4.1 Major Mid-term Goals

This capability enables continued operations at parallel runways without reduction in throughput in lower visibility conditions.

A-2.4.2 Mid-term Operational Needs/Shortfalls

"Currently, dependent (staggered) operations are allowed in Instrument Meteorological Conditions (IMC) on parallel runways between 2500 feet and 4300 feet. Improved throughput is needed during ceiling and visibility conditions that are less than Visual Meteorological Conditions (VMC) on these runways, as well as those more closely spaced than 2500 feet. Establishing criteria for closely-spaced runways will allow airports to include new runway construction plans compatible with long-term NextGen operations." [Increase Arrivals/ Departures at High-Density Airports Solution Set Smart Sheet, 2008]

A-2.4.3 Mid-term Planned Capabilities

The mid-term capabilities described in Section A-2.4.3.1 are direct quotes from NextGen documents and those in Section A-2.4.3.2 are clarifications developed via the methodology described in Section A-2.1.4. At this point in time, the clarified capabilities in Section A-2.4.3.2 are only assumptions.

A-2.4.3.1 Documented Capabilities

"This OI involves enhanced procedures (cockpit and ground) enabling parallel runway improvements, reducing impact to airport/runway throughput in lower visibility conditions. It maintains access to closely-spaced parallel runways in limited visibility conditions by integrating new aircraft technologies that will ensure safety through

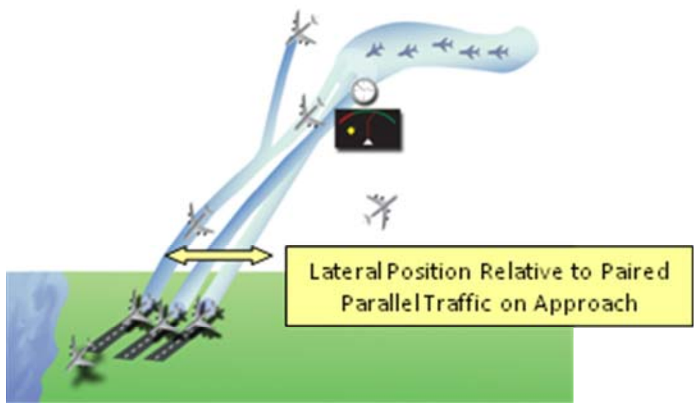
- Precision navigation,
- Aircraft-based monitoring of the aircraft on the parallel approach, and
- Flight guidance to avoid wake vortex generated by parallel traffic.

This capability will apply aircraft-based technologies to maintain closely spaced parallel runway access in IMC, as well as support a new Instrument Flight Rules (IFR) standard for runway spacing.

This OI seeks VMC arrival and departure rates in IMC through use of onboard displays and alerting for independent parallel runways. Using precision navigation, cooperative surveillance, and onboard algorithms and displays allows the reduction of lateral separation requirements for parallel runway operations in IMC. It also includes independent approaches to parallel runways that are centerline distances greater than 2500 ft." [NextGen IWP v1.0, 2008]

A-2.4.3.2 Capabilities Clarified

It is assumed this capability addresses lateral position relative to paired parallel traffic, whereas Flexible Terminal wake vortex related capabilities address longitudinal separation. Additionally, it is assumed that this OI encompasses all IFR parallel runway operations, ranging from a lateral runway separation of 4300 feet down to as little as 750 feet or possibly even less. This distance is a contradiction to the OI's title, which infers only closely spaced parallel runways are being considered, although the IWP OI description in the preceding section states independent approaches to parallel runways with centerline distances greater than 2500 feet are also included. Operationally, the pilot will be advised of the type of operation in effect and will maintain the required lateral position relative to paired parallel traffic that is specified for that type of operation. The aircraft may be operating under ground-managed time-based spacing (OI-0325) or airborne merging and spacing (OI-0326); current thinking is that both types of operations will be supported and may even peacefully co-exist within a single arrival stream.



A-2.4.4 Mid-term Design/Architecture

"To achieve closely-spaced parallel approaches, it is assumed responsibility for separation between aircraft would be delegated to the aircraft, minimizing the latency of any corrective actions. Aircraft may need assistance during initiation of a paired-approach to ensure they maintain an acceptable along-track tolerance. This maintenance will support other runway procedures (as close as 700 feet) in IMC conditions. Key Enabling Programs include:

- ADS-B."

[Increase Arrivals/Departures at High-Density Airports Solution Set Smart Sheet, 2008]

A-2.4.5 Mid-term Candidate Weather Integration

Weather information is needed to determine whether a set of parallel runways should be:

- Operating under IFR or Visual Flight Rules (VFR) conditions and
- Using parallel offset procedures.

Weather thresholds are established for these determinations. However, there are probably no mid-term needs for integrating weather into DS rules based algorithms and no 'new' weather information needs have yet been identified. Possibly, cross winds and turbulence conditions paired with lateral runway separation are used to determine dependant vs. independent runway operations. Additionally, the TMC may access space weather to determine whether certain procedures are prohibited due to the impact of solar conditions on Global Positioning System

(GPS). These 'potential' weather information needs will be examined further and this document will be updated accordingly.

A-2.4.6 Linkage to Near- and Far-term

The mid-term OI, Improve Operations to Closely Spaced Parallel Runways, is a first step towards a full NextGen capability. Table A-2.4.6 describes this initial step, links it back to today's capabilities and commitments, and describes its future evolution. Section A-2. 4.7 then develops scenarios, based on this mid-term capability, which are subsequently used in Section A-2.4.8 to assist us in identifying mid-term weather needs.

Table A-2.4.6 Improve Operations to Closely Spaced Parallel Runways – Linkage to Near- and Far-term
Near –Term a) There is no common weather picture available to all users, weather information is gathered from multiple sources (e.g., METAR), and individual ANSP perceptions are used to determine the "best source". b) In the near term, determining whether a set of runways should be operating under IFR or VFR conditions, running dependent or independent operations, and using parallel offset procedures is based on established rules for that runway pair involving values of ceiling and visibility.
Mid-Term (Transition to NextGen) a) Common weather situational awareness is available to all aviation stakeholders and automation capabilities (i.e., 4-D Wx SAS) b) The TMC looks at the ceiling and visibility display and determines the operations in effect based on established rules for that runway pair. The determination of independent vs. dependent (paired) operations is based on the lateral separation between runways. c) The pilot is informed whether operations are IFR or VFR, if runway operations are dependent or independent, and whether parallel runway offset procedures are in effect. d) The pilot maintains the required lateral position relative to paired parallel traffic, specified by the type of operations.
Far-Term (Full NextGen) a) This capability will evolve and improve over time, but there are no follow-on OIs planned; improvements may include more advanced techniques and procedures for handling runway blunders, triples, and quads. b) Weather OIs also evolve in the far-term to include: d. OI-103119a: *Full (2016-2025) Initial Integration of Weather Information into NAS Automation and Decision Making* a. OI-103121: *Full (2016-2025) Improved Weather Information and Dissemination*

A-2.4.7 Mid-term Operational Scenarios

This section contains the following scenario:

- Determine runway operations, given existing weather conditions

A-2.4.7.1 Determine Runway Operations, Given Existing Weather Conditions

Step 0: Weather information is made available by the 4-D Wx Data Cube and its initial 4-D Wx SAS. The TMC consults with weather displays to acquire weather situational awareness.

Step 1: TMC uses ceiling and visibility conditions to determine: whether parallel runway offset procedures can be used and whether the airport is operating under IFR or VFR conditions. Possibly, TMC looks at cross winds and turbulence conditions paired with lateral runway separation to determine dependant vs. independent runway operations or the TMC may access space weather to determine whether certain procedures are prohibited due to the impact of solar conditions on GPS.

Step 2: The controller advises the pilot of whether airport operations are IFR or VFR, dependent or independent, and whether parallel runway offset procedures are in effect.

Step 3: The pilot maintains the required lateral position relative to paired parallel traffic, specified for the type of operation.

A-2.4.8 Mid-term Weather Needs Analysis

Based on the scenarios developed in the previous section, weather needs are analyzed in Table A-2.4.8. The 1st column identifies the weather integration need (i.e., the operational decision that will be supported by a DST), the 2nd column attempts to identify the functional weather needs of that DST, the 3rd column identifies the weather information that will be available in the mid-term (according to current plans), and the 4th column identifies gaps, and the 5th column provides recommendations.

Work on this table has only just begun. The next immediate steps are to focus on and complete columns 2 and 3, so that columns 4 and 5 can be addressed. Please note that in its final form, column 3 will not reference weather 'products', rather it will identify the characteristics of the weather 'information' available in the mid-term

Table A-2.4.8 Improve Operations to Closely Spaced Parallel Runways – Mid-term Weather Needs Analysis

Mid-Term Wx Integration Need	Mid-Term Wx Information Need	Mid-Term 4-D Wx Cube Capability	Mid-Term Wx Information Gap	Recommendations
Displays make weather information available to the TMC, who determines the	Current weather conditions: • Ceiling/visibility	Ceiling/Visibility • METAR • TAF • SIGMET • AIRMET • G-AIRMET	TBD	TBD

operations in effect (i.e., parallel runway offset procedures, IFR/VFR) based on established rules for the runway pair				

A-2.5 Initial Surface Traffic Management (OI-0320, OI-104209)

A-2.5.1 Major Mid-term Goals

This capability provides improved sequencing and staging of surface traffic flow at high density airports with consideration for en route weather constraints and availability of routes, enhanced local collaboration between ANSP and airport stakeholders, and an increased opportunity for aircraft operators to meet their operational and business objectives. This capability is also responsible for airport configuration.

A-2.5.2 Mid-term Operational Needs/Shortfalls

"Currently, air traffic demand exceeds inadequate NAS resources. Traffic-flow managers apply a variety of tools, particularly various types of traffic management initiatives (TMIs), to handle departure runways at high-density airports. These initiatives depend upon the capability of controllers. Managing surface traffic to enable aircraft to depart or land at airport runways within tightly scheduled time windows is a daunting task. There is an increasing demand for decision-support tools to assist controllers in accomplishing this daunting task. Appropriate surface data, when developed, will be shared with flight planners, FOCs, as well as airport authorities." [Increase Arrivals/Departures at High-Density Airports Solution Set Smart Sheet, 2008]

A-2.5.3 Mid-term Planned Capabilities

The mid-term capabilities described in Section A-2.5.3.1 are direct quotes from NextGen documents and those in Section A-2.5.3.2 are clarifications developed via the methodology described in Section A-2.1.4. At this point in time, the clarified capabilities in A-2.5.3.2 are only assumptions.

A-2.5.3.1 Documented Capabilities

"Departures are sequenced and staged to maintain throughput. ANSP automation uses departure-scheduling tools to flow surface traffic at high-density airports. Automation provides surface sequencing and staging lists for departures and average departure delay (current and predicted). ANSP DSTs integrate surveillance data to include weather data, departure queues, aircraft flight plan information, runway configuration, expected departure times, and gate assignments. Automation provides surface sequencing and staging lists for departures and average departure delay (current and predicted). Local collaboration between ANSP and airport stakeholders improves information flow to DS as well as the ability for aircraft operators to meet their operational and business objectives." [NextGen IWP v1.0, 2008]

A-2.5.3.2 Capabilities Clarified

Initial Surface Traffic Management is automated and includes a capability to facilitate looking out into en route flow acceptance rates to determine a more effective flow for high-density airport departures to better sequence, stage, and flow surface traffic. This initial mid-term departure-scheduling tool provides runway assignment, 2-dimensional (2-D) taxi routes, departure routing, surface sequencing and scheduling, as well as average departure delays (current and predicted). To accomplish this, the following information is integrated into the decision making process:

- Weather information,
- Aircraft flight plans,
- Runway configuration,
- Expected departure times, and
- Departure Gate.

Additionally, this capability supports/recommends airport configuration changes and works closely with the Integrated Arrival/Departure Airspace Management's arrival/departure configuration capability. Lastly, this capability provides surface management information in support of a determination of airport capacity. Future versions of this paper will explore this information sharing capability and any related weather integration needs it may have.

In the far-term, follow-on surface traffic management OIs will introduce 'new' or more sophisticated NextGen capabilities, building on this mid-term capability.

According to the ATO-P draft ConUse for Surface Trajectory Based Operations (STBO) Segments 1&2, v0.1, dated 12 December 2008 this surface TBO DST functionality includes:

- Planning and scheduling use of airport resources (e.g., runways and taxiways) to meet user demand, current airport operations, and traffic flow management restrictions, including time-based metering
- More planning and predictability for airport surface traffic management and better coordination among airport stakeholders
- Flight planning may be 2-24 hours before the flight departs and can include early intent flight plans
- Seamless integration and compatibility with other capabilities and operations in conventional towers and Traffic Management in all facilities
- Managing queues for departing flights, at busy airports during peak demand, taking arrivals into account; efficiently using capacity, and providing the mechanism for ATC-flight operator collaboration on departure decisions
- Improving the scheduling of airport surface resources without overly constraining operators

- No change to operational responsibilities; the responsibilities of Air Traffic Control Tower, Traffic Management, Ramp Control, flight operators, and pilots remain the same
- Taking weather (e.g., wind, visibility/ceiling, thunderstorms) into account
- Implementation through the execution of TMIs
- No requirement for new flight deck technologies

A-2.5.4 Mid-term Design/Architecture

"The surface traffic management tool suite will receive data from and provide data to automation systems using Application Programming Interfaces (APIs) and services provided by those systems. Information must be shared with the appropriate systems, such as Traffic Flow Management System (TFMS) infrastructure and ERAM. Appropriate surface management tools may be distributed as needed to support required response times. Key Enabling Programs include:

- Tower Flight Manager (2015+)."

[Increase Arrivals/Departures at High-Density Airports Solution Set Smart Sheet, 2008]

A-2.5.5 Mid-term Candidate Weather Integration

Initial Surface Traffic Management is assumed to provide the following capabilities:

- Supports/recommends runway assignment, 2-D taxi routes, departure scheduling, and surface sequencing and scheduling, based on an analysis of traffic density, performance capabilities of the aircraft, environmental considerations in effect, plus numerous weather factors at various points around the airport and en route, including terminal area winds, winds aloft, convection, ceiling/visibility, as well as rapidly changing and highly localized weather conditions (e.g., pop-up thunderstorms on arrival/departure routes). For surface sequencing and staging lists, taxi speed will be affected by visibility and environmental factors impacting surface conditions.
- Supports/recommends airport configuration changes, working closely with Integrated Arrival/Departure Airspace Management's arrival/departure configuration capability.
- Provides surface management information supporting the determination of airport capacity. Potential weather integration candidates for this capability are still being considered.

A-2.5.6 Linkage to Near- and Far-term

The mid-term OI, Initial Surface Traffic Management, is a first step towards a full NextGen capability. Table 5.6 describes this initial step, links it back to today's capabilities and commitments, and describes its future evolution. Section 5.7 then develops scenarios, based on this mid-term capability, which are subsequently used in Section 5.8 to assist us in identifying mid-term weather needs.

Table A-2.5.6 *Initial Surface Traffic Management* – Linkage to Near- and Far-term

<u>Near –Term</u>

a) There is no common weather picture available to all users, weather information is gathered from multiple sources, and individual ANSP perceptions are used to determine the "best source".
b) ANSPs do not have DSTs to aid them in sequencing and staging surface traffic flow and in determining current and future average departure delay.

<u>Mid-Term (Transition to NextGen)</u>

a) Common weather situational awareness is available to all aviation stakeholders and automation capabilities (i.e., 4-D Wx SAS).
b) DS supports/recommends an optimal day of flight airport configuration.
c) DS proactively supports/recommends airport configuration modifications, far enough in advance of predicted weather (e.g., wind shift), to efficiently move traffic to new airport and arrival/departure configurations.
d) DS departure scheduling tools plug weather values directly into equations to produce surface sequencing and staging lists and to determine average departure delays (current and predicted).
e) *Initial Surface Traffic Management* needs to be integrated with *Integrated Arrival/Departure Airspace Management* to coordinate airport and arrival/departure configurations.

<u>Far-Term (Full NextGen)</u>

a) *Initial Surface Traffic Management* is the first of eight steps leading to the full NextGen surface traffic management capability; the remaining seven steps are:

   <u>Additional Surface Traffic Management Capabilities</u>
   - OI-0321: *Enhanced Surface Traffic Operations*
   - OI-0332: *Ground-Based and On-Board Runway Incursion Alerting*
   - OI-0322: *Low-Visibility Surface Operations*
   - OI-0327: *Surface Management - Arrivals/Winter Ops/Runway Configuration*
   - OI-0340: *Near-Zero-Visibility Surface Operations*

   <u>Integration with Other Capabilities</u>
   - OI-0331: *Integrated Arrival/Departure and Surface Operations*
   - OI-0339: *Integrated Arrival/Departure and Surface Traffic Management for Metroplex*

b) By breaking this complex implementation into more manageable steps, benefits are realized sooner and implementation risks are reduced.
c) Weather OIs also evolve in the far-term to include:
   - OI-103119a: *Full (2016-2025) Initial Integration of Weather Information into NAS Automation and Decision Making*
   - OI-103121: *Full (2016-2025) Improved Weather Information and*

Dissemination

A-2.5.7 Mid-term Operational Scenarios

This section contains the following three scenarios:

- Baseline (strategic) airport configuration plan for the flight day, using weather forecasts
- Proactive change in airport configuration due to forecasted wind shift
- Departure staging of surface traffic flow

A-2.5.7.1 Baseline (strategic) Airport Configuration Plan for the Flight Day, Using Weather Forecasts

Step 0: Weather information is made available by the 4-D Wx Data Cube and its initial 4-D Wx SAS. DS subscribes to the weather information needed to plan the airport configuration for the flight day.

Step 1: DS assists with the development of or recommends an airport configuration. DS may base this recommendation on comparisons of existing weather conditions with historical ASPM data analysis, which empirically identifies weather-parameter thresholds (e.g., winds) that are associated with actual runway configuration usage, or the DS may use other methodologies to make its recommendation.

Step 2: The baseline airport configuration is coordinated within the facility and with Integrated Arrival/Departure Airspace Management, which is responsible for the corresponding baseline arrival/departure configuration.

A-2.5.7.2 Proactive Change in Airport Configuration Due to Forecasted Wind Shift

Step 0: Weather information is made available by the 4-D Wx Data Cube and its initial 4-D Wx SAS. DS subscribes to the weather information needed to identify and plan for airport configuration changes.

Step 1: DS monitors wind shift timing information to better predict when changes to airport configuration is required.

Step 2: As a wind shift approaches (i.e., far enough in advance to efficiently move traffic to a new arrival/departure configuration), DS assists with the development of or recommends an airport configuration change. DS may base this recommendation on comparisons of existing weather conditions with historical ASPM data analysis, which empirically identifies weather-parameter thresholds (e.g., winds) that are associated with actual runway configuration usage, or the DS may use other methodologies to make its recommendation.

Step 3: The airport configuration change is coordinated within the facility and with Integrated Arrival/Departure Airspace Management, which is responsible for the corresponding arrival/departure configuration changes.

Step 4: The tower controller, determines which aircraft will be the last in sequence to use the current runway configuration.

Step 5: The Terminal Radar Approach Control Facility (TRACON) starts sequencing other aircraft to the new airport and arrival/departure configuration.

A-2.5.7.3 Departure Staging of Surface Traffic Flow

Step 0: Weather information is made available by the 4-D Wx Data Cube and its initial 4-D Wx SAS. DS subscribes to the weather information needed to manage surface traffic.

Step 1: DS integrates weather information, current departure queues, aircraft flight plans, runway configuration, expected departure times, and departure gate to determine sequencing and staging lists and average departure delays.

A-2.5.8 Mid-term Weather Needs Analysis

Based on the scenarios developed in the previous section, weather needs are analyzed in Table A-2.5.8. The 1st column identifies the weather integration need (i.e., the operational decision that will be supported by a DST), the 2nd column attempts to identify the functional weather needs of that DST, the 3rd column identifies the weather information that will be available in the mid-term (according to current plans), and the 4th column identifies gaps, and the 5th column provides recommendations.

Work on this table has only just begun. The next immediate steps are to focus on and complete columns 2 and 3, so that columns 4 and 5 can be addressed. Please note that in its final form, column 3 will not reference weather 'products', rather it will identify the characteristics of the weather 'information' available in the mid-term. Please note that in its final form, column 3 will not reference weather 'products', rather it will identify the characteristics of the weather 'information' available in the mid-term.

Table A-2.5.8 ***Initial Surface Traffic Management*** **– Mid-term Weather Needs Analysis**

Mid-Term Wx Integration Need	Mid-Term Wx Information Need	Mid-Term 4-D Wx Cube Capability	Mid-Term Wx Information Gap	Recommendations
Support/recommend a stable, baseline airport configuration plan for flight day	Forecasts out ~8 hrs: • Surface winds • Convection • Ceiling/visibility *Accuracy TBD* *Resolution TBD* *Forecast Update Rate TBD* *Latency TBD*	Terminal Area Winds • ITWS Terminal Winds Diagnostic a) 10 km horizontal, 50 mb vertical, 30 min update, sfc-50,000 ft b) 2 km horizontal, 50 mb vertical, 5 min update, sfc-18,000 ft • HRRR a) 3 km horizontal,	TBD	TBD

		hourly update, 15 min resolution, CONUS • RUC a) 13 km horizontal, 50 vertical levels, hourly update, 0-12 hr forecasts, CONUS • WRF -RR <u>Convection</u> • CIWS (0-2 hr) • CoSPA (2-8 hr) <u>Ceiling/Visibility</u> • TAF • SIGMET • AIRMET • G-AIRMET		
Proactively support/recommend an airport configuration change, far enough in advance of predicted weather (e.g., wind shift), to efficiently move traffic to the new airport and arrival/departure configuration	Forecasts out ~1 hr: • Wind shift timing • Convection • Ceiling/visibility *Accuracy TBD* *Resolution TBD* *Forecast Update Rate TBD* *Latency TBD*	<u>Wind shift timing</u> • Derivable from ITWS Terminal Winds Diagnostic <u>Convection</u> • CIWS (0-2 hr) <u>Ceiling/Visibility</u> • METAR • TAF • SIGMET • AIRMET • G-AIRMET	TBD	TBD
Support/recommend surface sequencing and staging lists and determine (current and predicted) average departure delays	Forecasts out ~2-24 hrs: • Terminal area winds because of their impact on aircraft speed (defined by a cone with a radius of 150 nm about the airport, with height up to FL270) • Convection • Ceiling/ visibility	<u>Terminal Area Winds</u> • ITWS Terminal Winds Diagnostic a) 10 km horizontal, 50 mb vertical, 30 min update, sfc-50,000 ft b) 2 km horizontal, 50 mb vertical, 5 min update, sfc-18,000 ft • HRRR	TBD	TBD

	Accuracy TBD *Resolution TBD* *Forecast Update Rate TBD* *Latency TBD*	a) 3 km horizontal, hourly update, 15 min resolution, CONUS • RUC a) 13 km horizontal, 50 vertical levels, hourly update, 0-12 hr forecasts, CONUS • WRF-RR Convection • CIWS (0-2 hr) Ceiling/Visibility • TAFs • SIGMET • AIRMET • G-AIRMET		

A-2.6 Findings, Conclusions, and Recommendations

Much analysis and discussion are required before a final set of mid-term weather integration candidates for Increase Arrivals/Departures at High Density Airports can be identified. From among the ‘potential’ weather integration candidates listed below, some may be incorporated into Increase Arrivals/Departures at High Density Airports ConOps documents, forming the basis for NextGen weather integration requirements.

A-2.6.1 Findings

To-date, the following mid-term, Increase Arrivals/Departures at High Density Airports, weather-related, operational decisions have been identified as ‘potential’ candidates for inclusion into DSTs.

Integrated Arrival/Departure Airspace Management

- Support/recommend a stable, baseline arrival/departure configuration plan for the flight day
- Proactively support/recommend arrival/departure configuration modifications, far enough in advance of predicted weather (e.g., wind shift), to efficiently move traffic to new arrival/departure configurations
- Reactively support/recommend arrival/departure configuration modifications in response to rapidly changing and highly localized weather conditions (e.g., pop-up thunderstorms on arrival/departure routes)

Time-Based Metering Using RNP and RNAV Route Assignments

- Calculation of a set of 'attainable' CTAs to an arrival metering fix, taking weather's impact on aircraft speed and performance into account
- Improve Departure Routing, by Increasing the Accuracy of Predicted Trajectories

Initial Surface Traffic Management

- Support/recommend a stable, baseline airport configuration plan for the flight day
- Proactively support/recommend airport configuration modifications, far enough in advance of predicted weather (e.g., wind shift), to efficiently move traffic to new airport and arrival/departure configurations
- Support/recommend surface sequencing and staging lists and determine (current and predicted) average departure delays

A-2.6.2 Conclusions

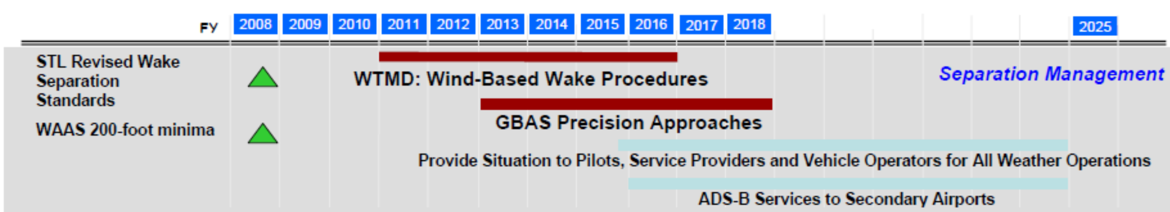
The authors of this document need to perform more analysis and receive more feedback on this initial version, before conclusions can be reached.

A-2.6.3 Recommendations

The authors of this document need to perform more analysis and receive more feedback on this initial version, before recommendations can be made.

A-3. Increase Flexibility in the Terminal Environment

Flexible terminal solutions focus on improvements to the management of separation at all airports. Such capabilities will improve safety, efficiency and maintain capacity in reduced visibility high density terminal operations. At airports where traffic demand is lower, and at high density airports during times of low demand, operations requiring lesser aircraft capability are conducted, allowing access to a wider range of operators while retaining the throughput and efficiency advantages of high density operations. Both trajectory and non trajectory-based operations may be conducted within flexible terminal operations.



A-3.1 Separation Management

<u>Near-term Commitments</u>

<u>STL Revised Wake Separation Standards</u>

This initiative will provide for dependent, staggered operations at St. Louis on closely-spaced parallels based on an understanding of wake transport limits.

<u>Weather Integration Considerations – Infrastructure Roadmap (IR)</u>

None listed

<u>Comments</u>

Prediction of wake transport and decay requires accurate ambient winds and turbulence, even in the near term.

<u>*WAAS 200-Foot Minima*</u>

This initiative will extend the use of the Wide-Area Augmentation System down to 200 feet above an airport's elevation at runway ends without instrument landing systems in Alaska.

<u>Weather Integration Considerations – Infrastructure Roadmap (IR)</u>

None listed

<u>Mid-term Capabilities</u>

A-3.1.1. Wake Turbulence Mitigation for Departures (WTMD) - Wind-Based Wake Procedures

This operational improvement will leverage improved wake vortex (WV) prediction capabilities, and the integration of that WV information into display systems and decision support tools (DSTs) which identify and mitigate the impact of wake turbulence generated by one aircraft on a following aircraft. As compared to the generalized methodologies employed today, this flight pair-specific approach to dealing with wake turbulence should allow for the reduction of spacing between aircraft, thereby improving runway capacities across a range of weather conditions and operating regimes. Implicit in this statement is that existing wake vortex-based separation rules will be changed based on the capability of WTMD-based systems to predict the transport or decay of wake vortices and their precise impact on the trailing aircraft.

Although this Operational Improvement (OI) specifically focuses on wake mitigation in the departure regime, and is therefore assumed to be concerned primarily with longitudinal separation between departing aircraft, there is also the need for similar capabilities in the arrival regime, and especially for arrivals to Closely Spaced Parallel Runways (CSPRs). It is almost certain that the display systems and DSTs created to provide Wake Turbulence Mitigation for Arrivals (WTMA) will require the same weather inputs as will procedures and DSTs designed to provide WTMD, despite the fact that the resultant arrival processes are likely to be concerned with the lateral, instead of longitudinal, separation of aircraft landing on adjacent runways. See Appendix A-2.3, Improved Operations to Closely Spaced Runways, for additional WTMA discussion in the context of closely spaced parallel runways.

Framework Assumptions (AOC/FOC = Airline/Flight Operations Center, ATC = Air Traffic Control, PIC = Aircraft)

Today / Near-term (current to 2010)

- (ATC) The impact of current weather on wake turbulence is not a factor in the development of arrival/departure rates

- (ATC) The impact of wake turbulence is manually mitigated through the application of miles in trail between departure aircraft following standards based on the application of FAA rules
- (ATC) The impact of wake turbulence on the airport operation is manually computed
- (AOC/FOC, PIC) Neither the dispatcher nor the pilot has any awareness of the real time impact of wake turbulence on the airport operation
- (ATC) The estimation of traffic demand is derived from multiple sources and then manually adjusted based on history and controller experience
- (ATC, PIC) Pilots are allowed to use their judgment of the impact of wake turbulence on their flight during visual approach only in following traffic

Mid-term (2010-2018)

- (ATC) A wake turbulence mitigation model based on actual local weather conditions will be developed and used by local ATC
- (ATC) The impact of wake turbulence on airport arrival/departure rates will continue to be manually derived through human interpretation of the wake turbulence mitigation models and related information
- (ATC) Human interpretation of tower displays will be used to make departure runway assignments and apply departure separation criteria on the basis of wake turbulence
- (PIC) There will be no change in cockpit wake turbulence information or rules
- (AOC/FOC, PIC) The dispatcher and the pilot will continue to be unaware of the real time impact of wake turbulence on the airport operation

Far-term (2018-2025)

- (ATC) Decision support tools (DSTs) which include an integrated wake turbulence mitigation model based on local weather conditions will be used to automatically calculate wake turbulence-based separation criteria and make related operational decisions
- (AOC/FOC, ATC, PIC) These DSTs will provide a visual display of wake turbulence impact zones to AOC/FOC, ATC and aircraft cockpit display systems
- (ATC) These DSTs will automatically adjust airport arrival and departure rates based on the integrated wake turbulence mitigation model and local weather conditions
- (AOC/FOC, ATC, PIC) Dispatchers, controllers and pilots will all see a common view of wake turbulence, and share a common understanding of the impact of wake turbulence on the airport operation
- (AOC/FOC, ATC) When coupled with more accurate and detailed surface forecasts, dispatchers and controllers will share an early and common understanding of the impact of wake turbulence on the capacity of the airport later in the day

Comments

- WTMD weather integration is envisioned to mean that high resolution, real time local wind data and high resolution, high refresh rate wind forecasts are part of a wind forecast algorithm which in turn is integrated into the WTMD processing function
- Prediction of wake transport and decay requires accurate ambient winds and turbulence, even in the near term. Terminal area (and/or airborne - longer term) wake sensor systems are also important to confirm predictions, and for safety.
- ATC policies and procedures will have to be changed to allow differing separation criteria based on information from wake turbulence mitigation models, regardless of whether the separation criteria are calculated and assigned manually or automatically

Weather Integration Considerations – Infrastructure Roadmap (IR)

- Enhanced Forecasts - Terminal Winds – must be input to wake vortex (WV) system. More specifically, wake vortex prediction systems are anticipated to create high temporal and spatial wind observation and reporting requirements.

Integrated Work Plan (IWP) Review

- There are two IWP Operational Improvements (OIs) and several underlying Enablers (ENs) that support the envisioned capabilities for Wake Turbulence Mitigation found in the NextGen Implementation Plan (NIP) Flex Terminal Solution Set Separation Management Swim Lane.
- OI-0402 - Wake Turbulence Mitigation: Departures - Dynamic Wind Procedures (2018) has as its focus predicting wake drift and decay. It is envisioned that this will be used to dynamically adjust longitudinal departure spacing and separation rules based on ground-based winds, aircraft type and algorithms. This OI builds on the ability to adjust for lateral wake effects and associated static procedures for Closely Spaced Parallel Runways (CSPR).
- EN-0029 - Wake Detection/Prediction with Dynamic Wake Spacing - Level 1 Wake Drift (2014) is a ground-based wake vortex advisory system based solely on wake transport.
- EN-0030 - Wake Detection/Prediction with Dynamic Wake Spacing - Level 2 Wake Drift/Decay (2016) builds on EN-0029 to include wake decay.

Comment: EN-0029 and EN-0030 describe a ground-based wake vortex advisory system that presumably includes high spatial and temporal wind observations and whose sole focus is on wake vortex detection, prediction and aircraft spacing guidance in the terminal area, and especially for impacts to operations on closely spaced parallel runways (CSPR). It has been estimated in the NextGen Portfolio Work Plan on Resource Planning Data (RPD) that several additional departures per hour from CSPRs are possible, if the dissipation and transport of the wake turbulence can be predicted. Regardless, however, of where or how weather information is integrated, the net effect on improved operations will be driven by changes in separation standards and procedures.

OI-0409 - Net-Centric Virtual Facility (2018) is an overarching OI that supports Flex Terminal as well as other airport-based improvements. This OI has a focus of obtaining situational awareness information remotely. The OI is aided by weather, traffic and other surface surveillance information displayed on a tower information display system and a suite of decision support tools using ground system and aircraft-derived data.

REDAC Review

Nothing noted

Weather/ATM Integration Conference Review

Nothing noted

A-3.1.2 Ground-Based Augmentation System (GBAS) Precision Approaches

Global Positioning System (GPS)/GBAS will support precision approaches to Category I (as a non-federal system), and eventually Category II/III minimums for properly equipped runways and aircraft. GBAS can support approach minimums at airports with fewer restrictions to surface movement and offers the potential for curved precision approaches. GBAS also can support high-integrity surface movement requirements.

As an integral part of the overall ATM system, it is essential that airports provide and manage surface guidance systems, maximizing the airport capacity, and providing enhanced protection against runway incursions and misrouting, under all weather conditions. Currently surface movement radar is the basic means for ATC surface surveillance. However radar only provides an approximate position of the aircraft and by itself does not provide the required accuracy for surface movement under zero visibility conditions to increase situational awareness and mitigate potential runway incursions. Further, it is envisioned that the current IFR Landing Systems will not be able to meet future capacity and safety needs of CAT III approaches Thus, in order to optimize travel operational capacity, the functionality for surface movement and potential effects from weather should be incorporated into the GBAS architecture for Category-III landings.

The Global Positioning System (GPS)/GBAS will support precision approaches to Category I (as a non-federal system), and eventually Category II/III minimums for properly equipped runways and aircraft. GBAS can support approach minimums at airports with fewer restrictions to surface movement and offers the potential for curved precision approaches. GBAS also can support high-integrity surface movement requirements.

Framework Assumptions (AOC/FOC = Airline/Flight Operations Center, ATC = Air Traffic Control, PIC = Aircraft)

Today / Near-term (current to 2010)

- (ATC) The instrument landing system (ILS) is the current standard at most major airports, with the equipment and level of ILS (Cat I/II/III) based on level of traffic and the level of weather impact.

- (PIC) Aircraft equipment and pilot training can impact the ILS Cat the flight is able to use.
- (AOC/FOC, PIC) Some aircraft operators equip and train to a cost/benefit level for the normal operations at the airport.
- (ATC) RNAV approaches have been developed at number of airports
- (ATC) RNAV STARS have been developed for a number of airports
- (ATC) Surface radar is installed at most of the major airports for tracking surface operations
- (ATC, PIC) Visual observation on surface operations is still the primary mode used today with pilot position reports as a supplements

Mid-term (2010-2018)

- GBAS is based on the current RNAV equipment and, augmented by Local Area Augmentation System (LAAS), transition should be seamless.
- Current RNAV approach development should lead to rapid transition to GBAS approaches.
- Current satellite systems are being upgraded to block IIF and eventually block III. Note – KS-M suggests that, based on her knowledge of satellite launch schedules, this date will not be met. I have asked her for more information and/or to change the words appropriately. Standing by for feedback.
- Ground based system is currently being tested at Memphis.
- Transition from ground based equipment to satellite based will be cost driven for both the FAA and customers life cycle of equipment and airport needs will be a factor.
- Based on the cost to upgrade aircraft equipment, the development of a program atmospheric impact on system may be needed.

Far-term (2018-2025)

- Continue development as needed.
- New civilian frequency for GPS (L5) will be available by 2015

Weather Integration Considerations – Infrastructure Roadmap (IR)

- Enhanced Forecasts – Forecasts of Space Weather - solar activity can degrade GPS signal

<u>Issues/Risks/Comments</u>

The effects of weather and its integration within GBAS calculations may be driven by functions that perform differential corrections (to improve accuracy), integrity monitoring (to ensure that errors are within tolerable limits with a very high probability and thus ensure safety), and ranging (to improve availability). Additional corrections of the GPS may be necessary due to ionospheric scintillation. However, new GPS receivers and codes are being implemented that will allow ionospheric ranging errors to be removed. In the late mid-term, aircraft based systems including radar and imaging sensors may be used to confirm the aircraft's position by comparing sensor data to databases of terrain and cultural features, confirming and augmenting GPS/GBAS to provide enhanced accuracy and integrity. There may be additional consideration for degraded GBAS signal on the flight deck before ground-based detection. This would infer the need for weather integration into cockpit avionics for this application.

Integrated Work Plan (IWP) Review

The IWP OI which supports the IFTE NIP Swim Lane capabilities for GBAS is OI-0381 GBAS Precision Approaches (2017). It is envisioned that a single GBAS system would provide precision-approach capabilities to multiple runways or landing areas when combined with other technologies such as enhanced lighting systems.

GBAS provides a service that is robust to atmospheric phenomena that might cause loss of Satellite-Based Augmentation Systems (SBAS) vertical guidance. However all radio systems which rely on radio wave communication through the atmosphere are sensitive to the effects of atmospheric disturbances such as those produced by solar storms. Space weather impacts on GNSS include the introduction of range errors and the loss of signal reception. As such, the arrival (begin time), duration, or end time of solar radiation maximums, geomagnetic storm activity, solar flares, coronal mass ejections and other high solar energy, radio blackout or degraded communication frequency events may be needed. The space weather performance and fidelity requirements will need to be determined.

No supporting enablers were identified.

REDAC Review

Nothing noted

Weather/ATM Integration Conference Review

Nothing noted

Far-term Capabilities

Provide Surface Situation to Pilots, Service Providers and Vehicle Operators for All-weather Operations

Aircraft and surface vehicle positions are displayed to air navigation service providers (ANSP) and equipped aircraft and vehicles. This capability increases situational awareness in restricted visibility conditions and provides more efficient surface movement.

Weather Integration Considerations – Infrastructure Roadmap (IR)

- Weather Information in user specified resolution for integration to DSTs
- Provide Improved Weather Information Distribution

Issues/Risks/Comments

- Weather capability support: Near-real time dissemination of weather information
- To all ground users: High resolution observed visibility

ADS-B Services to Secondary Airports

Expanded Automatic Dependent Surveillance-Broadcast (ADS-B) coverage, combined with other radar sources, provides equipped aircraft with radar-like services to secondary airports. Equipped aircraft automatically receive airborne broadcast traffic information. Surface traffic information is available at select non-towered satellite airports.

Weather Integration Considerations – Infrastructure Roadmap (IR)

None listed

A-3.2 Trajectory Management

Near-term Commitments

Limited Use of Continuous Descent Arrivals at SDF, LAX, ATL

This will extend the use of Continuous Descent Arrivals during very low traffic situations at Louisville, Los Angeles, and Atlanta so that aircraft can perform efficient, low noise and low pollution arrivals.

Weather Integration Considerations – Infrastructure Roadmap (IR)

None listed

Mid-term Capabilities

A-3.2.1 Use Optimized Profile Descent

Optimized Profile Descents (OPDs) (also known as Continuous Descent Arrivals -- CDAs) will permit aircraft to remain at higher altitudes on arrival at the airport and use lower power settings during descent. OPD arrival procedures will provide for lower noise and more fuel-efficient operations.

Comments

The integration of high resolution terminal winds into aircraft equipped with onboard energy management guidance systems may allow these aircraft to fly precise 4DTs that are highly optimized for fuel efficiency. Minimally equipped aircraft, in contrast, may fly a more basic OPD that simply applies idle thrust wherever possible. In addition, the precise 4DT flown by an aircraft on an OPD will vary by a number of factors including winds aloft, aircraft weight, and top of descent point.

Although this capability focuses on the need for accurate winds aloft data for OPD operations, pilots and controllers will need more information in order to consistently plan and complete

OPDs, such as improved observations and forecasts of winds and hazards to aviation such as convectively induced turbulence (CIT), clear air turbulence (CAT), lightning and hail. Further investigation of these weather factors, any or all of which can impact OPD operations, and how to integrate them into OPD-related decision support tools, needs to be undertaken in order to improve OPD planning and operations.

To that end, existing airborne capabilities of measuring wind, turbulence, temperature, humidity and icing need to be improved and fully leveraged. Processes which enable and encourage the transmission of this information to ground systems and adjacent aircraft must be developed, and then that information must be incorporated into weather forecast models and ATM and onboard decision support tools as appropriate

<u>Framework Assumptions</u> (AOC/FOC = Airline Operations Center, ATC = Air Traffic Control, PIC = Aircraft)

Today / Near-term (current to 2010)

- Current arrival procedures limit OPD to low traffic volume times, late night and mid-night operations.
- Current TRACON Controllers lack DST's to support OPD operations.
- Current weather forecast provides limited use for the detailed preplanning of OPD operations.

Mid-term (2010-2018)

- Develop arrival procedures to enable pilots and equipped aircraft to utilize OPD operations.
- Increase the scale of terminal forecast to provide for OPD planning and operations
- Improved airborne observation capabilities including near real-time wind, turbulence, temperature, humidity and icing will be used to improve OPD planning and operations, along with the 4-D4-D Wx Data Cube and the 4-D Wx SAS

Far-term (2018-2025)

- ADS-B will allow aircraft to aircraft separation and link aircraft to follow each other.

<u>Weather Integration Considerations – Infrastructure Roadmap (IR)</u>

Enhanced Forecast – Terminal Winds

<u>Issues/Risks/Comments</u>

- Model output – Improved Forecast of Winds throughout descents
- 4-D Wx SAS – Improved Forecast Winds throughout descent
- Sensors feeding the 4-D Wx SAS: Wind shear detection (e.g. LLWAS), ASR-WSP, TDWR, LIDAR, ASR-8/9/11, NEXRAD, F-420, DASI, ASOS, AWOS, AWSS, SAWS, NextGen Surface Observing

- NextGen surface observation sensors that are networked and then combined to form a common, de-conflicted weather source

<u>Integrated Work Plan (IWP) Review</u>

The IWP OI which supports the IFTE NIP Swim Lane capabilities for OPD is OI-0329 Airborne Merging and Spacing with OPD (2015). This OI suggests that, together with airborne merging and spacing capability and airborne guidance, optimized OPD is performed while staying within assigned lateral and vertical airspace corridor limits. This results in improved individual aircraft fuel reduction through onboard energy guidance and enables reduced spacing buffers (increased throughput from precision airborne spacing). This OI requires an Implementation Decision to determine appropriate trajectory restrictions laterally, vertically, and in time, based on trade off between aircraft performance/efficiency versus optimal use of airspace, including weather and environmental constraints.

It would seem that the eventual migration of the Descent Advisor functionality would be the likely target for weather integration of high resolution terminal winds and wind shear zones. Tools that help determine compression spacing needs would also likely need similar weather information integration.

<u>REDAC Review</u>

Nothing noted

<u>Weather/ATM Integration Conference Review</u>

A key finding from the report was the need for common de-conflicted forecast winds throughout descent. This was specifically illustrated in the finding that NextGen Network Enabled Weather (NNEW) needs to provide wind observations along descent approaches to support high density operations, and analysis needs to be conducted to determine the performance requirements of these wind observations.

Conference attendees noted that strong winds, combined with wind shear between vertical layers, lead to trajectory complexity that limits the ability of human controllers to maintain high density operations. In order to address the super density compression problems resulting from these wind conditions, controllers need automation assistance. This automation will require accurate and timely wind observations along descent approaches.

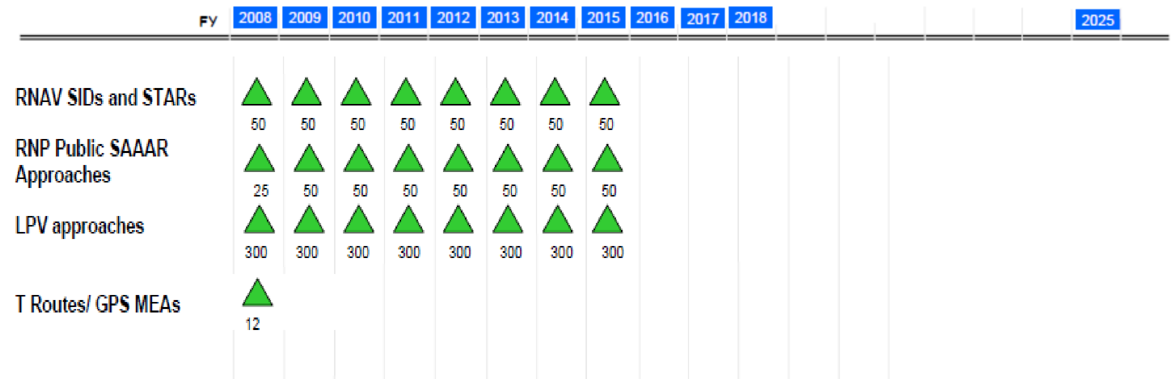
During “nominal” days, weather information is needed to support high density operation automated capabilities (e.g., merging and spacing, Continuous Descent Approaches (CDA), wake vortex procedures, runway configuration management). For example, CDAs and wake vortex avoidance are anticipated to create high temporal and spatial wind observation and reporting requirements. These and other SDO routine weather requirements need to be determined.

It is noted that the Weather/ATM Integration Conference report findings are consistent with the IWP language and interpretation for weather integration for CDAs.

<u>Far-term Capabilities</u>

None currently planned

A-3.3 Capacity Management



<u>Near-term Commitments</u>

RNAV SIDs and STARs

This will provide additional Standard Instrument Departures and Standard Terminal Arrival Routes based on increased RNAV equipage at more locations.

<u>Weather Integration Considerations – Infrastructure Roadmap (IR)</u>

None listed

RNP Public SAAAR Approaches

This will provides additional RNP public Special Aircraft and Aircrew Requirements based approaches at more locations.

<u>Weather Integration Considerations – Infrastructure Roadmap (IR)</u>

None listed

LPV Approaches

This will provide vertically guided approaches at more locations. When vertical guidance is not possible, an LP approach is provided.

<u>Weather Integration Considerations – Infrastructure Roadmap (IR)</u>

None listed

T Routes/GPS Minimum enroute Altitudes (MEAs)

This will provide RNAV routes (Tango routes and GPS MEAs) in support of Airspace Management Program and industry requests.

<u>Weather Integration Considerations – Infrastructure Roadmap (IR)</u>

None listed

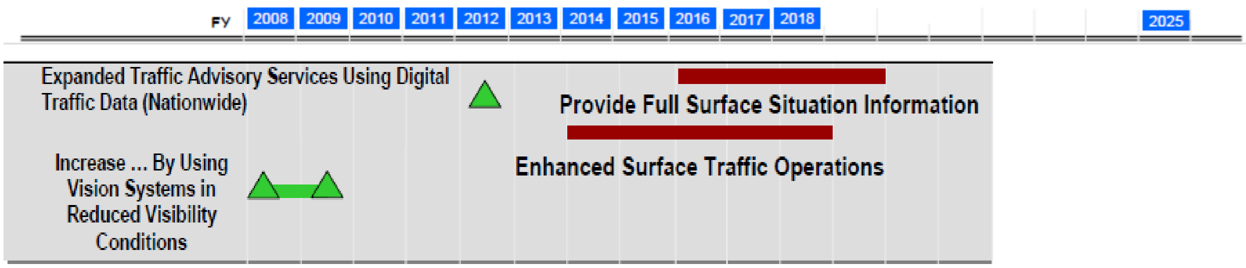
<u>Mid-term Capabilities</u>

None currently planned

<u>Far-term Capabilities</u>

None currently planned

A-3.4 Flight and State Data Management



<u>Near-term Commitments</u>

Expanded Traffic Advisory Services Using Digital Traffic Data (Nationwide)

Surrounding traffic information will be available to the flight deck, including Automatic Dependent Surveillance (ADS) information and the broadcast of non-transmitting targets to equipped aircraft. Surveillance and traffic broadcast services will improve situational awareness in the cockpit with more accurate and timely digital traffic data provided directly to aircraft avionics for display to the pilot.

<u>Weather Integration Considerations – Infrastructure Roadmap (IR)</u>

None listed

Increase Access, Efficiency, and Capacity by Using Vision Systems in Reduced Visibility Conditions

Vision systems will enable more aircraft to land, roll out, taxi, and take off in reduced visibility conditions, thus increasing access, efficiency, and capacity.

<u>Weather Integration Considerations – Infrastructure Roadmap (IR)</u>

None listed

<u>Mid-term Capabilities</u>

A-3.4.1 Provide Full Surface Situation Information

Automated broadcasts of aircraft and vehicle positions to ground and aircraft sensors/receivers will be used to populate a digital display of the airport environment. Aircraft and vehicles will be identified and tracked, providing a full comprehensive picture of the surface environment to the Air Navigation Service Provider (ANSP), equipped aircraft, and Airline Operations Centers (AOC/FOCs).

Decision support tool (DST) algorithms will use this enhanced target data to support identification and alerting of those aircraft at risk of runway incursion. This surface situation information will complement visual observation of the airport surface. Service providers, AOC/FOCs, and equipped aircraft need an accurate real time view of airport surface traffic and movement, as well as obstacle location, to increase situational awareness of surface operations. Currently, this can be difficult because of several factors, including, but not limited to poor visibility caused by weather or nighttime conditions.

General Comment

Although the above description would suggest that this OI is only about displaying surface traffic information to pilots, dispatchers and controllers, the underlying OI and EN would lead one to believe that there are traffic management decision support tools that are part of, or associated with, this capability. Consequently, the associated weather integration needs will be viewed from that traffic management DST perspective. That integration of airport weather, both current and forecast will be needed to develop a complete picture of airport operation. In the development of a plan for airport operations, weather is an integral part.

Framework Assumptions (AOC/FOC= Airline/Flight Operations Center, ATC = Air Traffic Control, PIC = Aircraft)

Today / Near-term (current to 2010)

- Surface operations are human based at the present time.
- Weather information is based on METAR for current conditions and TAF for forecast weather.

Mid-term (2010-2018)

Far-term (2018-2025)

Weather Integration Considerations – Infrastructure Roadmap (IR)

None listed

Issues/Risks/Comments

- No weather supported by this timeframe

Comments

See the General Comment above, and note the REDAC and JPDO Weather/ATM Integration Conference reports below, all in light of the supporting OI and EN.

The level of detail required of both observed and forecast weather will be much greater than current METARs and TAFs. Weather forecast will need to be tailored to the airport needs and operations.

Integrated Work Plan (IWP) Review

There are two Integrated Work Plan (IWP) Operational Improvements (OIs) and supporting enabler elements (ENs) identified that support the IFTE NIP Swim Lane capabilities for providing full surface situation information. These are highlighted below.

OI-0331 Integrated Arrival/Departure and Surface Operations (2018) describes the integration of advanced arrival/departure flow management with advanced surface operation functions to improve overall airport capacity and efficiency. Associated decision support tools enable ANSP flow managers to work collaboratively with flight operators and with ANSP flow contingency managers to effectively manage high capacity arrival and departure flows in the presence of various weather conditions.

EN-0026 - Surface Movement Decision Support - Level 2 Mid-term (2015) describes tools needed to enable safe and efficient flow of aircraft and ground equipment on the surface. This includes decision support automation for efficient flow management, real time information distribution, such as runway braking action reports, and ground-based runway incursion detection and alerting.

REDAC Review

(4.4.2.3) Finding: Integrating Airport Surface and Terminal Area Weather and ATM Tools could improve system performance and capacity.

Surface and terminal airspace operations could be improved if weather and traffic information were combined into a single system that computes the impact of the weather on potential traffic management decisions and provides the results in simple, easily understood display of decision options.

Recommendations: Expand the use of route availability tools to integrate airport and terminal area weather data and ATM Tools.

Expand the deployment of integrated tools, such as route availability, to additional airports and terminal regions to improve NAS performance at the largest airports impacted by convective activity.

Conduct research on enhancing the Traffic Management Advisor (TMA) to achieve a weather sensitive arrival planning tool.

Integrate RAPT, ITWS, DFM and TMA with surface management systems to provide a singular terminal management tool spanning departures, arrivals and surface movement. Consider common use by air traffic and operators for collaborative decisions.

Comment

It would seem that REDAC deemed the impact of weather on potential traffic management decisions to be important. While this is true, the DST should provide the guidance and the user of the DST should ultimately determine the impact.

Weather/ATM Integration Conference Review

The JPDO Weather/ATM Integration Conference provided a significant amount of feedback concerning runway surface information, as detailed below.

Section 2: Airport Operations

Finding: Need for improved forecasts of runway conditions.

The next area of research which was agreed upon was the need for better sensing and runway condition forecasts. With improved forecast reliability and accuracy, operators would be able to better trust in the weather information they were given. This would then allow them to more efficiently plan around anticipated hazardous weather events.

Finding: Need to take into account an integrated approach to weather impacts on airport parking, terminal and ramp areas, surface maneuvering of all vehicles, as well as aircraft.

Finding: De-icing activities need reduced costs and increased flexibility.

Continued research toward more efficient and environmentally-friendly anti/deicing methods/technologies was seen as highly beneficial by the group. An improvement toward more environmentally-friendly methods/technologies was seen as having the dual benefits of decreased costs and increased flexibility in usage. Increased efficiency of anti/deicing methods would also increase the efficiency of overall operations. Additionally, alternative delivery methods of both runway and aircraft deicing fluids were determined to be necessary avenues of research for the same reasons.

The group concluded that deicing by aircraft type would be advantageous in two primary ways. First, this would help to increase the safety of operations by maximizing the benefits gained. Second, this would help to reduce cost and economic impact by minimizing potential inefficient use of deicing fluids.

Recommendation: Address runway sensors that are non-representative of actual conditions. Improve runway forecasts' accuracy and reliability.

Recommendation: Develop and validate a requirements matrix to address user needs for weather as integrated with various surface movement operations.

Recommendation: Deicing should be standardized by aircraft type.

Finding: Derive and validate metrics from operational users.

The metrics to use would be the ability to predict delta from scheduled departure time from the gate and off runway during weather impacted operations. It is important that additional metrics be both derived and validated from operational users to insure their accuracy and applicability.

Weather Integration focus from the Airport Operations sub group

While the group's findings were on envisioned improvements in runway condition forecasts and de-icing techniques, via research initiatives, true weather integration into current operational or planned decision support functionality was not identified. The high confidence in forecast perception for runways is noted and must be well considered when weather information fidelity performance requirements are identified. The integration of runway/taxi/ramp/gate surface temperatures together with the onset/cessation of icing conditions into airport management decision tools would provide greater proactive guidance which in turn could lead to greater surface movement and de-icing efficiencies.

The group did start to address more weather integration issues with the identification of the numerous surface movement activities that should be integrated with regard to weather impact.

Each of the identified activities will have decision issues in time and location on the airport that may be affected by weather. These need to be examined for commonality so that differing activities affected by weather in similar ways can be better coordinated.

The discussion on metrics was very important in regard to weather integration in that operational metrics must be considered over more traditional meteorological metrics. This will eventually prove user perceived value. Operational metrics of user value will also drive weather integration fidelity performance requirements.

Trajectory Based Operations (TBO)

<u>Finding:</u> Need to quantify the effect of weather on the ability for aircraft to meet ‘wheels off time’ while still on the ground, to maintain a given trajectory, and to arrive at designated waypoints at expected points in time.

The ability for an aircraft to meet ‘wheels off time’ initiates a TBO construct. The continued ability of an aircraft or a flow of aircraft to maintain a given trajectory and/or arrive at designated waypoints at expected times are equally critical to successful TBO. Current weather, forecasted weather and its affect on aircraft performance will disrupt all these abilities. Equipage and unique agency concepts of operations will need to be taken into account.

<u>Recommendation:</u> There is a need to conduct TBO and weather research (e.g., time-based research) that overlaps with airport surface movement and weather research to understand and categorize wheels off departure/wheel on arrival times. This could be enhanced through the combined use of ground vehicles and aircraft sensors to determine position.

<u>Recommendation:</u> Research is needed to establish a set of agreed-upon thresholds that are not based on operations as described earlier, but based on aircraft performance and requirements for safe operation for weather phenomena such as icing for deicing, lightning for refueling, etc. Similar issues as previously identified emerge, such as what are the risk factors, who has authority to take the risk, levels of action (go/no/go) or can there be shades (red/yellow/green).

Super Density Operations (SDO)

A major conclusion identified by the Super Density Operations (SDO) group was that weather integrated into various SDO (automated) solutions may be different by location – due to varying operational nuances in major terminal areas. Weather research initiatives for SDO must be an early NextGen priority to identify specific airport impacts (both today and in NextGen).

It was also noted that a lack of wind velocity (calm wind conditions) can increase runway occupancy time and be considered “off-nominal.” Airport surface weather needs to be considered along with the weather conditions on approach and departure trajectories to maximize the efficient utilization of both airports and airspace.

<u>Weather Integration focus from the SDO sub group</u>

It seems that the significance of the comments from the SDO sub group is that each airport will likely have its own set of important operational thresholds. While the weather fidelity or performance attributes can be the same (such as from the 4-D Wx SAS), the impact trigger thresholds will vary and as such, decision support tools should be made to allow for adaptative control with regard to weather information. This could be a 'pull' type set up from the tool end or a 'push' type set up from the 4-D Wx SAS end.

A-3.4.2 Enhanced Surface Traffic Operations

Data communication between aircraft and Air Navigation Service Provider (ANSP) will be used to exchange clearances, amendments, requests, NAS status, weather information, and surface movement instructions. At specified airports data communications is the principal means of communication between ANSP and equipped aircraft.

Among the information being sent to the aircraft and integrated into on-board aircraft systems will be On-Demand NAS Information from the Super Computer Aided Operational Support System (S-CAOSS), the tower platform for Data Comm Program Segment 1 (NAS EA OI: 103305, 2013-2017). Terminal aeronautical information will be available to equipped aircraft and provided on demand via data communications between the FAA ground automation and the aircraft. This includes current weather, altimeter settings, runways in use, and other departure and destination airport information.

<u>Framework Assumptions</u> (AOC/FOC = Airline/Flight Operations Center, ATC = Air Traffic Control, PIC = Aircraft)

Today / Near-term (current to 2010)

Mid-term (2010-2018)

Far-term (2018-2025)

<u>Comments</u>

- The question of how will weather be used/integrated into DSTs for tower taxi route generation needs attention. It would appear that the condition of the airport runway, taxiway and ramp surfaces will play a role in determining how quickly an aircraft can move between two points on the airport surface, and that DSTs (e.g., taxi route generators) which calculate and suggest surface movement trajectories have to take this into account. Similarly, changing surface weather conditions and/or surface/boundary layer weather must have an influence on taxi route generation, especially when shifting combined with arrival and departure flows drive runway configuration changes. Improved airborne observation capabilities including near real-time wind, temperature, humidity and icing may be used to improve understanding of surface weather conditions and its impact on aircraft movement on the airport surface.
- The generation of initial and revised departure clearances and taxi route clearances direct to the aircraft will require changes to both aircraft and aircraft operator, automation, e.g., aircraft communication management units and possibly AOC/FOC operations management automation systems.

<u>Weather Integration Considerations – Infrastructure Roadmap (IR)</u>

Enhanced Forecasts - Surface Conditions and Terminal Weather.

<u>Issues/Risks/Comments</u>

- Ground-to-Air Data Communications
- NextGen WP1 – Enhanced Forecasts – Surface Conditions
- 4-D Wx SAS - Enhanced Observations
- Sensors feeding the 4-D Wx SAS: Wind shear detection (e.g. LL-WAS), ASR-WSP, TDWR, LIDAR, ASR-8/9/11, NEXRAD, F-420, DASI, ASOS, AWOS, AWSS, SAWS, NextGen Surface Observing

<u>Integrated Work Plan (IWP) Review</u>

There is an Integrated Work Plan (IWP) Operational Improvement (OI) and supporting enabler element (EN) identified that support the IFTE NIP Swim Lane capabilities for providing full surface situation information, both of which are highlighted below.

OI-0327 - Surface Management - Arrivals/Winter Ops/Runway Configuration (2018) calls for improvements in efficiency and safety of surface traffic movement, with a corresponding reduction in environmental impacts. Efficiency of surface movement is increased through the use of automation, on-board displays and data link of taxi instructions on arrival to properly equipped aircraft to reduce delay and environmental impacts and improve safety. This OI assumes the development of surface automation that is fully integrated with airborne operations and applies this to surface management operations.

EN-5004 - Airport GSE Surface Management System (2013) suggests that surveillance systems, either active or passive, will track Ground Support Equipment (GSE) on the airport surface. GSE location data will be available to the Ramp Operator, Air Navigation Service Provider (ANSP), and pilots as needed. Specifically, pilots will be aware of GSE movements which will be shown on flight deck situational displays. The system is needed to support low-visibility aircraft taxi operations, collision avoidance, and surface management. The system provides for interoperability between different types of GSE and aircraft.

<u>Comment</u>

The importance of this initiative is the communications aspect, and not necessarily the weather information aspect. There needs to be adequate bandwidth provided for the communication of weather information so that it can then be integrated. It is understood that other informational sources will command higher availability.

<u>REDAC Review</u>

Nothing noted

<u>Weather/ATM Integration Conference Review</u>

Nothing noted

Far-term Capabilities

None currently planned

A-4. Improved Collaborative Air Traffic Management (CATM)

This solution set covers strategic and tactical flow management, including interactions with operators to mitigate situations when the desired use of capacity cannot be accommodated. Collaborative Air Traffic Management (CATM) solution set includes flow programs and collaboration on procedures that will shift demand to alternate resources (e.g. routings, altitudes, and times). CATM also includes the foundational information elements for managing National Airspace System (NAS) flights. These elements include development and management of aeronautical information, management of airspace reservation, and management of flight information from pre-flight to post-analysis.

A-4.1 Flight Contingency Management

<u>Near-term Commitments</u>

Airspace Flow Program

Enroute congestion due to weather will be reduced by equitable management of departure times (e.g. ground delay to an airspace volume).

Integrated Surface Data: (ATL, ORD, and JFK)

Better surface flight event knowledge will be integrated into decision support tools, to improve accuracy of down-stream demand estimation and improve the use of flow management tools.

Reroute Impact Assessment and Resolution

Automation will be provided to support identification of flight-specific reroutes for weather related congestion and assessing the impact of those planned reroutes in resolving the congestion problem.

Execution of Flow Strategies

Exchange of aircraft-specific reroutes (required to resolve enroute congestion) between TFM and ATC automation.

International Flight Object Demonstration

This demonstration is part of the development of the U.S. flight object and collaboration on an international standard. It will show how, in a System Wide Information Management (SWIM) environment, subscribing to the flight object can provide continually updated status and be a vehicle for negotiation for Air Navigation Service Providers (ANSPs), AOC/FOCs, airports, and others.

<u>Mid-term Capabilities</u>

A-4.1.1 Continuous Flight Day Evaluation

Performance analysis, where throughput is constrained, is the basis for strategic operations planning. Continuous (real time) constraints are provided to ANSP traffic management decision support tools and National Airspace System (NAS) users. Evaluation of NAS performance is both a real time activity feedback tool and a post-event analysis process. Flight day evaluation metrics are complementary and consistent with collateral sets of metrics for airspace, airport, and flight operations.

Needs/Shortfall

Traffic-flow managers currently assess their performance after each day and use this information in future operations. This activity is not routine during the day, nor are consistent performance measures used among traffic flow managers. A robust suite of decision support tools is required in continuous real time. These tools will be used to monitor, evaluate, and adjust traffic flow management initiatives (TMIs). The intended purpose will be based on a commonly agreed upon set of system performance measures. The measures should impose minimum constraints on airport, terminal airspace, and enroute airspace capacity.

Operational Concept

ANSPs and users collaboratively and continuously assess (monitor and evaluate) constraints (e.g., airport, airspace, hazardous weather, sector workload, Navigational Aid (NAVAID) outages, security) and associated TMI mitigation strategies. Users and the ANSP dynamically adjust both pre-departure and airborne trajectories in response to anticipated and real time constraints. The ANSP, in collaboration with users, develops mitigation strategies that consider the potential constraints. A pre-defined set of alternatives is developed that maximizes airspace and airport capacity and throughput. The ANSP and users use (real time) constraint information and these mitigation strategies to increase operational predictability and throughput.

ANSP automation traffic management decision support tools perform a post-operational assessment of NAS performance. This capability includes ANSP automation to collect and support the analysis of airspace, airport, and flight day operational data as part of a comprehensive post-flight day analysis capability applicable to multiple domains and for multiple purposes. Flight day metrics are compared with performance metrics from each element of the system (e.g., aircraft, pilot, controller, airspace). NAS and operational resources are aligned to meet anticipated demand. This improves the ANSP pre-defined shared plans.

Long-term planning functions will improve due to continuous flight day evaluation. NAS performance will be improved and decision-makers will be able to predict and plan operations based on a validated tool.

Design/Architecture

The TFMS infrastructure will serve as the focal point for continuous flight day evaluation capability. The performance monitoring and evaluation tool suite will be integrated with other TFM decision support capabilities being developed to facilitate the identification of TFM problems, the generation and assessment of potential resolution strategies, and automation-based execution of TMIs. These other capabilities will include support for such features as reroute impact assessment, miles-in-trail impact assessment, integrated TMIs (this can include combinations of altitude, speed, and rerouting maneuvers), progressive planning (the use of multiple TMIs applied progressively to a particular traffic flow), future traffic display and congestion prediction.

Weather Integration Considerations – Infrastructure Roadmap (IR)

None listed

<u>Weather Involvement – Preliminary Review: TFM Concept Engineering Plan</u>

Performance analysis, where throughput is constrained, is the basis for strategic operations planning. Continuous (real time) constraints are provided to Air Navigation Service Provider (ANSP) traffic management decision support tools and National Airspace System (NAS) users. Evaluation of NAS performance is both a real time activity feedback tool and a post-event analysis process. Flight day evaluation metrics are complementary and consistent with collateral sets of metrics for airspace, airport, and flight operations. Concept Engineering initiatives classified in this Solution Set and promoting this Capability are listed in the table below

Table A-5 CATM Concept Engineering Initiatives

Organization	Topic	Concept Maturity
CSC	Enhanced Flight Segment Forecasting	CE
Metron Aviation	Airborne Delay Research	
Metron Aviation	Integrated Program Execution (IPE)	FSD
Metron Aviation	Integrated Program Modeling (IPM) Phase 2	PD
Metron Aviation	NextGen of FSM slot assignment logic	
Metron Aviation	Pre-day of Operations TFM concepts	
Metron Aviation	System Integrated TMIs	CE
Volpe	Analyze Uncertainty in Sector Demand Prediction	CE
Volpe	Prototype a New Metric for Sector Alerts	CE

<u>Based on the programs listed in the table above, the following programs may require integration of weather information in current or future phases:</u>

<u>1. Airborne Delay Research (Metron Aviation, CE Phase):</u> The project proposes the development of an application of existing algorithms for measuring where airborne delays occur, extension of prototype simulation capabilities to develop an Airspace Congestion Predictor (ACP), metrics for measuring existing airspace congestion, a capability to predict airborne delays and congestion, metrics for comparing candidate TFM strategies, and potential enhancement to

Jupiter. Potential weather integration needs include but are not limited to historical weather data for areas of weather impacted airspace.

2. Analyze Uncertainty in Sector Demand Prediction (VOLPE, CE Phase): The current methods used for of sector demand prediction are subjected to "flickering" as a sector goes in and out of alert status. This reduces traffic managers' confidence in the TFMS sector demand predictions. Understanding the uncertainty in the predicted demand will lead to more usable demand predictions. Previous work characterized the uncertainty in predictions of airport demand, but this analysis will analyze the uncertainty in sector demand. The results of the analysis will present predicted future demands to traffic managers in a more useful way that avoids misleading predictions and unnecessary workload. Potential weather integration needs include examining the impact of various weather phenomena such as convective weather, turbulence and in-flight icing to allow for more dynamic predictions of uncertainty in sector demand.

3. Integrated Program Modeling (IPM) Phase 2 (Metron Aviation, PD Phase): Integrated Program Modeling (IPM) is an attempt to display the interactions between AFPs and GDPs in terms of demand profiles and to aggregate delay statistics before programs are implemented. IPM Phase I, which was deployed in spring of 2008, provides the capability to model the effects of a program on multiple resources. The Phase I capability is useful for analyzing the effects of one AFP on many airports, or one GDP cancellation on many FCAs. The second, known as the IPM Phase II prototype will have the ability to see the effect of multiple AFPs on airport demand, will provide total delay estimations for combinations of GDPs and AFPs and effectiveness comparisons of AFPs versus GDPs. IPM will be a tool to support Traffic Managers to validate decisions to implement traffic management initiatives (TMIs) or to avoid unnecessary programs. Potential weather integration needs include examining the impact of various weather phenomena such as convective weather, turbulence, in-flight icing and ceiling and visibility to allow for more dynamic assessments of TMIs.

4. Pre-day of Operations TFM concepts (Metron Aviation): There are a number of airports that experience congestion on a regular basis. Some of this congestion can be traced to too many flights being scheduled collectively by all customers during busy time periods. This project will explore and evaluate concepts for conducting Traffic Flow Management activities before the day of operations using predominately airline schedule information and/or historical data. Potential weather integration needs include but are not limited to long range forecasts (12-24 hours) of convective weather, turbulence, ceiling and visibility.

5. System Integrated TMIs (Metron Aviation, CE Phase): Congestion problems on a national scale are usually remedied through Ground Delay Programs (GDPs), Airspace Flow Programs (AFPs), and national-level reroutes. These TMIs are highly structured and robust, but only address the management of demand at the constrained resource. Each program may produce residual effects at different resources throughout the NAS. System-Integrated TMIs (SIT) will research the interactions of multiple initiatives for system-wide effects. . The SIT effort will examine interactions between over-lapping initiatives. It will provide insight that will create a foundation for a pre-implementation system-impact assessment tool that provides common situational awareness, increases certainty on how multiple TMIs may interact, and provides adequate metrics to facilitate planning. Potential weather integration needs include examining the

impact of various weather phenomena such as convective weather, turbulence, in-flight icing and ceiling and visibility to allow for more dynamic assessements of TMIs.

Weather Involvement – Preliminary Review: MITRE Initial Evolution Analysis for Mid-Term Operations and Capabilities

Mid-term continuous flight day evaluation will provide performance analysis and improvement capabilities which address two distinct operational areas: current day congestion prediction and decision-making; and enhanced post operations analysis.

Current Day Congestion Prediction

Enhancements to congestion prediction will focus on improving demand and capacity prediction accuracy by integrating data from multiple sources to get a better picture of the status of the NAS. Integration of surface event data from terminal systems will improve predictions on flight departures, while integration of trajectory data from other sources, such as enroute automation, will improve accuracy and ensure consistency with the TFM-specific trajectory modeling capability.

Demand prediction will be further improved through enhanced modeling capabilities, including flight trajectory and Miles-in-Trail (MIT) restriction modeling. Modeling enhancements will provide the basis for what-if analysis and planning that will allow traffic managers to better understand the potential impacts of changing flight patterns in the NAS. Automation and displays will be enhanced to account for uncertainty and risk in predictions by depicting probability distributions, as well as to allow traffic managers to view graphical depictions of current and predicted future flight positions in conjunction with convective weather forecasts. TMs will have access to improved real time situational awareness of NAS conditions through the use of a 'NAS Performance' dashboard function. Automation will allow TMs to select from various performance metrics for display on a tailored, web-based display page, providing dynamically updated NAS situational information in a concise, integrated fashion. This display capability will be able to be tailored by Traffic Management Unit (TMU) personnel to individual requirements.

Capacity prediction improvements are another significant enhancement for TFM in the mid-term, with the most significant improvement resulting from the enhancement and integration of weather prediction information. This will allow weather information to be used not only in capacity predictions, but in demand prediction and aircraft trajectory modeling displays as well, further improving the TMs understanding of NAS status. Later in the mid-term, automation will predict sector capacity based on traffic flows and weather predictions, instead of using the Monitor Alert Parameter as a proxy for sector capacity.

Post Operations Analysis

In the mid-term, Post Operations Analysis improvements must first focus on establishing a baseline data collection, storage and analysis capability. Once this is accomplished, it will enable improvements in the ability to provide significant next day post operations analysis and operational improvements. NAS status information (such as congested routes, severe weather, and runway visibility range information) will be gathered from various TFM, Enroute

Automation Modernization (ERAM) and Terminal domain automation systems and stored according to a consistent and common information model, supporting 'what-if' analysis and prediction through stored and ad-hoc queries. A common meta-data model will maximize the ability to correlate information across multiple sources and domains.

In the later mid-term, automation will evolve to monitor and record traffic flow patterns and the TMIs taken in response to them, in addition to recording NAS situation and performance data. This advanced NAS Situation and TFM planning snapshot capability will provide for more in-depth and timely quality assurance reporting and post-ops analysis of TMI effectiveness. In the far-term, this capability could evolve to allow automation to perform comparative analysis of potential resolution actions by showing several courses of action that have historically been suggested given similar circumstances, and the historical effectiveness of each, improving the information provided to TFM planners.

<u>Weather Involvement – Preliminary Review: MIT/LL Weather Integration Roadmap</u>

<u>Weather Integration into Enhanced Congestion Prediction</u>

More accurate predictions of NAS resource congestion (enroute sector, airspace flow evaluation area and airport) are a major focus of future Traffic Flow Management concepts. Traffic managers use congestion predictions to establish the type, timing and scope of TMIs. Because of the uncertainty in today's predictions, TMs often implement highly conservative strategies as a hedge against worse-than-forecast conditions.

Uncertainty in future resource congestion arises from both inaccuracies in estimating future demand, and from very limited capability to predict the future capacity of NAS resources during adverse weather. Demand predictions today do not even fully account for the impact of currently approved TMIs (for example MIT or arrival fix restrictions), and certainly do not attempt to estimate the impact of future TMIs that may be imposed as new weather constraints develop. Quantitative, dynamic predictions of resource capacity are not currently available and as a result, TMs must subjectively estimate the impacts of adverse weather on future airport operations rates and enroute airspace capacity.

<u>Sector Demand Prediction</u>

Probabilistic resource demand predictions must model not only currently approved TMIs but the likely effects of future TMIs that will be needed in response to weather constraints that are worsening or may not yet have developed. To properly model these future flow restrictions, a NAS-wide model accounting for time-varying future resource capacities and total (scheduled and pop-up) demand is needed. Since the skill of the demand and weather constraint predictions will generally improve rapidly for shorter look-ahead times, this model must cycle rapidly (~ twice per hour) in order to take advantage of the improving information on future constraints. Development of such a real time model that fully integrates state-of-the-art weather predictions, weather-impact translations and traffic demand forecasts is a major undertaking that does not appear to be adequately supported in the current weather and TFM research portfolios.

<u>Resource Capacity Prediction</u>

"CATM Report 2007" states that CIWS forecast data will be used in the mid-term timeframe to predict the reduction in expected resource capacity. Further, for each resource and each look-ahead time, the probability distribution function of the capacity will be determined by TFM. This may be implemented for enroute sectors as a reduction in the Monitor Alert Parameters (MAP), based on the weather coverage, route blockage or other considerations. Realizing a robust capacity prediction capability will require major effort in at least three areas.

- Continued progress in diagnosing and forecasting relevant weather phenomena over the 0-8 hour time scales needed for TFM is essential with research focused on extending the look-ahead time for convective weather forecasts to 6-8 hours, and on improved 0-2 hour "nowcasts" of turbulence and airport weather conditions (ceiling and visibility, winds, winter precipitation) that effect capacity.

- Validated models for translating the weather information into quantitative resource constraint metrics are required. Research in this area is in its infancy. For airspace constraints, it is believed that approaches based on algorithms for reduction of sector MAPs are problematic. MAPs are widely recognized to be subjectively determined and inconsistent across the NAS, even during nominal conditions. Scaling of MAPs to account for weather impacts must account for the directionality of major flows within a sector and, that the associated weather blockage that may be quite different for different major flows. Objective models for airspace capacity during both nominal and off-normal conditions are likely to be more useful (e.g., Welch et al., 2007; Martin et al, 2007; Song et al., 2007) but these approaches must be integrated, validated and adapted as necessary to future, more automated ATC paradigms. Augmented research on the impacts of non-convective weather phenomena (turbulence, icing) on airspace capacity is needed, as is a more comprehensive capability for predicting weather impacts on future airport operating rates.

- Viable methods for estimating and conveying the uncertainty of future resource capacity predictions must be defined. This will require tightly coupled effort involving the meteorological forecasting and ATM research communities. It is felt that "ensemble" approaches are most likely to be effective – that is, a set of discrete weather forecasts will be developed that span the expected range of future scenarios, and these will be translated individually to associated estimates of capacity constraints on specific NAS resources. From these ensembles, appropriate metrics and visualizations of uncertainty can be transmitted to automated decision support tools and TMs.

Route Blockage and Route Congestion Prediction

In the mid-term time frame, route blockage will be determined for airport departures and arrivals and for transition and high-altitude enroute operations. This capability will expedite Departure Flow Management, in-flight rerouting and arrival management. While these concepts are based on the Route Availability Planning Tool (RAPT) already in operational use at New York City airports, considerable effort is needed to adapt the concept to departure operations at other airports, to integrate it with other information on departure constraints (surface and downstream) and to extend it to enroute and arrival operations.

A major first step is to develop flight-specific route blockage prediction capability which is tied to the aircraft trajectory (“wheels up time”, arrival-time at flight path “way points”) and to an efficient capability to determine viable alternatives when the filed route of flight is blocked by adverse weather. Route congestion prediction will require the additional development of algorithms for translating “partial blockage” scenarios into estimates of required Miles (or Minutes) in-trail constraints. The approach described by Martin et al. (2007) for calculating the impact of partial route blockage on route throughput could be interpreted in terms of increased miles-in-trail restrictions although the authors do not discuss this point explicitly nor show any experimental data to confirm this interpretation. Significant additional research is needed to determine what transpires operationally in route usage when the route availability determined by this method is intermediate between 0 and 1. More generally, there is an urgent need to validate the route blockage models for airspace usage (e.g., storm impacts on routes, merge points, use of adjacent routes carrying traffic in a given direction when one of those routes is blocked) under various degrees of intersections by weather avoidance fields (WAF).

Work (similar to the RAPT concept) needs to be expanded to explicitly forecast when arrivals deviating into departure airspace will become an operational constraint to departures. There is a research item that needs to be considered:

> There is a need to provide an enhanced capability for tactical adaptive, incremental traffic routing as a complement to “strategic” flight planning that requires much higher accuracies in 2-8 hour convective forecasts than seems achievable in the near-term. This was recommended by the REDAC WAIWG (REDAC, 2007). Also, the approach used to forecast Airspace Flow Program (AFP) throughput could be used to forecast throughput rates for “overlap AFPs” under investigation currently by the CDM Flow Evaluation Team (FET). A critical next step in evaluating the operational applications and benefits of this AFP throughput forecast will be to exercise the route blockage/flow rate restriction model with CIWS forecast products, as opposed to actual VIL and Echo Tops data used for the results reported in Robinson, Martin, Evans and DeLaura (2008). The use of specific TMIs for appropriately modulating demand through AFP regions, based on guidance from the AFP throughput model, needs to be modeled and assessed for multiple real weather case scenarios. This work would benefit from the participation from operational Traffic Management subject matter experts (SMEs). To the extent possible, benefits of the dynamic AFP rate concept would be assessed relative to actual NAS operations on the case days considered. This research work should be accomplished in close collaboration with the work underway by the CDM Flow Evaluation Team (FET) to develop “adaptive AFP” concepts.

<u>Weather Integration into Automated Airspace Congestion Resolution</u>

Automated airspace congestion resolution concepts build on improved customer information exchange and enhanced congestion prediction capabilities to provide automated assistance to TMs in developing and executing reroute and delay programs.

In the mid-term time frame (2010-2015) TFM automation will disseminate probabilistic demand and capacity predictions for all monitored NAS resources to TMs and NAS customers. TMs will specify flow evaluation areas (FEA) indicating the airspace volumes where demand may need to be reduced, and will notify customers via a Planning Advisory. After customers review this information and submit prioritized flight preferences, TMs will use the Automated Airspace Congestion Resolution capability as an aid in resolving the predicted congestion. TMs can guide the automated solution via input on preferred resolution strategies (ground delay vs. rerouting), special guidance for individual airports, maximum ground delay and maximum distance increase for reroutes.

In the initial phase (2011-2014), the current FAA plan is to implement an initial Automated Airspace Congestion Resolution (AACR) capability in which the TMs will identify the Flow Evaluation Areas (FEAs) and then the automation will propose a single, one-time resolution that will attempt to resolve the congestion that arises from the FEA all at once.

In the post 2011-2014 time frame, TFM automation will identify the congestion problems and candidate FEAs and will propose incremental resolutions that maintain congestion risk at an acceptable level, while retaining the flexibility to modify the or expand the resolutions as the future demand and constraint situation evolves. This approach will presumably reduce the number of flights affected by the initial TMIs. Thus if the congestion problem turns out to be less severe than originally forecast, the overall impact on customer operations will be reduced.

Weather Integration into Phase 1 Mid-Term Automated Airspace Congestion Resolution

An efficient "one time" automated congestion resolution would require high fidelity forecasts of the weather out to 0-6 hours as well as accurate translation of these forecasts into capacity impacts. Although multi-hour CoSPA forecasts of convection will be introduced during this phase, it is to date uncertain as to whether their accuracy (or the accuracy of necessary weather-capacity impact models) will be sufficient to support such onetime resolutions. In addition, errors in the capacity forecasts will translate into uncertainty about what future flow constraints will be necessary. This uncertainty in turn will result in errors in demand prediction that will also make one time, automated congestion resolution strategies very problematic.

One view is that in the 2010-2015 timeframe, the major emphasis should be on improving the performance of human TMs through the provision of increasingly high quality information on future constraints. This capability will fall out of the enhanced information exchange and congestion prediction thrusts described previously, and will lead to both better NAS operational performance and "real-world" experience with strategies for exploiting the enhanced information to improve congestion resolution.

It is recommended that proposed concepts for these Phase 1 congestion resolution strategies be vetted through analysis and HITL simulations using realistic projections for future weather forecast capabilities. This should be accomplished as a precursor to any investment decision in this area to quantify the frequency with which the automated congestion resolution produces substantive investment decisions.

A-4.1.2 Traffic Management Initiatives with Flight-Specific Trajectories (Go Button)

Individual flight-specific trajectory changes resulting from Traffic Management Initiatives (TMIs) will be disseminated to the appropriate Air Navigation Service Provider (ANSP) automation for tactical approval and execution. This capability will increase the agility of the NAS to adjust and respond to dynamically changing conditions such as bad weather, congestion, and system outages.

<u>Needs/Shortfall</u>

The current automation does not support the assignment of flight-specific trajectories. The ANSP needs to incrementally perform more surgical flight-specific TMIs that will be less disruptive to the system.

<u>Operational Concept</u>

Traffic Flow Management (TFM) automation prepares TMIs appropriate to the situation at the flight-specific level. After ANSP approval, changes/amendments are electronically delivered to the controller for in-flight operations.

<u>Design/Architecture</u>

Traffic managers and applications within the TFMS infrastructure will interact with air traffic controllers and Enroute Automation Modernization (ERAM) to implement this capability. TFMS automation will support identification of flights that are subject to TMIs. The TFMS automation will then communicate the requested flight plan adjustments to ATC automation for tactical evaluation, approval, and execution of those flights subject to TMIs, to bring them into conformance with the TMIs.

<u>Weather Integration Considerations – Infrastructure Roadmap (IR)</u>

While no weather integration considerations were identified in the Infrastructure Roadmap, space weather alerts should be integrated into TFM to allow for aircraft altitude adjustments during significant solar activity.

<u>Weather Involvement – Preliminary Review: TFM Concept Engineering Plan</u>

No specific plans noted.

<u>Weather Involvement – Preliminary Review: MITRE: Initial Evolution Analysis for Mid-Term Operations and Capabilities</u>

TFM automation will continue to incorporate enhancements, including decision support tools to enable the collaborative process among service providers and NAS users in the development and implementation of congestion resolutions. Decision support tools will encompass integration of probabilistic information, management of uncertainty, what-if analysis, and incremental resolution of alternatives supporting development and implementation of flexible, incremental traffic management strategies to maintain the congestion risk to an acceptable level and to minimize the impact to the flights involved in the congestion. The strategies are monitored and modified or canceled to avoid underutilization of resources and over conservative actions.

The resolutions may include one or more TMIs such as ground delay, reroutes, altitude profile changes, airspace schedules and if necessary miles-in-trail. The automation will propose to the traffic manager flight-specific tailored resolutions or changes (reroutes, altitude, schedules changes) that take into account and accommodate NAS user preference when possible. Impact assessment of the resolution is also presented to the traffic manager to enable the decision to modify, cancel or execute a given initiative.

Once the traffic manager decides on the initiative, flight-specific changes are disseminated with automation support ("Go Button") to ATC personnel and NAS users to enable the implementation of the strategy and maintain common situational awareness (i.e., knowing why a given flight has been changed).

Weather Involvement – Preliminary Review: MIT/LL Weather Integration Roadmap

No specific plans noted.

Far-term Capabilities

TBD

A-4.2 Capacity Management

Near-term Commitments

Currently, there are no defined near-term commitments.

Mid-term Capabilities

A-4.2.1 Improved Management of Airspace for Special Use

Assignments, schedules, coordination, and status changes of special use airspace (SUA) are conducted machine-to-machine. Changes to status of airspace for special use are readily available for operators and Air Navigation Service Providers (ANSPs). Status changes are transmitted to the flight deck via voice or data communications. Flight trajectory planning is managed dynamically based on real time use of airspace.

Needs/Shortfall

Both National Airspace System (NAS) service providers and NAS users need a common, accurate, and timely understanding of the status of SUAs so that their collaborative planning and decision-making can be done both efficiently and effectively. Currently, although most daily SUA status information is readily available in electronic form for immediate use by enroute and/or traffic flow management (TFM) automation via the Federal Aviation Administration's (FAA's) Special Use Airspace Management System (SAMS), there has been no integration of this information across FAA systems. Automated computer–to-computer communications, with acknowledgements, is needed between the Department of Defense scheduling agencies and SAMS.

Operational Concept

Airspace use is optimized and managed in real time, based on actual flight profiles and real time operational use parameters. Airspace reservations for military operations, unmanned aircraft system flights, space flight and re-entry, restricted or warning areas, and flight training areas are managed on an as-needed basis. Enhanced machine-to-machine communications and collaboration enables decision makers to dynamically manage airspace for special use, increasing real time access and use of unused airspace. This will enable ANSP decision support tools, integrated with machine-to-machine flight planning, to have increased access and improved coordination of airspace use. Flight deck automation is enhanced to include data communications capabilities and to recognize SUA-encoded data. The SUA status is available via uplink to the cockpit in graphical and automation-readable form, supporting pre-flight and in-flight planning.

Aircraft and Operator Requirements

There are no aircraft or operator requirements associated with this capability. Operators can choose the degree to which they use the SUA scheduling information in their flight planning. Operators choosing to participate in this capability must interface their airline operations center with SWIM. Aircraft equipped with Flight Information Service-Broadcast (FIS-B) can receive SUA status in the cockpit.

Design/Architecture

The source of information regarding the definition and status of SUAs is likely to be SAMS. This information will be shared among NAS stakeholders during flight planning, supported by the SWIM infrastructure. The Surveillance Broadcast Services (SBS) will distribute this information to the aircraft.

Weather Integration Considerations – Infrastructure Roadmap (IR)

None listed

Weather Involvement – Preliminary Review: TFM Concept Engineering Plan

None listed.

Weather Involvement – Preliminary Review: MITRE Initial Evolution Analysis for Mid-Term Operations and Capabilities

Airspace use is optimized and managed in real-time, based on actual flight profiles and real-time operational use parameters. Airspace reservations for military operations, unmanned aircraft system flights, space flight and re-entry, restricted or warning areas, and flight training areas are managed on an as-needed basis. Enhanced machine-to-machine communications and collaboration enables decision-makers to dynamically manage airspace for special use, increasing real-time access and use of unused airspace.

This will enable ANSP decision-support tools, integrated with machine-to-machine flight planning, to have increased access and improved coordination of airspace use.

Flight deck automation is enhanced to include data communications capabilities and to recognize SUA-encoded data. The SUA status is available via uplink to the cockpit in graphical and automation-readable form, supporting pre-flight and in-flight planning.

No specific weather integration needs were identified.

Weather Involvement – Preliminary Review: MIT/LL Weather Integration Roadmap

None listed.

Far-term Capabilities

TBD

A-4.3 Flight and State Data Management

Near-term Commitments

Currently, there are no defined near-term commitments.

Mid-term Capabilities

A-4.3.1 Trajectory Flight Data Management

Trajectory Flight Data Management will improve the operational efficiency and increases the use of available capacity by providing for improved flight data coordination between facilities. This will enable access to airports by readily facilitating reroutes. Additionally, it will support more flexible use of controller/capacity assets by managing data based on volumes of interest that can be redefined to meet change to airspace/routings. Trajectory Flight Data Management will also provide continuous monitoring of the status of all flights – quickly alerting the system to unexpected termination of a flight and rapid identification of last known position.

Needs/Shortfall

The current flight data management systems are a related set of functionalities that are not complementary, limiting the ability of various Air Traffic Management (ATM) processes to link decisions. The current system has limited capacity, which forces a reliance on Official Airline Guide (OAG) for future schedules and the use of historical routings in the strategic flow planning. Computational efficiencies required by legacy computer systems inhibit the ability to distribute and share flight progressive information and coordination leading to limitations on clearance management. Further, there is a fundamental need to facilitate trajectory negotiation and update in a collaborative manner if both the traffic flow objectives of ANSPs and NAS airspace users' flight preferences are to be met. Currently, ANSPs use a variety of traffic management initiatives (TMIs), scheduling tools, and trajectory-based operations agreements. These achieve the traffic flow management (TFM) goal of balancing air traffic demand with system capacity to ensure the safe, orderly, and expeditious flow of air traffic while minimizing delays. At the same time, airspace users need approved flight plans that match, as closely as possible, their operational needs.

Operational Concept

In trajectory flight data management, there will be complete end-to-end management of the flight from pre-flight to post analysis. Flight planning and filing will be supported up to flight departure. This will replace reliance on OAG for future schedules and historical routing to identify potential flight profiles and will provide information commensurate with development of longer-term strategic flow initiatives. Further, by filing early, the user will receive updates until departure date, identifying changes in constraint status, and permitting early reevaluation and replanning of the flight. This will include restrictions for special events or planned NAS outages. The flight plan management system will use "volumes of interest" to determine the relationship of the projected trajectory and the interest of service providers. This supports the separation assurance and advisory services through more flexible distribution of flight data, the automatic generation of point-outs and the coordination functions for control of aircraft. This move to volumes will also mean that the flight data management system can support user preference from runway-to-runway without requiring any fixed-routing segments for processing. The flight data processing system will increasingly incorporates flight data information provided by the flight deck into the trajectory and conformance modeling, improving the support to service-provider and decision support tools.

Finally there will be a change in the "ownership" of the active profile. Changes to flight profiles beyond the window of the tactical service providers will be negotiated with a strategic planner and updated without requiring tactical service-provider involvement. This will reduce the workload on the tactical-provider while placing responsibility in the hands of strategic-flow, ensuring change will be consistent with current flow objectives.

Design/Architecture

This integrated advancement will leverage new capabilities in TFM and Enroute Automation Modernization (ERAM), as well as allow for expanded opportunities by the flight object to move to a full trajectory flight data management. This will be made possible by the implementation of System-Wide Information Management (SWIM). This implementation will also require the NAS to move to a common information grid structure.

Weather Integration Considerations – Infrastructure Roadmap (IR)

Improved Observations, Enhanced Forecasts and a de-conflicted common weather picture is needed.

Weather Involvement – Preliminary Review: TFM Concept Engineering Plan

Trajectory Flight Data Management will improve operational efficiency by increasing the use of available capacity. Advanced flight data coordination between facilities will maintain access to airports by facilitating reroutes, and supporting more flexible use of controller/capacity assets. By managing data based on volumes of interest, airspace/routings can be redefined to accommodate change. Trajectory Flight Data Management will also maintain continuous monitoring of the status of all flights, quickly alerting the system to unexpected termination of a flight and rapid identification of last known position. Concept Engineering initiatives classified in this Solution Set and promoting this Capability are listed in the table below.

Organization	Topic	Concept Maturity
Metron Aviation	Additional AFP Capabilities and Usage	CE
Metron Aviation	Environmental Modeling & Analysis of TFM performance (fuel burn estimation)	
Metron Aviation	Reroute Impact Assessment (RRIA)	CD
Metron Aviation	Special Use Airspace (SUA) Information Research	

Based on the programs listed in the table above, the following programs may require integration of weather information in current or future phases:

1. Control by CTA (Metron Aviation, CE Phase): The objective of a GDP is to create a managed flow of arrivals within the capacity of the arrival airports constraints. However, the GDPs are implemented at the departure end by assuming that flight operators will prefer to fly the same ETE. This ignores additional constraints that may exist in the airspace or at the departure airport. This research proposes the development of the concept for managing a GDP via controlling the arrival time, thus allowing the carriers to conserve fuel by flying more efficient routes/speeds and still meet GDP objectives. Potential weather integration needs include but are not limited to convective weather, turbulence, in-flight icing, and ceiling and visibility.

2. Environmental Modeling & Analysis of TFM Performance - Fuel Burn Estimation (Metron Aviation, CE Phase): The goal for this research is to develop (using, e.g., POET-R and NASEIM) methods to compute fuel burn for individual flights. This capability would allow performing analyses that show the impact of various TFM actions on fuel burn. For instance, a reroute might cause NAS users to need to burn additional fuel, and this could be weighed against the benefits of the reroute. In addition to enabling analysis of historical performance from a fuel burn perspective, this would represent a first step towards a fuel burn analysis capability that could be incorporated into decision support tools. Potential weather integration needs include but are not limited to accurate and reliable flight level wind information as well as determination of weather impacted airspace.

3. Reroute Impact Assessment (RRIA) (Metron Aviation, CD Phase): Existing rerouting strategies require the traffic manager to manually identify route alternatives via a process that can be both time-consuming and ineffective at mitigating the underlying capacity constraints. The purpose of the RRIA project is to conduct analysis and rapid prototyping capabilities for evaluating alternative rerouting strategies. Proposed task areas include integration methods for querying the RMT database and functionality from TSD, Reroute Data Analysis to for historical data analysis to enable predictions of which reroute option will be selected, and Graphical Reroute Construction (Reroute Builder) to provide point and click creation of flyable reroutes. Potential weather integration needs include but are not limited to convective weather, turbulence, in-flight icing, flight level winds and ceiling and visibility.

Weather Involvement – Preliminary Review: MITRE Initial Evolution Analysis for Mid-Term Operations and Capabilities

An important part of Trajectory Flight Data Management (TFDM) will be the success of the System Wide Information Management (SWIM) program, incorporating the concept of Net-Centricity which was developed by the Department of Defense (DoD) to address data sharing issues. To successfully integrate into the SWIM environment and meet the NextGen vision, the concept of a common flight profile has to be fully deployed.

The flight profile describes a single flight with a compilation of information elements, available for distribution (electronically) and used by both the NAS users and the ANSPs. As the NAS advances with new capabilities, this concept enables the sharing of flight information elements among new and existing functions. Sharing common information elements improves the accuracy and availability of flight information updates, the consistency of flight planning in different ATM system domains, and enhances the availability of user preferences and recorded history information.

In a limited fashion, the concept of a common flight profile is currently available in the future enroute automation system to make data available to various internal components. Interim transition measures are in place for the sharing of enroute flight data information in the near term with other domains once the future enroute system is fielded.

It is expected that the mid-term evolution of the common flight profile managed from pre-departure to post-flight will be adopted across the NAS, offering a single reference for each flight in the NAS. While collaborating with NAS users, TFM trajectory flight data management services will be responsible for instantiating and publishing the common flight profile when the flight plan is filed. Other domains will have access to the flight data elements through publish-subscribe, request-response, and other exchange mechanisms available through SWIM core messaging services. TFM TFDM Services must also subscribe to updates from enroute, terminal, user systems and others in order to continuously monitor for changes that may impact each pre-departure flight and provide feedback to the user. Updates from enroute and terminal TFDM Services may include status such as airspace changes and problem predictions/resolutions (aircraft-to-aircraft, aircraft-to-airspace, aircraft-to-TFM Flow Constraint, Aircraft-to-Severe Weather), and changes in the Terminal Area. A parameter time before departure, control of the active profile will be transferred to the appropriate ATC domain (terminal or enroute) responsible for the departure airport. Each ATM system will have the responsibility to create and maintain specific information elements within the common profile in an operationally acceptable manner.

In TFDM, the aircraft's trajectory is monitored during all phases of the flight. The interaction of that trajectory with other trajectories or hazards will be managed to achieve the optimum system outcome, with minimal deviation from the user-request flight trajectory, whenever possible. During enroute "ownership" of the flight profile as the aircraft progresses through enroute airspace, dynamic information, including 4D trajectories, position, controlling entity, conformance status and security risk elements will be maintained. To improve support for service providers and decision support tools, flight data information provided by the flight deck will be increasingly incorporated into the more precise and complete trajectory modeling. Trajectories will also be shared between terminal and enroute domains, allowing for more consistency and better coordination as aircraft transition between enroute and terminal airspaces. Additionally, data-link capable aircraft will down link dynamic information such as state and weight which will allow for trajectories to be more precisely calculated.

Weather Involvement – Preliminary Review: MIT/LL Weather Integration Roadmap

Weather Integration into Departure Flow Management (DFM)

Departure flow management deals with the efficient movement of aircraft from their gates to the active runway, the timing and sequencing of departures so as maintain runway throughput and overhead aircraft flows (particularly when MIT are in effect). Congestion constraints further downstream are also important in managing departures since it may not be possible to clear aircraft for takeoff if enroute facilities along their route of flight are overloaded.

Considerable effort is underway to develop concepts for integration of weather information into DFM. One needs to consider weather impacts on the departing flights and the flights that are in the overhead stream.

Departing aircraft weather constraints

The prototype Route Availability Planning Tool (RAPT) in operation at New York utilizes CIWS forecasts of storm intensity and height to compute the time intervals where departures from a specific airport will be impacted by storms along specific departure routes. This operational tool incorporates many elements of the weather integration paradigm (frequently updated, automated forecasts of relevant weather parameters, and “translation” of these forecasts into time varying determinations of the availability of a specific NAS resource, in this case a departure route).

Ongoing RAPT work is directed at improving the weather blockage models, developing usable metrics for the uncertainty of the route blockage estimates and extending the concept of operations to less rigid departure route structures than those in use in the NYC airspace where RAPT is being prototyped. There is a need to develop and validate pilot weather avoidance models for terminal areas as well as developing and validating models for terminal airspace usage when impacted by convective weather.

Operational testing of RAPT has illustrated the need for a more integrated departure management process which covers surface movement, rapid reroute planning when the filed route for an aircraft on the surface becomes blocked by weather, integration of overhead stream and downstream sector constraints into the departure planning, and much-improved information exchange involving tower, TRACON and ARTCC controllers and TMs. Weather information requirements for this more integrated departure management process include:

- Nowcasts of airport weather conditions that affect runway usage and airport operations rates (storms, wind shear, wind shifts, winter precipitation, ceiling and visibility changes), in support of proactive replanning of surface operations so as to minimize runway throughput losses and recovery time when major weather changes occur

- Nowcasts of weather conditions (temperature, precipitation rate and type) that affect de-icing holdover time
- Nowcasts of weather conditions that affect gate and ramp operations (lightning, winter precipitation, intense precipitation or hail)
- Accurate gridded wind data and short term forecasts (0-30 minutes) which should extend from the surface to flight level, with horizontal and vertical grid spacing to be established based on analysis of the trajectory modeling requirements, all in support of trajectory planning from the runway through the departure fixes and transition airspace
- Highly reliable wind estimates (effectively measurements) and short-term forecasts (0-20 min) extending from the surface to approximately 1000' AGL to support wind-dependent wake turbulence departure procedures (see Lang et al., ATM2005) (Note: ongoing wake turbulence research will develop analogous arrival procedures which will facilitate both arrival and departure operations at some airports during appropriate conditions. These require reliable wind estimates to approximately 6000' AGL and must extend outwards approximately 6 nmi from the airport)
- Forecasts of convective parameters (intensity, height, turbulence) necessary to evaluate departure route availability and to assess the uncertainty associated with these evaluations (Note - the 0-2 hour look-ahead-times provided by CIWS forecasts have proven to be useful for this function although longer forecast horizons would be valuable)
- Diagnoses and forecasts of weather conditions that may change the rate and/or routes at which arrivals can be brought into the airport (Note - examples of such conditions include icing conditions or turbulence in holding areas, or storms blocking major arrival flows to an airport. Operation of the RAPT prototype at New York has shown that when major arrival routes are blocked, the stream of arrivals can deviate into departure airspace which in turn prevents departures from using that airspace [Robinson, DeLaura, Evans and McGettigan, 2008])

A possible vehicle for addressing the above weather factors in improving departure operations is a set of automation-assisted, tower user support tools collectively designated as the Arrival/Departure Management Tool (A/DMT). A/DMT integrates information from a variety of systems (including airport surveillance) and decision support tools to create a comprehensive data base characterizing arrival and departure demand, relevant airport operating parameters and surface/airspace constraints that may affect capacity, efficiency and safety. This data base will be used to develop and manage an integrated plan for active and scheduled arrival and departure operations at the airport, based on 4D trajectory assignments.

In particular, A/DMT will provide decision support for tower controllers working traffic from the enroute environment to the gate, and for departure movements from the gate to the tower/TRACON handoff to enroute control. It will also assist traffic management functions in the tower, TRACON and overlying ARTCC by providing integrated information on constraints and demand.

The vision is that A/DMT will integrate the TFM constraints provided by the Departure Flow Manager (DFM) with weather constraints, wake vortex constraints, runway occupancy constraints, surface congestion constraints and airline constraints to determine the best departure route and associated departure time for each flight. For each aircraft subject to TFM restrictions, DFM would provide a list of departure times for each such aircraft that ensures compliance with the constraints. The A/DMT receives lists of possible departure times from multiple sources [e.g., DFM, Route Analysis and Planning Tool (RAPT), airlines, surface congestion model, etc.], and combines them to determine the set of time windows that each flight can depart to satisfy all constraints. A/DMT provides the window of times for each aircraft for display to the ATCT Controllers. The ATCT Controller selects a departure time from the range in the window, and sends this selected time (and the range of available times) back to DFM in the ARTCC. The communications and displays in the tower would be accomplished by Tower Flight Data Manager (TFDM) which is a new terminal local area network that will establish a highly capable data collection and processing architecture for tower operations. TFDM will consolidate functionality provided today by systems such as Flight Data Input/Output (FDIO), Electronic Flight Strip Transfer System and the Airport Resource Management Tool. TFDM will drive a versatile tower-user display suite consisting of a surface surveillance display, a terminal traffic display, an extended electronic flight strip or “flight data report (FDR)” display, an airport information display and an airport systems status display.

The combination of an upgraded ITWS could provide the wind shear, winds and wind shift information discussed above (albeit the current ITWS surface winds forecast capability is not adequate in terms of lead time for forecasts and the ability to forecast non gust front induced changes). The plan is for the CoSPA to provide both the forecasts of precipitation (including snow) and convective storm impacts.

<u>Overhead traffic weather constraints</u>

If convective weather is present in the terminal area and/or ARTCC, there is a good likelihood that the overhead streams of traffic may also be impacted by convective weather. In particular, when flights deviate around storms such that their flight trajectories no longer correspond to the flight trajectory expected by the DFM software, the DFM computation of flight time from the airport to fit into the overhead stream (or, arrive at a metering fix) will not be accurate. As a result, the departing aircraft might not fit into the expected slot in the overhead stream or at the metering fix. Since the DFM functions that involve departure time adjustments to fit aircraft into the overhead stream are a particular instance of time-based flow management, there will be a need to conduct research on how time-based flow management system can successfully operate in convective weather.

<u>Weather Integration into Time-Based Arrival Flow Management (TMA)</u>

Although neither arrival flow management nor the Traffic Management Advisor (TMA) were addressed in the “CATM Report 2007”, it is logical to consider this function in this roadmap since TMA is in operation at several locations that are frequently impacted by convective weather and hence could be used for experimental testing of concepts.

TMA determines the probable time of arrival of aircraft in enroute airspace to an terminal area arrival fix and then determines how much a plane needs to be sped up or slowed down to yield an appropriate sequence of arrivals over that arrival fix. The desired change in aircraft arrival time to the arrival fix is provided to enroute controllers who then accomplish speed and/or trajectory changes such that the plane passes over the arrival fix at the desired time. The required arrival fix time adjustment is continually updated as the plane proceeds to the arrival fix to provide closed loop control.

The TMA software currently assumes that an aircraft will fly the normal fair weather trajectory. If the plane deviates from the expected flight profile so much that the computed time difference between the desired arrival time at an arrival fix and the current expectation is too large to adjust (especially, when the plane will be quite late in arriving), then the only recourse would be to modify the time sequence of aircraft over the arrival fix. An important feature of the current TMA software is the "freeze horizon" which is typically a range ring from 200 nautical miles to 400 nautical miles around the airport inside which the time sequence of aircraft over an arrival fix is frozen. The time sequences of aircraft over the various arrival fixes are coordinated so as to yield an appropriate sequence of aircraft landing on the various runways assuming the aircraft fly the expected flight profile from the arrival fix to the runway.

It is our understanding that TMA can be operated in some cases where there is limited convective impacts in the enroute airspace of concern to TMA. If the storm impacts are limited to the area near one or more arrival fixes, aircraft scheduled for those fixes which are outside the "freeze horizon" can be transferred to a different arrival fix and TMA will resequence them. If a small number of aircraft deviate around storms such that TMs could accurately estimate the additional flight time to the arrival fix, and determine that there would a suitable arrival fix time slot associated with the extra flight time, then in theory it might be possible to manually resequence the planes. However, if large numbers of aircraft are deviating around storms and it cannot be determined manually what the extra time of flight will be and what sequence order is appropriate, then the current practice is to shut down the operation of TMA and revert to the previous manual control methods.

Research needs to be conducted on methods of making TMA more useful in convective weather. Key elements of the required research include:

- Convective weather events need to be analyzed to determine the fraction of time that convection impacts the region between the "freeze points" and the arrival fixes without also impacting the arrival routes within the TRACON
- If it appears that an operationally useful capability can be achieved by only improving TMA capability when convection is impacting the ARTCC (as opposed to both the ARTCC and terminal), development of a pilot weather avoidance model for descending aircraft in enroute airspace is clearly a first step

- The ability of TMA to consider non standard routings from the principal jet routes to arrival fixes (e.g., routes that might be manually drawn around a FCA using the CATM phase 1 reroute assessment utility) needs to be investigated.

We have recommended manually input routes as opposed to automatically generated routes around storms (e.g. routes generated by algorithms of the type described in Krozel, et. al., 2004) since it appears that the current automatic route generation algorithms do not consider complexity (Histon, et. al., 2002) in determining merge points whereas humans would consider controller complexity.

Extensive testing of various modifications to the TMA software using data sets from the current TMA sites (e.g., ATL, DFW, or IAH) seems essential. Given that NASA Ames was the principal research organization for the development of the TMA algorithms and, has been the principal source of funding to date for development of pilot weather avoidance models, it would seem logical for the FAA to conduct discussions with NASA to determine if Ames would be interested in investigating near-term modifications to the TMA algorithms to provide some enhancement in the ability to use TMA in convective weather.

In parallel, the FAA should utilize existing experienced TMA sites with significant convective weather impacts (e.g., ZTL) as locations to conduct exploratory investigations of how the ATL traffic managers could utilize CIWS weather products (and WAF fields) in determining approaches to extending the ability to use TMA with slight or moderate convective weather impacts. Since the controllers play a key role in the overall operation of TMA (by "closing the feedback loop" to achieve the desired arrival times at arrival fixes, it would be very important for the ZTL areas to have access to the CIWS products (and, additional experimental products that might be developed out of the interaction between TFM weather researchers and the ZTL operational community).

Weather Integration into Integrated Time-Based Flow Management

Integrated Time-Based Flow Management (ITBFM) will provide traffic managers an improved capability to develop, execute and adjust a common and integrated departure-to-arrival schedule for all aircraft that supports both TFM objectives and, to the extent possible, NAS customer preferences. The vision is that this capability will integrate or replace today's separate, uncoordinated and sometimes conflicting time-based metering restrictions (GDP, EDCT, AFP) to provide a more consolidated strategy for NAS resource management. Although ITBFM can be viewed as extension to the time-based flow management concepts embodied in DFM, the need for a departure-to-arrival schedule plan imposes a considerably broader set of requirements relative to weather information. There is a considerable difference between the Metron DFM prototype and TMA to accomplish what appear to be quite similar functions of achieving a desired arrival time at a location (arrival slots or metering fixes for DFM, arrival fix for TMA). The DFM prototype functions essentially as an open loop system that relies on the controllers to manually determine if a flight's trajectory needs to be adjusted to merge into traffic at the desired aircraft in trail spacing whereas the TMA software seeks to arrive at the arrival fix at a specific time.

As a consequence of these differences, there may well be differences in the details of the weather forecast translation into ATC impacts for DFM versus TMA. Hence, it will be important to determine the anticipated mode of operation for ITBFM so as to determine if there are additional weather-to-capacity translation issues that need to be considered in achieving an operationally useful ITBFM. For example, RAPT and the Metron DFM prototype are basically not concerned about forecasting departure rates. Rather, they simply attempt to optimize the departure rate for the sequence of planes that is ready to depart. One might be able from the current RAPT timelines to infer a departure rate for the next 30 minutes. But, such a short duration rate estimate would hardly be helpful for ITBFM and/or GDPs due to convective weather in the terminal area.

A major problem is forecasting arrival or departure rates at an airport an hour or more in advance is that the circumstance where the greatest capacity rate impact is likely to occur is when storms are over or very near the airport (e.g., within 5 nmi). Achieving high accuracy multi-hour forecasts of storms impacts over such a relatively small region for anything other than strong synoptic squall lines is a very difficult challenge.

It may well be that the operational concepts for ITBFM may have to be adjusted to have a much more limited scope of operation (e.g., use of TBFM over relatively short look ahead intervals such as an hour) during convective weather. We recommend that early on in the ITBFM development that there be simulations with representative convective weather data sets so as to address concerns at the outset rather than attempting to add on fixes to a deployed system such as will have to be accomplished with TMA.

A-4.3.2 Provide Full Flight Plan Constraint Evaluation with Feedback

Timely and accurate NAS information allows users to plan and fly routings that meet their objectives. Constraint information that impacts proposed flight routes is incorporated into Air Navigation Service Provider (ANSP) automation, and is available to users for their pre-departure flight planning. Examples of constraint information include special use airspace status, significant meteorological information (SIGMET), infrastructure outages, and significant congestion events.

Needs/Shortfall

Aircraft operators must plan flights to best meet business objectives. Concurrently, traffic flow managers need to understand the impact of future aircraft operator demand on system capacity. The current system does not provide feedback on any advisories or constraints that affect the flight plan. Currently, the resolution of traffic flow management (TFM) issues are often done without specific input concerning user flight preferences, or with limited understanding of operator impact of actual or planned NAS constraints on preferred route of flight.

Operational Concept

Constraint information is both temporal and volumetric. Constraint volumes can be “hard constraints” (no access to this volume for this time period), “conditional constraints” (flights are subject to access control), and “advisory constraints” (service reduction or significant weather). Flight trajectories are built from the filed flight plan and the trajectory is evaluated against the constraint volumes. Feedback is provided to the filer (not the flight deck) on the computed trajectory with a listing of constraints, the time period for the constraints, and the nature of access. A user can adjust the flight plan based on available information, and refile as additional information is received, or can wait for a later time to make adjustments. Up to NAS departure time, as constraints change, expire, or are newly initiated, currently filed flight plans are retested. Update notifications are provided to filers if conditions along the trajectory change. In addition, the user can submit alternative flight plans.

<u>Design/Architecture</u>

It is likely that the TFM System (TFMS) infrastructure will serve as the focal point for full flight plan constraint-evaluation and feedback capability prior to activation of the flight. TFMS, as one of its many services, will

- Accept aircraft operator trial plans
- Evaluate those plans for how they would be impacted by NAS system constraints
- Provide the operator with timely, accurate, and complete feedback on relevant system constraints
- Accept early intent and filed flight plans
- Forward such flight plans to the TFMS for trajectory-modeling and resource-demand prediction

<u>Weather Integration Considerations – Infrastructure Roadmap (IR)</u>

Weather needs identified include a de-conflicted common weather picture of enhanced forecasts of convection, turbulence and icing. Improved observations are also needed.

<u>Weather Involvement – Preliminary Review: TFM Concept Engineering Plan</u>

No specific information found.

<u>Weather Involvement – Preliminary Review: MITRE Initial Evolution Analysis for Mid-Term Operations and Capabilities</u>

The “Flight Plan Constraint Evaluation and Feedback” capability will allow the NAS user to be a pro-active participant in the collaborative process, by selecting the most efficient routes that conform to both overall NAS objectives and own business needs. Likewise, the ANSP will have access to common flight plan evaluation capabilities to support the planning of Traffic Management Initiatives (TMIs), the coordination with the NAS user and the allocation of user requested preferences when possible. Prioritized user-preferences will be used by the Traffic Manager (TM) whenever possible to implement a traffic management initiative. In this case, the NAS user will receive feedback indicating that one of its submitted preferences will be used or the TM assigned resolution.

This evaluation capability will provide the user with feedback that is based on consistent information to that of the ANSP, thereby increasing common situational awareness. The feedback will include current and predicted information for a flight along its complete flight path (i.e., full route) throughout the flight’s life cycle.

The feedback will include weather information, probabilistic information, TMIs (including delay information), airspace information (e.g., High Performance Airspace (HPA)/Mixed Performance Airspace (MPA), Area Navigation (RNAV) routes), required aircraft performance characteristics (e.g., Required Navigation Performance (RNP), RNAV requirements), active routes, restrictions (e.g., Letter of Agreements (LOAs), Standard Operating Procedures (SOPs), Special Activity Airspace (SAA)), terminal status information (e.g., airport conditions, runway closures, wind, arrival rates, Runway Visual Range (RVR), airport (current and planned) configurations, surface information and other NAS status information and changes along the path of the evaluated route or filed route. In addition, the nature (e.g., fully restricted or conditional access), the time, and the impact (e.g., distance, delay) associated with any restriction or constraint will be provided. It is expected that the evaluation feedback will evolve as changes in airspace, new information and systems become integrated and available.

The NAS user will also have the ability to evaluate one or more prioritized alternatives for a single flight or a group of flights. The evaluation capability will be able to provide flight-specific feedback (e.g., estimated departure time, estimated delay and additional distance for a given route) and more generic feedback (e.g., icing conditions at a given airport, restricted airspace) along the path of the flight. The evaluation will also support what if functionality to provide the NAS user with greater flexibility during the evaluation (i.e., time, altitude, routes, and aircraft characteristics).

Based on the evaluation feedback, the NAS user will have the options to:

- Provide intended flights (i.e., as early intents) which represent the best known information about a future flight or intended flight by the NAS user
- File a flight plan or modify an existing filed flight plan
- Provide prioritized alternative routings (i.e., user preferences) for a given flight to address possible events such as the implementation of planned traffic management initiatives, the modification or cancellation of them (i.e., concept System Enhancements for Versatile Electronic Negotiation (SEVEN) and user preference negotiation)

The ANSP will be able to accommodate the user preferences as much as possible based on common consistent evaluation feedback. The NAS user will receive feedback on the selected option from the traffic manager to address a given traffic management initiative. Note that the flight plan negotiation and rules of engagement between the NAS user and the ANSP are to be defined and developed in collaboration with the user community.

It is expected that airline operators, general aviation, and military users will have access to varying levels of the capability depending on their own level of sophistication of flight planning capabilities. The information, however, is consistent with that of the ANSP.

Beyond the mid-term (i.e., 2019+), this capability could evolve to allow the NAS user the option to automatically file an evaluated flight plan or to submit a route modification (i.e., amendment) to a filed flight plan based on the feedback received and NAS user pre-defined criteria. In the far-term, this capability may evolve into an automated, interactive flight planning and coordination capability to support the NAS user and ANSP negotiation of trajectories.

Weather Involvement – Preliminary Review: MIT/LL Weather Integration Roadmap

More accurate predictions of NAS resource congestion (enroute sector, airspace flow evaluation area and airport) are a major focus of future Traffic Flow Management concepts. Traffic managers use congestion predictions to establish the type, timing and scope of TMIs. Because of the uncertainty in today's predictions, TMs often implement highly conservative strategies as a hedge against worse-than-forecast conditions.

Uncertainty in future resource congestion arises from both inaccuracies in estimating future demand and from very limited capability to predict the future capacity of NAS resources during adverse weather. Demand predictions today do not even fully account for the impact of currently approved TMIs (for example MIT or arrival fix restrictions), and certainly do not attempt to estimate the impact of future TMIs that may be imposed as new weather constraints develop.

Quantitative, dynamic predictions of resource capacity are not currently available and as a result,

TMs must subjectively estimate the impacts of adverse weather on future airport operations rates and enroute airspace capacity.

In the initial mid-term time frame (2010-2011) CIWS weather forecasts will be integrated with the traffic display to allow TMs to visualize the impact of the weather on major routes, sectors and other airspace volumes. The display of CIWS product information on traffic management displays (as opposed to being provided on separate CIWS displays) will significantly enhance traffic flow decision making in adverse weather because traffic flow and weather information will now be available on a single display. Additionally, this transition will free up display space at crowded facilities and, provide CIWS products to some decision makers that could not easily view the CIWS demonstration system displays due to facility space restrictions. Additionally, TMUs and area managers in ARTCCs west and south of the northeast quadrant of the United States will obtain access to the CIWS products.

CIWS weather forecasts will be integrated with the "future traffic display" to allow TMs to visualize the impact of the weather on the specific flights that are expected to be traveling on major routes, sectors and other airspace volumes. This should assist the TM in determining which flights to move or conversely, when to cancel currently active TMIs that may no longer be needed. Use of more explicit mappings of the weather diagnoses/forecasts into constraint estimates, such as the WAF described previously, would further enhance the operational utility of the future traffic display. Use of the CoSPA forecast should facilitate extension of this concept to longer (0-6 hour) look ahead times in the mid-term time frame (2012-2013).

Probabilistic resource demand predictions must model not only currently approved TMIs but the likely effects of future TMIs that will be needed in response to weather constraints that are worsening or may not yet have developed. To properly model these future flow restrictions, a NAS-wide model accounting for time-varying future resource capacities and total (scheduled and pop-up) demand is needed. Since the skill of the demand and weather constraint predictions will generally improve rapidly for shorter look-ahead times, this model must cycle rapidly (~ twice per hour) in order to take advantage of the improving information on future constraints. Development of such a real time model that fully integrates state-of-the-art weather predictions, weather-impact translations and traffic demand forecasts is a major undertaking that does not appear to be adequately supported in the current weather and TFM research portfolios.

"CATM Report 2007" states that CIWS forecast data will be used in the mid-term time-frame to predict the reduction in expected resource capacity. Further, for each resource and each look-ahead time, the probability distribution function of the capacity will be determined by TFM. The authors speculate that this may be implemented for enroute sectors as a reduction in the Monitor Alert Parameters (MAP), based on the weather coverage, route blockage or other considerations. Realizing a robust capacity prediction capability will require major effort in at least three areas. Continued progress in diagnosing and forecasting relevant weather phenomena over the 0-8 hour time scales needed for TFM is essential. Research may be focused on extending the look-ahead-time for convective weather forecasts to 6-8 hours, and on improved 0-2 hour "nowcasts" of turbulence and airport weather conditions (ceiling and visibility, winds, winter precipitation) that affect capacity.

Validated models for translating the weather information into quantitative resource constraint metrics are required. Research in this area is in its infancy. For airspace constraints, the authors believe that approaches based on algorithms for reduction of sector MAPs are problematic. MAPs are widely recognized to be subjectively determined and inconsistent across the NAS, even during nominal conditions. Scaling of MAPs to account for weather impacts must account for the directionality of major flows within a sector and, that the associated weather blockage that may be quite different for different major flows. Objective models for airspace capacity during both nominal and off-normal conditions are likely to be more useful (e.g., Welch et al., 2007; Martin et al, 2007; Song et al., 2007) but these approaches must be integrated, validated and adapted as necessary to future, more automated ATC paradigms. Augmented research on the impacts of non-convective weather phenomena (turbulence, icing) on airspace capacity is needed, as is a more comprehensive capability for predicting weather impacts on future airport operating rates.

Viable methods for estimating and conveying the uncertainty of future resource capacity predictions must be defined. This will require tightly coupled effort involving the meteorological forecasting and ATM research communities. The authors believe that "ensemble" approaches are most likely to be effective – that is a set of discrete weather forecasts will be developed that span the expected range of future scenarios, and these will be translated individually to associated estimates of capacity constraints on specific NAS resources. From these ensembles, appropriate metrics and visualizations of uncertainty can be transmitted to automated decision support tools and TMs.

A-4.3.3 On-Demand NAS Information

National Airspace System (NAS) and aeronautical information will be available to users on demand. NAS and aeronautical information is consistent across applications and locations, and available to authorized subscribers and equipped aircraft. Proprietary and security sensitive information is not shared with unauthorized agencies/individuals.

<u>Needs/Shortfall</u>

Aircraft operators depend on the timely distribution of information on the status of NAS assets and aeronautical information to plan and conduct safe flights. Currently, the distribution of NAS information is sporadic, at times incomplete, and implemented with a variety of communication methods. Many aviation accidents have been traced to incomplete or untimely reception of NAS information.

<u>Operational Concept</u>

Information is collected from both ground systems and airborne users (via ground support services), aggregated, and provided via a system-wide information environment, data communications, or other means. Information and updates are obtained in near real time and distributed in a user- friendly digital or graphic format. The data is machine-readable and supports automated data processing. Flight Service Stations will be able to provide improved information for flight planning and in-flight advisories.

<u>Aircraft & Operator</u>

Operators can choose among an assortment of information services to access the NAS data. Equipment to receive Flight Information Services-Broadcast (FIS-B) will provide access to Special-Use Airspace status and Notice-to-Airmen (NOTAM)-related data over the Universal Access Transceiver (UAT) link. Data communications will provide access to Digital Automated Terminal Information System (ATIS) data. For flight planning, any user can access the NAS information through System-Wide Information Management (SWIM).

<u>Design/Architecture</u>

The SWIM program office will coordinate Communities of Interest (COI) to define producer and consumer requirements for the improved distribution of NAS information. Using standards and technology approved by the SWIM Program Office, COI producers employ approved standards and technologies to develop the services required to publish necessary NAS information. Such information can then be made available quickly and easily, using standard uniform interfaces to COI consumers. In parallel, COI consumers will develop interfaces to subscribe to provider services that can provide information tailored to user-specified information needs. Due to the loosely coupled nature of SWIM technology, the on-demand NAS information capability will evolve as each producer and consumer completes their individual developments. For those equipped with UAT FIS-B, special use airspace status and NOTAM data will be available. For those equipped with data communications, digital ATIS information will be available.

<u>Weather Integration Considerations – Infrastructure Roadmap (IR)</u>

Deconflicted Common Weather Picture available for TFM and AOC/FOCs

<u>Weather Involvement – Preliminary Review: TFM Concept Engineering Plan</u>

No specific tasks noted.

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On-Demand NAS Information (ODNI) will support the need for shared situational awareness between ANSPs and NAS users by supporting the dissemination of consistent and accurate NAS status information in a standard, structured format to ground-based and aircraft-based NAS users. NAS status information is any information concerning the establishment, condition, or change in any component (facility, service, or procedure, hazard, airspace, or route) of the NAS. This is distinct from flight-specific information, which provides information related to a specific flight.

NAS status information may be either static or dynamic in nature. Examples of static information include:

- Airspace structures
- Airway definitions
- NAS facility locations
- Inter-facility letters of agreement, and memorandums of understanding
- Standard procedures
- Special Activity Airspace (SAA) definitions

Static information does not typically require immediate dissemination and is most often used by NAS users to baseline their own information and systems. However, dynamic NAS status information requires timely and reliable dissemination for NAS users to be able to respond appropriately. Some examples of dynamic NAS status information include:

- Congestion predictions
- Planned and active Traffic Management Initiatives (TMIs)
- Current weather constraints and SIGMETs
- SAA usage schedules
- Facility outages and runway closures
- Airspace constraints

The ODNI capability will provide automation which will:

- Collect constituent data from ANSP authoritative data sources.
- Process collected data into NAS Status information in a standardized format.
- Disseminate the information to NAS users in a timely manner via most appropriate means.

Raw data which provides the basis for standard, consistent and usable NAS status information is maintained in systems across the various FAA domains. This information will be collected, stored and processed to create the NAS status information elements to be provided to the NAS user community. Processing of the data will result in standardized, structured machine-readable information formats to support automated information sharing. This information must also be easily transformed for display in human readable format as well, to support dissemination to NAS users who lack the sophisticated automation to receive the machine-readable information.

Standardized information exchange models will be developed and/or adopted, with consensus from appropriate Community(-ies) of Interest (COI), to ensure broad NAS status information interoperability. The Aeronautical Information Exchange Model (AIXM), currently being developed by the FAA and the International Civil Aviation Organization (ICAO), is an example of a candidate information exchange model which will support interoperability standards for NAS status information. Research is required to identify whether other standards may be applicable.

NAS status information will be disseminated to ground-based NAS users in one of two ways, depending on the ability of the NAS users to receive the NAS status information. NAS users that can take advantage of system-to-system information exchange will receive NAS status information via a SWIM-based external service interface. NAS users that do not have the ability to process SWIM-based service interface digital data will be able to access NAS Status information through an improved web capability which will provide rich and dynamic functionality. This improved NAS Status web capability will allow users to maintain login profiles with tailored content and display preferences.

NAS status information will be disseminated to properly equipped aircraft via planned enhancements to data communications which will allow modernized Flight Management Systems (FMSs) to receive and display the status information. Aircraft equipped with Universal Access Transceiver (UAT) Flight Information Services-Broadcast (FIS-B) will have access to Special Use Airspace status and Notice to Airmen (NOTAM) data. For those equipped with Data Communications, digital Automated Terminal Information System (ATIS) information will be available.

Consumers of NAS information, regardless of whether they are systems or direct users, will be able to request subsets of the information to maximize the efficiency of data communications. Information will be made available in both request/response (pull) and publish/subscribe (push) style interchanges.

Although NAS users will be able to access a wide range of information representing the status of the NAS, as understood by various systems used by ANSPs, they will not have access to the same level of detail or, in some cases, all of the types of information which can be accessed by ANSP personnel. Appropriate security and information safeguards will be implemented to ensure that NAS users will only be provided the appropriate level of information in NAS status information feeds or web-pages.

<u>Weather Involvement – Preliminary Review: MIT/LL Weather Integration Roadmap</u>

<u>Sector Demand Prediction</u>

Probabilistic resource demand predictions must model not only currently approved TMIs but the likely effects of future TMIs that will be needed in response to weather constraints that are worsening or may not yet have developed. To properly model these future flow restrictions, a NAS-wide model accounting for time-varying future resource capacities and total (scheduled and pop-up) demand is needed. Since the skill of the demand and weather constraint predictions will generally improve rapidly for shorter look-ahead times, this model must cycle rapidly (~ twice per hour) in order to take advantage of the improving information on future constraints. Development of such a real time model that fully integrates state-of-the-art weather predictions, weather-impact translations and traffic demand forecasts is a major undertaking that does not appear to be adequately supported in the current weather and TFM research portfolios.

Far-term Capabilities

TBD

A-4.4 Additional Initiatives and Targets

Weather Integration Review: TFM Concept Engineering Plan

System Enhancement for Versatile Electronic Negotiation (SEVEN) (Metron Aviation. PD Phase): Rerouting flights can be manually intensive, time and attention-consuming while giving little consideration to NAS customer input. SEVEN provides a concept for managing enroute congestion that allows NAS customers to submit prioritized lists of alternative routing options for their flights. It also provides traffic managers with a tool that algorithmically takes these customer preferences into consideration as it assigns reroutes and delays to flights subject to traffic flow constraints. SEVEN has the potential to reduce traffic manager workload, while allowing better traffic control in uncertain weather situations. Thus, SEVEN gives NAS customers greater flexibility to operate their flights according to their business priorities.

Input from MIT/LL Weather Integration Roadmap

During the mid- to late WP2 time frame (2012-2015) it assumed that the NAS customer will be able to submit to TFM multiple, priority-ordered flight plan alternatives for each flight during both pre-departure planning and airborne flight phases. It is assumed that the customer will determine the selected alternatives and their priorities based on information from TFM describing the location and probability of congestion that aircraft are expected to encounter based on their early-intent flight plan. The customer, will in fact, be able to use this information to “distribute” the expected impact of TMIs amongst their affected flights so as to minimize the overall disruption to their operations. For example, delay on “critical” flights could be traded off to other less critical flights. The “System Enhancements for Versatile Electronic Negotiation (SEVEN)” concept under development by Metron Corporation can be viewed as a prototype for this capability.

The TFM system would be able to choose between the various flight plans prior to take off and then modify the routing later in the flight when shorter lead time and more accurate information was available.

Traffic managers can assess the impact of various flight plan options on system congestion using an Interactive Dynamic Flight Lists (IDFL) and choose an option from the customer submitted list that provides weather avoidance and meets airspace capacity constraints. Changes to the filed flight plan are executed automatically and does not require coordination with the customer nor other facilities.

The utility of this concept when it is used to mitigate weather impacts on NAS customers will vary substantially from case to case, depending on the skill of the weather forecasts (which is a function of the type of weather and the look-ahead-time needed), the ability to accurately estimate NAS resource constraints from these forecasts, and the sophistication of the customer's process for utilizing this information to define and prioritize alternatives for the impacted aircraft. At minimum, we believe that the TFM weather information system supporting this concept should provide the following capabilities.

The phenomenology and severity of the predicted weather constraint should be identified (e.g. convection, turbulence, ceiling/visibility or runway winds limitations at an airport).

The observing and/or forecast systems used to determine the constraint should be identified, and the "raw" meteorological observations/forecasts provided by these systems should be available as an optional source of information for the NAS customer. This provides customers the ability to potentially improve their operational processes through use of private-sector aviation weather forecasting services.

Quantitative, time-varying forecasts of the reduction in NAS resource availability due to the weather should be provided. Appropriate metrics may are discussed in section 4. Useable estimates of the uncertainty in NAS resource availability should be provided.

There are a number of subject areas that have been identified, which are possible candidates for weather integration, these topic required further review as the plan is refined and evolves; these include the following areas and domains:

- • Increase Safety, Security and Environmental Performance (SSE)
- • Transform Facilities (Facilities)
- • JPDO Working Group Initiatives
- • AJN Initiatives
- • DOD Considerations
- DOD Methodologies for Weather Integration into ATM Decisions
- Operation of Civil Aircraft in Military Controlled Airspace and Terminals
- Transitions Between Civil and Military Airspace
- Air Carrier Considerations
- GA Considerations
- High-End GA
- Low-End GA
- HEMS
- Commercial Space Transportation Operational Activities

B. TECHNOLOGY AND METHODOLOGY

B-1. Survey of ATM Weather Impact Models

B-1.1 En route Convective Weather Avoidance Modeling

In order to determine the impacts of convective weather on en route air traffic operations, it is necessary first to partition airspace into passable and impassable regions. As shown in Figure B-1, en route Convective Weather Avoidance Models (CWAM) calculate Weather Avoidance Fields (WAFs) as a function of observed and/or forecast weather. WAFs are 2D or 3D grids whose grid points are assigned either a probability of deviation or a binary deviation decision value (0 or 1).

Since the pilot is responsible for weather avoidance, CWAM requires both the inference of pilot intent from an analysis of trajectory and weather data and an operational definition of deviation. Two approaches have been taken to model and validate weather-avoiding deviations using trajectory and weather data: trajectory classification [RKP02, DE06, DRP08, CRD07] and spatial cross-correlation [PBB02, K08].

In the trajectory classification approach, planned and actual trajectories of individual flights are compared and each flight is classified as a deviation or non-deviation, based on criteria derived from fair weather operations (e.g., operational route boundaries) or the judgment of a human analyst. Characteristics of the weather encountered along the planned trajectories and the trajectory classification are input to statistical pattern classification algorithms to identify the weather characteristics that best predict deviations.

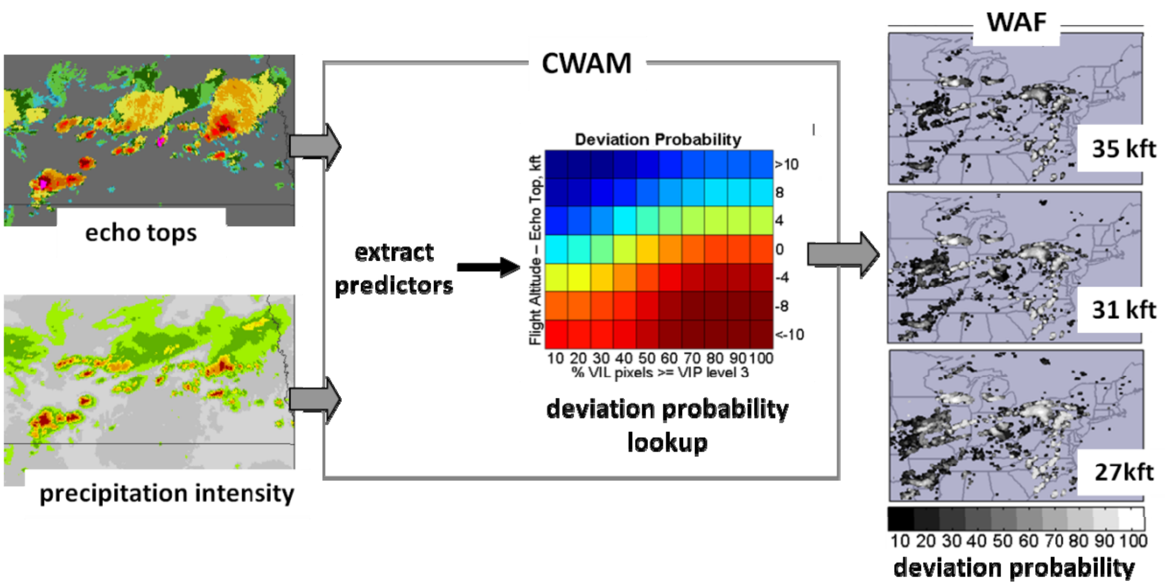


Figure B-1 CWAM implementation to create WAFs.

In the spatial cross-correlation approach, spatial grids of aircraft occupancy are cross-correlated with grids of weather data. Occupancy counts on weather-impacted days are compared to fair-weather counts. Regions where weather-impacted counts are low relative to fair-weather counts are assumed to be areas that pilots are avoiding due to the weather present in the area. The correlation of observed weather with areas of avoidance is used to identify the weather characteristics that best predict the observed weather avoidance.

Both approaches have strengths and weaknesses. Trajectory classification is highly labor intensive, restricting the size of the statistical dataset used in the model, but gives very detailed insights into pilot behavior. Spatial cross-correlation greatly reduces the labor involved in the analysis, vastly increasing the modeling dataset, but does not provide information about individual decisions. Spatial cross-correlation is also subject to errors arising from the displaced weather impacts (e.g., local air traffic counts are abnormally low because airways leading to the region are blocked by weather upstream) or traffic management initiatives that distort demand (e.g., pro-active reroutes to avoid predicted weather that does not materialize as expected).

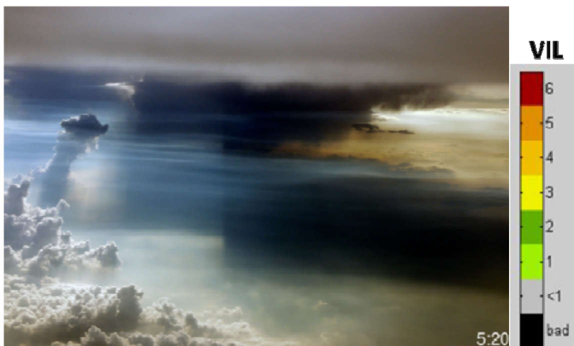
To date, CWAM studies have only considered weather characteristics derived from ground-based weather radar products (precipitation intensity, echo top height). Studies using both methodologies have identified the difference between aircraft altitude and echo top height as the primary predictor of weather-avoiding deviation in en route airspace, with precipitation intensity playing a secondary role. Current CWAM are most prone to error for en route traffic flying at altitudes near the echo top, particularly in regions of moderate precipitation intensity. Since current CWAM are based only on ground-based weather radar, they do not readily discriminate between relatively benign decaying convection and stratiform rain and turbulent downwind from thunderstorms, both of which are often characterized by echo tops in the 30-40 kft. range and moderate precipitation intensities [DCF09]. Further research is needed to examine additional weather information (e.g., satellite, winds, convectively-induced turbulence estimates [CML04]) that may help differentiate between benign and hazardous regions with similar radar signatures. Research is also needed to identify the human factors (see C-5) associated with pilot decision-making, particularly in circumstances where CWAM performs poorly.

B-1.2 Terminal Convective Weather Avoidance Modeling

In order to determine the impacts of convective weather on terminal air traffic operations, it is necessary to partition terminal area airspace into passable and impassable regions. CWAM that take into account the constraints of terminal area flight need to calculate WAFs that apply specifically to terminal area operations. Each WAF grid point is assigned a probability and/or a binary value (0 or 1) that represents that likelihood that pilots will choose to avoid convective weather at a point location in the terminal area.

CWAM for terminal areas are likely to differ from en route CWAM in significant ways. Departures and arrivals are constrained to follow ascending or descending trajectories between the surface and cruise altitude, leaving little flexibility to avoid weather by flying over it. Pilots of aircraft ascending or descending through weather are likely to have few or no visual cues to inform their decision, unlike those in en route airspace who may have clear views of distant thunderstorms as they fly above the clouds. Aircraft flying at low altitudes in the terminal area appear to penetrate weather that en route traffic generally avoids [K08]. The willingness of pilots to penetrate severe weather on arrival increases as they approach landing [RP98].

CWAM for departures and arrivals are also likely to differ from each other, for example, as illustrated in Figure B-2. The observed difference in behavior is not completely surprising, since arriving and departing flights are characterized by very different constraints and circumstances: arrivals must get down from the sky, while departures can wait on the ground until the weather is more favorable; departures must climb out at full power and hence have little opportunity to deviate to avoid weather in the first few minutes of flight, while arrivals have flexibility to maneuver until final approach; arrivals descending from above the cloud base have less information about the severity of the weather below than departures climbing from the ground.



View of thunderstorm and turbulent rotor (at right of photo), seen from underneath the cloud base. Ascending departures sometimes have a clear view of thunderstorm details that may be hidden from the view of arrivals descending into the airspace from above the cloud base.

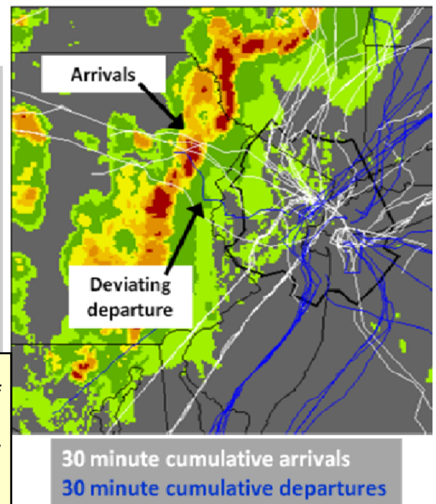


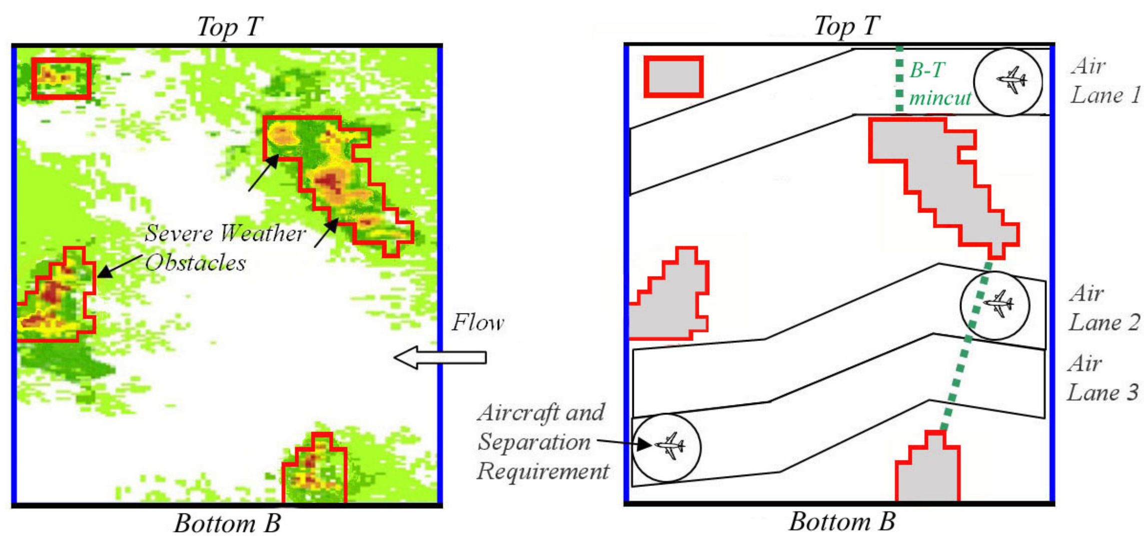
Figure B-2 Arriving pilots penetrate weather that departures seek to avoid.

For NextGen, terminal area CWAM research is needed both to understand the factors that affect pilot decision making in the terminal area during departures and arrivals, to identify the set of weather characteristics that correlate best with observed weather avoidance in the terminal area, and to understand how unstructured routing and Required Navigation Performance (RNP) in NextGen may change the characteristics of terminal area throughputs [KPM08].

B-1.3 Mincut Algorithms to determine Maximum Capacity for an Airspace

For NextGen when jet routes can be dynamically redefined to adjust flows of traffic around weather constraints and when controller workload is not a significant constraint, the maximum capacity of an airspace region may be determined using extensions of MaxFlow/Mincut Theory [AMO93,M90,KMP07]. The network MaxFlow/Mincut Theorem has been extended to a continuous version of the maximum flow problem [M90, I79, St83], which is suitable for estimating the maximum throughput across an en route airspace given a traffic flow pattern [SWG08], a uniform distribution of flow monotonically traversing in a standard direction (e.g., East-to-West), or random, Free Flight conditions [KMP07]. The maximum capacity of transition airspace may also be determined by transforming the problem into an analysis over the ascent or descent cone modeling terminal airspace [KPM08].

The translation is shown in Figure B-3. Given convective weather constraints and a method of defining the weather hazard (e.g., thresholding convective weather at NWS Level 3 or using the CWAM model [CRD07]), a geometric hazard map (or WAF) may be determined. Next, one defines the width of an air lane (equivalently, the required gap size between adjacent hazardous weather cells) that is required for a flow of traffic passing through the airspace, any geometric polygonal shape (such as a sector, FCA, grid cell, or hex cell) in a given period of time. The required gap size between weather constraints may be expressed in terms of RNP requirements for aircraft using the air lane passing through those gaps. In one version of the problem, mixed air lane widths are used to represent a non-uniform RNP equipage and/or set of preferences by aircraft arriving into the airspace [KPM08]. An algorithmic solution identifies the mincut bottleneck line – this mincut line determines the maximum capacity in terms of the maximum number of air lanes that can pass through the gaps in the weather hazards. The maximum number of air lanes can be determined by analyzing weather constraints as a function of time given a weather forecast product.



(a) Weather hazard is defined

(b) Mincut bottleneck determines the maximum number of lanes of traffic that may pass

Figure B-3 The translation of convective weather into maximum ATM throughput.

The described approach is a geometric analysis of the weather constraints transformed into maximum throughput for a given flight level. For NextGen, complexity and human workload (controller and/or pilot) limitations must be taken into account for determining the capacity of an airspace.

B-1.4 Weather-Impacted Sector Capacity considering CWAM and Flow Structure

Sector capacity as an indicator of controllers' workload threshold is not a single value even on clear weather days, since controller workload is not only a function of the number of aircraft, but also a function of traffic complexity. One way to describe traffic complexity is with traffic flow patterns [SWG06]. Traffic flow patterns are described with clustered flow features, which are more predictable and perturbation-resistant than metrics which rely on single-aircraft events or aircraft-to-aircraft interactions. NAS sectors typically exhibit a small set of common traffic flow patterns, and different patterns represent different levels of traffic complexity. In higher-complexity conditions, it takes fewer flights to generate high workload for the controller team, and thus the sector capacity is lower.

As illustrated in Figure B-4, quantifying sector capacity as a function of traffic flow pattern [SWG06] provides a basis for capturing weather impact on sector capacity. In addition to the size of the weather, the shape and the location of the weather in a sector are also captured in a flow-based weather-impacted sector capacity prediction [SWG07]. A Weather Avoidance Altitude Field (WAAF) that most aircraft would deviate is generated based on a CWAM model [DE06, CRD07]. (Note: The WAAF is a 3D version of the WAF of the CWAM.) The future traffic flow pattern in the sector is predicted and described with flows (sector transit triplets) and flow features. The available flow capacity ratio of each flow in the predicted traffic flow pattern is then determined by the MaxFlow/Mincut Theory [AMO93, M90, KMP07]. The available sector capacity ratio is the weighted average of the available flow capacity ratio of all the flows in the predicted traffic flow pattern. The weather-impacted sector capacity is the available sector capacity ratio times the normal sector capacity given the predicted traffic flow pattern. The flow-based available sector capacity ratio has a strong linear correlation with the estimated actual sector capacity for the sectors with dominant flows [SWG08].

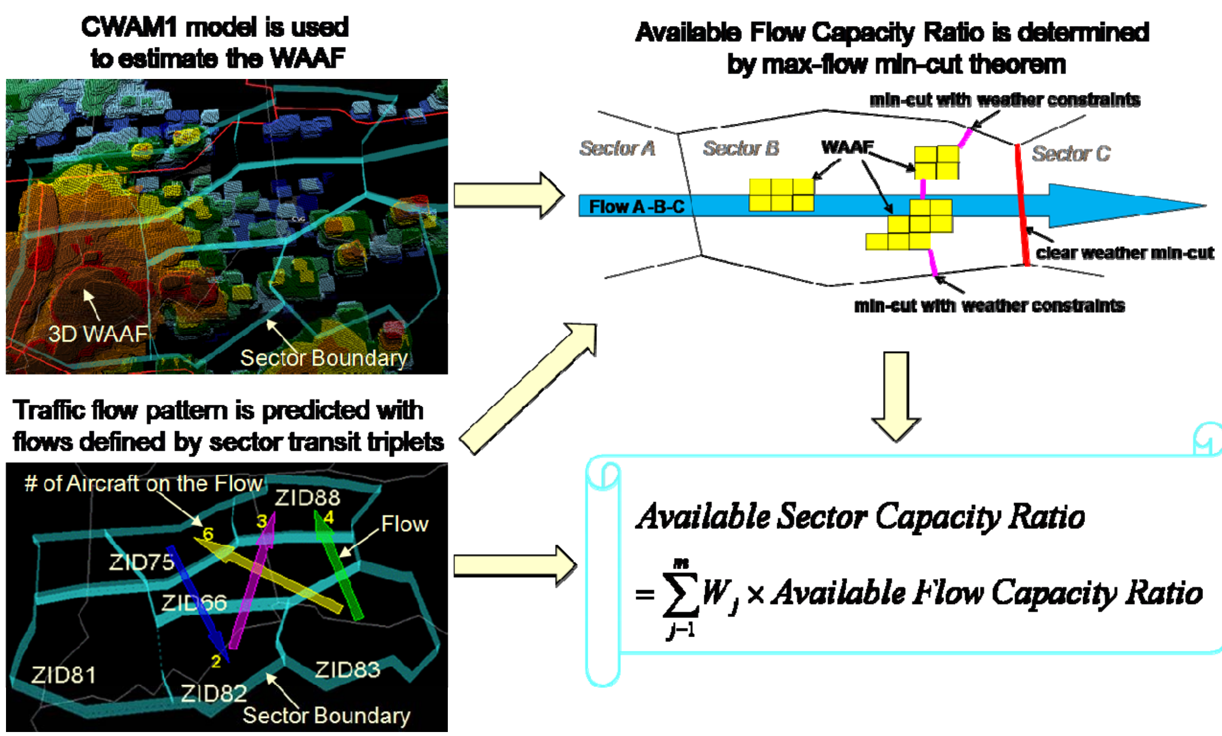


Figure B-4 Weather impacted sector capacity estimation

An alternative approach to quantifying sector capacity given the fair weather traffic flow patterns is to determine to what extent the fair weather routes are blocked and the fraction of the overall sector traffic carried by those routes [M07]. This model estimates the usage of the sector predicted by a route blockage algorithm (which is discussed next).

B-1.5 Route Availability in Convective Weather

Several ATM tasks, including departure and arrival flow management and the planning of weather-avoiding reroutes, require the assessment of the availability and/or capacity of individual traffic routes or flows. Thus, it is natural to extend Maxflow/Mincut, CWAM, and WAF concepts into route availability prediction tools.

A route defines a spatially bounded trajectory. A route is available if there is a way for traffic to generally follow the trajectory and stay within the bounds while avoiding hazardous weather. The route capacity is the rate of traffic flow that an available route can support. Estimating route availability may be achieved by Maxflow/Mincut (MM) [M90, KMP07, SWG07, SWG08] and Route Blockage (RB) techniques [RBH06, M07]. Both methods identify weather-avoiding paths that traverse a portion of airspace along a route. Capacity estimates based on MM and RB must account for the workload and uncertainty involved in flying the weather-avoiding trajectories that they identify.

MM begins with a deterministic partition of the airspace into passable and impassible regions. MM identifies all paths that traverse the airspace without crossing weather obstacles, and characterizes each path by its minimum width. Route availability and capacity are related to the number, required width (gap between hazardous weather cells), and complexity of paths identified.

RB uses a probabilistic partition of airspace, in which each pixel is assigned a probability of deviation around the pixel. RB finds the best path that traverses the space, defined as the widest path that encounters the minimum probability of deviation in the traversal. The route blockage is a weighted average of all pixels in the space with deviation probabilities ≥ the minimum probability encountered by the best path. RB differs from MM in that it identifies a single path that traverses the airspace, and it takes into account the nature of the weather that trajectories are likely to encounter on their traversal of the airspace (Figure B-5, left).

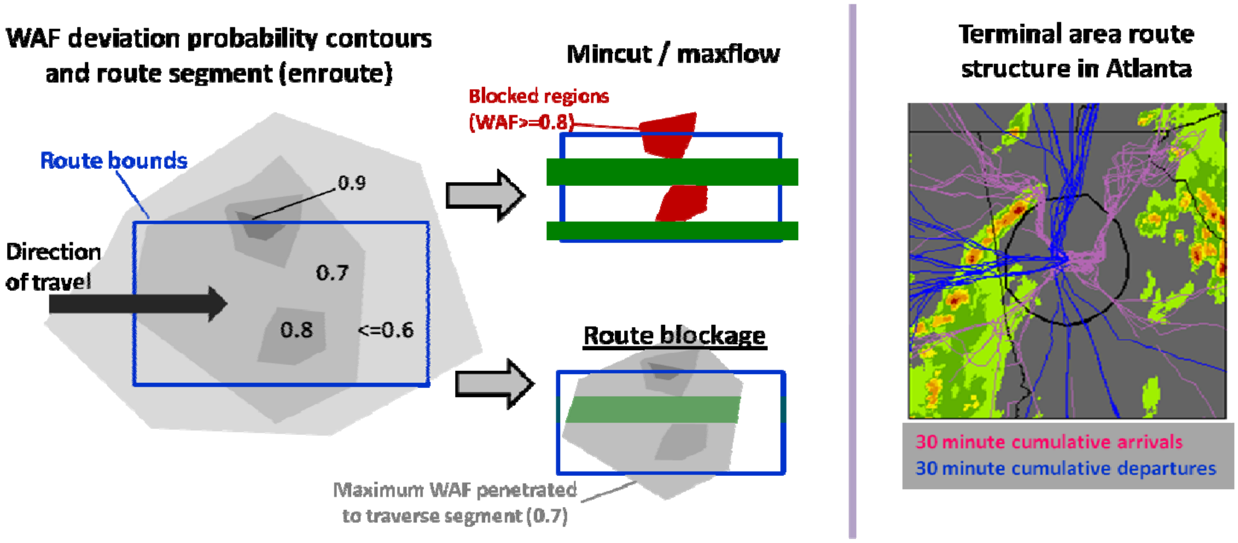


Figure B-5 Maxflow/Mincut and Route Blockage estimate route availability in structured, en route airspace (left) and flexible routing to avoid terminal area convective weather (right).

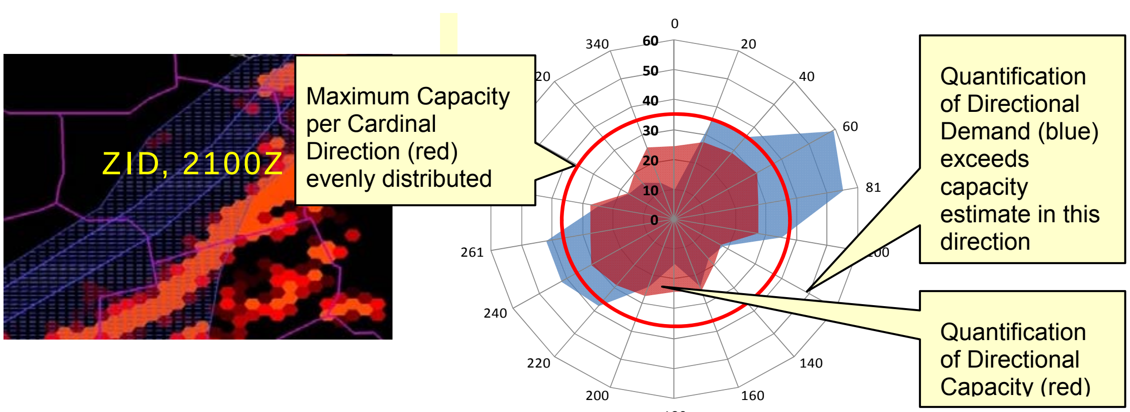
Estimating route availability in terminal areas has additional difficulties. Air traffic controllers have considerable flexibility to route aircraft around weather in terminal areas, and the bounds on traffic flows may be fluid and difficult to define (Figure B-5, right). Route availability in the terminal area may not be accurately determined simply by characterizing the weather impacts on nominal (i.e., fair weather) departure and arrival routes and sector geometry. The constraints on traffic flows at any given time depend on specific details of the flow structure and the nature of the demand (balance between arrivals and departures). Uncertainty in predicting flight time from runway to departure fix (or from metering fix to runway) when aircraft are maneuvering to avoid weather also has an impact on capacity that is difficult to estimate. Significant research is needed to develop terminal area airspace usage models that can be combined with WAFs to provide reliable estimates of route availability and time of flight between the runway and en route airspace.

B-1.6 Directional Capacity and Directional Demand

In addition to capacity being a function of flow pattern for a given airspace unit, airborne separation and RNP requirements, and convective weather impacting the airspace, capacity is also a function of traffic demand, both spatial and temporal. Since traffic flow patterns are directional, capacity is also directional. If the majority of traffic in a given period of time wants to traverse a center in the east-west direction and the center airspace capacity cannot accommodate this demand (e.g. due to weather blocking large portions of the east-west flows), the fact that the center might have, in principle, plenty of capacity to accommodate north-south traffic does not help. Consider for instance, the case of a squall line weather system, and traffic flow trying to pass through gaps in the squall line vs. parallel to it. Queuing delays will ensue when the capacity is limited in a particular direction, and upstream traffic will be forced to deviate around the constraint, be held upstream, and/or back at origin airports.

The capacity of an airspace can be estimated for a series of ‘cardinal’ directions, e.g., the standard directions of North (N), East (E), South (S), West (W) and the diagonals NE, NW, SE, and SW [ZKK09]. Also, directions can be quantified every □ degrees (e.g., □=20 deg.), spaced around a given NAS resource, for instance, around an airport, metroplex, or fix location, or within a section of airspace [KPM08, KCW08]. For each angular wedge of airspace, the maximum capacity for traffic arriving from or traveling in that direction may be established. MaxFlow/Mincut techniques [ZKK09, KPM08] as well as scan line techniques [KCW08] have been demonstrated for this purpose. The maximum capacity for a particular angular wedge of airspace will quantify the permeability of the weather with respect to traffic arriving from [KPM08] or traveling in [KCW08] this particular direction. The permeability can be calculated using pre-defined permeability thresholds [SSM07] that indicate at what probability or actual intensity of convective weather will most aircraft be likely to deviate (or plan the flight around the weather in the first place).

Directional capacity percent reductions may be used to determine the acceptable number of aircraft that can be accepted from or can travel in a particular direction. This may be expressed in units relative to the maximum capacity for the airspace when no weather is present. Demand can also be calculated in each direction using the primary direction a flight will take within a given unit of airspace (grid cell, hex cell, sector, center, FCA, etc.). By comparing directional capacity vs. demand on a rose chart, for instance as illustrated in Figure B-6, directional demand-capacity imbalances can be identified as well as regions where there may be excess directional capacity to accommodate additional demand. In NextGen, en route traffic flow patterns may be adjusted [ZKK09] or terminal traffic flow patterns may be adjusted (e.g., route structures and metering fix locations around a metroplex [KPM08]) in order to maximize the capacity by restructuring the traffic flow pattern (demand) to best meet the directional capacity.



v) Forecasted Weather Constraint (b) Directional Impact

Figure B-6 Directional capacity and demand rose chart.

NextGen researchers must still address how directional capacity should consider the complexity of the traffic demand and controller workload issues. Hence, if flow is largely directional, but there are very important traffic merge points within the region of interest [HH02], or if there are occasional crossing traffic constraints, then the directional capacity estimates must address these issues.

B-1.7 ATM Impact based on the Weather Impacted Traffic Index

The Weather Impacted Traffic Index (WITI) measures the number of flights impacted by weather (Figure B-7). Each weather constraint is weighted by the number of flights encountering that weather constraint in order to measure the impact of weather on NAS traffic at a given location. Historically, WITI has focused on en route convective weather, but the approach is now applied to other weather hazard types as well. In WITI's basic form, every grid cell of a weather grid W is assigned a value of 1 if above a severe weather threshold and a value of 0 otherwise. The CWAM model [CRD07] can be used to identify whether a pilot will fly through a weather hazard or will deviate around it at a given altitude. The number of aircraft T in each grid cell of the weather grid W is counted. The WITI can then be computed for any time period (such as 1 minute intervals) as the sum over all grid cells of the product of W and T for each grid cell [CDC01]. A WITI-B variation evaluates the extent to which a flight would have to reroute in order to avoid severe weather [KCWS08]. If a planned trajectory encounters severe weather, the algorithm finds the closest point in a perpendicular direction to the flow where no severe weather is present. The WITI score for that route is then weighted by the number of cells between the original impeded cell and the unimpeded cell found for the re route.

Various methods for determining the traffic count have been explored. WITI can use actual flight tracks from "good weather days" as the traffic data source [CS04], current day flight plan trajectories [PBB02], or great circle tracks between the origin and destination airports as the ideal, shortest-path unimpeded flight trajectories [KJL07]. Actual scheduled flight frequencies on these flows for the day in question are used. The En route WITI (E-WITI) for a flow is the product of its hourly flight frequency and the amount of convective reports in rectangular or hexagonal grid cells. This is then aggregated to the NAS level and to a 24-hour day, as well as by center, sector, or general airspace geometry. Another approach apportions all en route WITI measures to origin and destination airports. Even though en route delays may not be due to any local airport weather, the resulting delays will originate and/or eventuate at the departure or arrival airports. A grid cell's WITI score for a flow is apportioned to each airport proportional to the square root of the distance from the cell to those airports. The closer a weather cell is to an airport, the larger the portion of the WITI will be assigned to that airport. This provides a national WITI score broken out by airport – consistent with how NAS delays are recorded in ASPM today [KJL07].

Given that the WITI is an estimation of NAS performance, WITI has also been used as a measure of NAS delays [S06]. Multiple years of weather, traffic, and delay data have been analyzed, and a strong correlation exists between the WITI metric and NAS delays. Recent research considers other factors in addition to delay, such as the number of cancellations, diversions, and excess miles flown in reroutes [Kl05].

The correlation between the WITI and delays has improved as additional types of weather besides en route convection have been considered. Terminal WITI (T-WITI) considers terminal area weather, ranked by severity of impact, and weights it by the departures and arrivals at an airport. Types of weather include local convection, terminal area winds (direction, severity, and altitude), freezing precipitation, and low ceilings/visibility. The impact of turbulence on en route flows is also being studied as an inclusion to WITI [CKW08].

The National Weather Index (NWX) implements the WITI for the FAA. In addition to calculating E-WITI and T-WITI, it considers the additional delays due to queuing during periods where demand exceeds capacity, both en route and at airports. This 4-component NWX is referred to as the NWX4 [CKW08]. Current research is now exploring the use of the WITI for airline route evaluation, departure and arrival fix evaluation at TRACONs, and principal fix evaluation in ATM centers [KMK09].

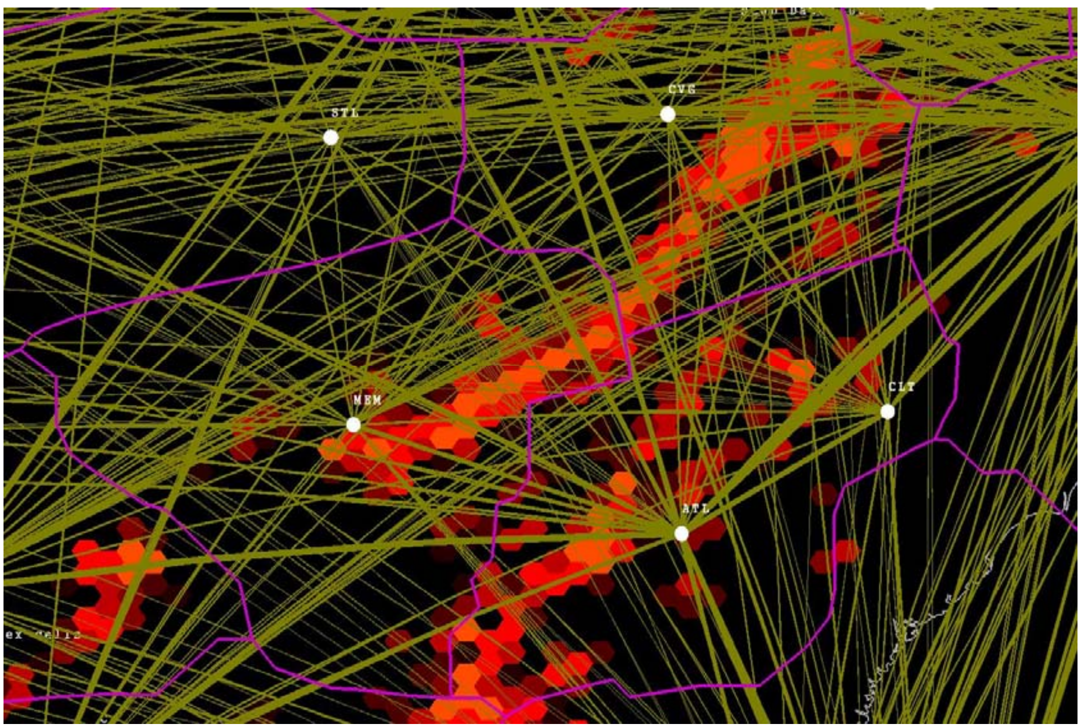


Figure B-7 Factors included in a WITI calculation.

B-1.8 Weather-Weighted Periodic Auto Regressive Models for Sector Demand Prediction

Traditional air traffic flow prediction models track the aircraft count in a region of the airspace based on the trajectories of the proposed flights. Deterministic forecasting of sector demand is routinely done within ETMS, which relies on the computation of each aircraft's entry and exit times at each sector along the path of flight. Since the accuracy of these predictions is impacted by departure time and weather uncertainties [MC02, E01], and since weather forecast uncertainty causes errors in the sector count predictions [KRG02, WCG03], traditional methods can only predict the behavior of NAS for short durations of time – up to 20 minutes. It is difficult to make sound strategic ATM decisions with such a short prediction accuracy. If a severe storm blocks a sector or regions near it, both sector capacity and demand may drop dramatically [SWG07 SWG08]; trajectory predictions must account for this.

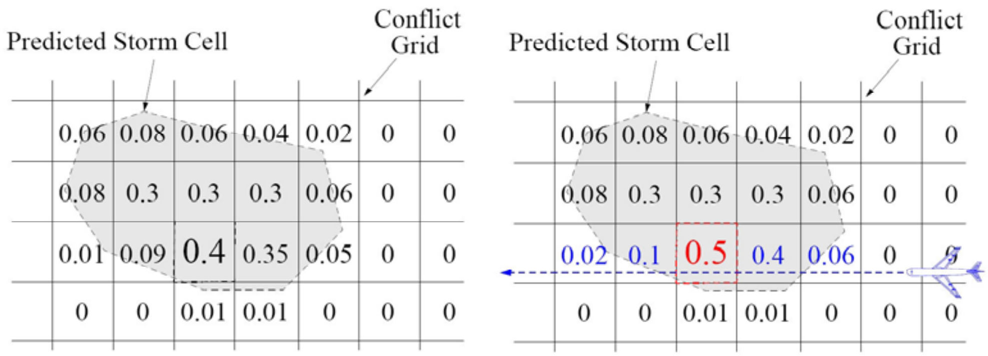
An empirical sector prediction model accounts for weather impact on both short-term (15 minutes) and mid-term (30 minutes to 2 hours) predictions. Different from traditional trajectory-based methods, a Periodic Auto-Regressive (PAR) model and its variants [Lj99, FP03] evaluate the performance of various demand prediction models considering both the historical traffic flows to capture the mid-term trend, and flows in the near past to capture the transient response. A component is embedded in the model to reflect weather impacts on sector demand. In addition, to capture the impact on all low, high, and super high sectors, storm echo tops information is needed. Only the storms with the echo tops above the lower boundary of the sector are considered. Results indicate improvements over the traditional sector demand models [CS09].

B-1.9 ATM Impact in terms of a Stochastic Congestion Grid

The effects of weather (convection, turbulence, or icing) on airspace capacity may be formulated in terms of a Stochastic Congestion Grid (SCG) [J05]. The SCG quantifies congestion (density of aircraft) in a way that accounts for the uncertainty of the aircraft demand and uncertainty of the weather forecast for long look-ahead times, as required by strategic TFM planning processes.

As illustrated in Figure B-8, each grid cell (a horizontal 2D grid is shown) records an estimate of the probability that the expected traffic exceeds a threshold level established by the ANSP. In NextGen, 4D trajectories are submitted for each aircraft flying in the NAS, they are stored in the 4D congestion grid by projecting the 4D trajectory onto the grid with an error model for along track error and cross track error. An increase in probability of congestion occurs where the traffic flow increase coincides with the predicted weather constraint. A probability that a weather constraint will exist is described on a grid cell instead of a binary value for a constraint versus no constraint. If the probability that traffic in any 4D grid cell exceeds tolerable thresholds set by ANSP (dependent on a weather-to-ATM impact model [CRD07, SWG08]), then an airspace resource conflict is monitored and appropriate action is taken by the ANSP.

For strategic look-ahead times, all information is probabilistic for when and where TFM strategies must take action. As an aircraft nears a location of a weather constraint, the probability for when and where the aircraft traverses the grid cell becomes more tightly bounded (that is, more deterministic as the variance goes down). Furthermore, the geometry and severity of the forecasted weather constraints are also more tightly bounded. This congestion management method limits the number of aircraft within a given region of airspace, but at this point it does not need to specifically determine which aircraft are in conflict with one another, nor the specific conflict geometry between two aircraft; the SCG is simply a congestion monitor.



(a) before addition of aircraft demand at time t

(b) congestion prediction after addition of the probability of an aircraft passing at time t

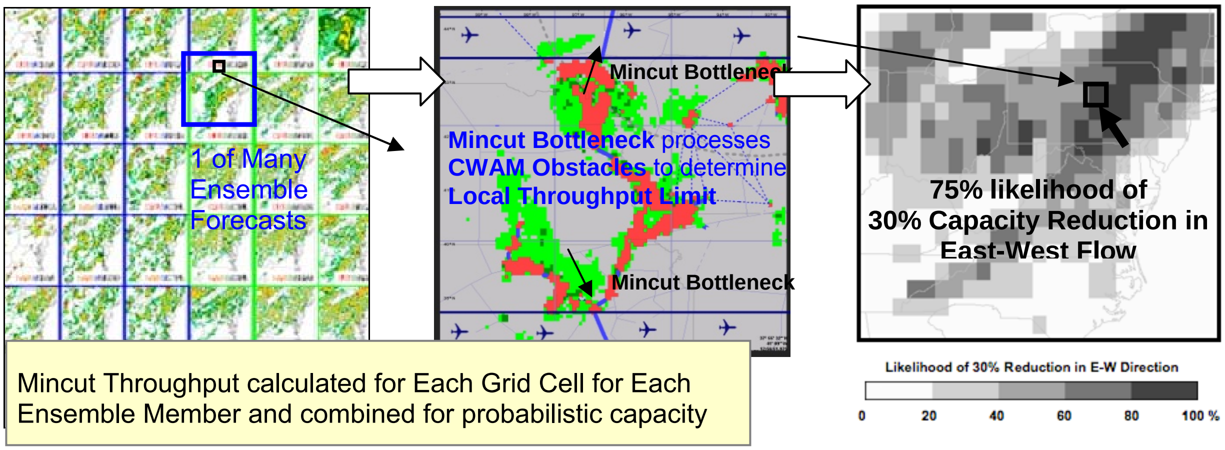
Figure B-8 Stochastic congestion grid with combined traffic and weather constraint probabilities.

The SCG is a prediction of large-scale regions of high aircraft density, including bottleneck regions between weather constraints or airspace regions with high demand. The SCG may be implemented with square or hex cells, and may be applied to sectors, centers, or the entire NAS. The ANSP can use the SCG to help make strategic decisions to identify FCAs and manage the predicted congestion.

B-1.10 Translation of Ensemble Weather Forecasts into Probabilistic ATM Impacts

In NextGen, in order to capture the uncertainties posed by long-term weather forecasting, ATM will rely on utilizing automated Decision Support Tools (DSTs) that will integrate probabilistic ensemble weather forecast information into ATM impacts [SM08, SB09], thus forming the basis for strategic TFM planning. The use of probabilistic forecasts will provide better tools to assist with a risk-based decision making. In the coming years, however, an understanding of the operational use of probabilistic forecasts will need to be developed, where probability may be either a measure of how likely it is that an event will occur (in space and time) or a number expressing the ratio of favorable cases to the whole number of cases possible. The move to probabilistic forecasting has been helped with the continued development of high-resolution Numerical Weather Prediction (NWP) models and ensemble prediction systems, both spurred by increases in computing power and a decrease of equipment cost, which enables NWP models to process more data in a shorter time period. Future research must explore the benefits from the breadth of short-range to long-range forecasts, as well as fine-scale to course-scale forecast grids to better understand the trade space.

Figure B-9 illustrates the ensemble-based translation concept. Ensemble forecast systems generate a series of deterministic forecasts of potential weather outcomes (i.e., members of the ensemble). Each ensemble forecast represents a possible weather scenario that may emerge later in the day. These ensemble weather forecasts, in turn, are translated into ATM impacts with relative likelihoods and probability density functions (pdfs) for either use by humans-over-the-loop or computer-to-computer ATM applications [SK09].



(a) Ensemble of Forecasts (b) Local ATM impact per Grid Cell (c) ATM Impact Map

Figure B-9 Procedure for translating an ensemble of weather forecasts into a probabilistic capacity map in terms of likelihood of a given capacity reduction.

This process will be adapted to the needs of particular ATM applications. It can be performed using tactical 1-hour as well as strategic 2, 4, or 6-hour forecasts, processing anything from 2-member to 30-member (or more) ensemble weather forecasts. The definition of a weather hazard could be for convection, turbulence, icing, or other aviation-relevant hazards and events (e.g., major wind shifts at an airport), and any appropriate weather hazard model can be placed into the ensemble-translation process; for instance, the CWAM WAF [DE06, CRD07] for a given altitude range. The airspace capacity reduction could be directional [KCW08, ZKK09], for instance, in the East-West direction, or in any particular direction where TFM plans to organize and direct traffic.

The resulting probabilistic ATM impact maps, once they become routinely available during the NextGen era (perhaps a decade from now), will be used by many decision makers to assess risks when formulating tactical and strategic plans. Air traffic controllers, traffic flow managers, airline dispatchers, airport operators, and NextGen automated DSTs, for example, will use these results to help reason about the weather forecast uncertainties when making decisions about traffic flows and operational impacts from one to several hours into the future.

B-1.11 Translation of a Deterministic Weather Forecast into Probabilistic ATM Impacts

While the previously mentioned ensemble approach for characterizing uncertainty of forecasts is promising for long term weather forecasts, other methods may be useful in short look ahead times. In NextGen, systems can benefit from understanding how a single deterministic forecast in a grid-based format, and some error bounds associated with the forecast, can be used to create probabilistic ATM impacts for a given region of airspace [KZM09].

Providing error bounds to a deterministic forecast attempts to characterize the forecast uncertainty. The estimate of error bounds could be based on general approximations about potential errors in forecast intensity, location, and shape, or the error bounds could be a lot more sophisticated, possibly based on some probabilistic approach (e.g., the statistical post-processing of a forecast). In contrast, a probabilistic forecast can be created based on spatial filtering or on ensemble forecasting. If probabilistic forecasts are properly calibrated to be reliable and have sharpness to them, they may be more accurate and useful than a deterministic forecast (even if error bounds are provided). However, the creation of a proper calibration of probabilistic forecasts is a non-trivial problem that is still under research, so in the short term, use of deterministic forecasts with estimated error bounds may hold merit for ATM impact analysis.

Figure B-10 illustrates the concept for convective weather. A single deterministic forecast is input, and variations on this forecast are created by considering error models that account for possible errors in timing, errors in coverage, translational errors, or echo top errors. Given a standard deviation that describes the potential error in each of these dimensions, a synthetic ensemble of forecasts is created that are similar (perturbations) to the input deterministic forecast. The intermediate ensemble of erroneous forecasts is then input into an ATM-impact model, for instance, a Maxflow/Mincut method, route blockage method, or CWAM model, and a set of ATM-impacts is output. The ATM impacts may be quantified in terms of a cumulative distribution function (cdf), probability density function (pdf), a set of scenarios or maps and associated metrics, or some other format. The set of erroneous forecasts represents “what if” cases; “what if the weather system arrives early”, “what if it arrives late”, “what if it is larger than expected”, “what if it is smaller than expected”, etc. The underlying assumption is that the weather organization has been correctly forecasted, but the growth or decay of weather cells may be in question. The ATM impact model can determine, say, through a cdf, what is the probability that two lanes of traffic will be available for routing traffic through transition airspace to the North-East quadrant around a metroplex.

This process will be adapted to the needs of the particular ATM application. This process can be performed using tactical 15-minute to 1-hour look ahead. At some point, true ensemble methods (ensembles of NWP forecasts) will perform better than this method of creating synthetic ensembles, so future research is needed to identify at what look ahead time this method should be replaced with the processing of true ensemble forecasts. The benefit of the synthetic ensemble method is that it provides a well-defined sensitivity estimate of the ATM impact given errors in a single deterministic forecast. This method helps the user (or DST) reason about potential weather forecast uncertainties when making decisions about traffic flows and operational impacts.

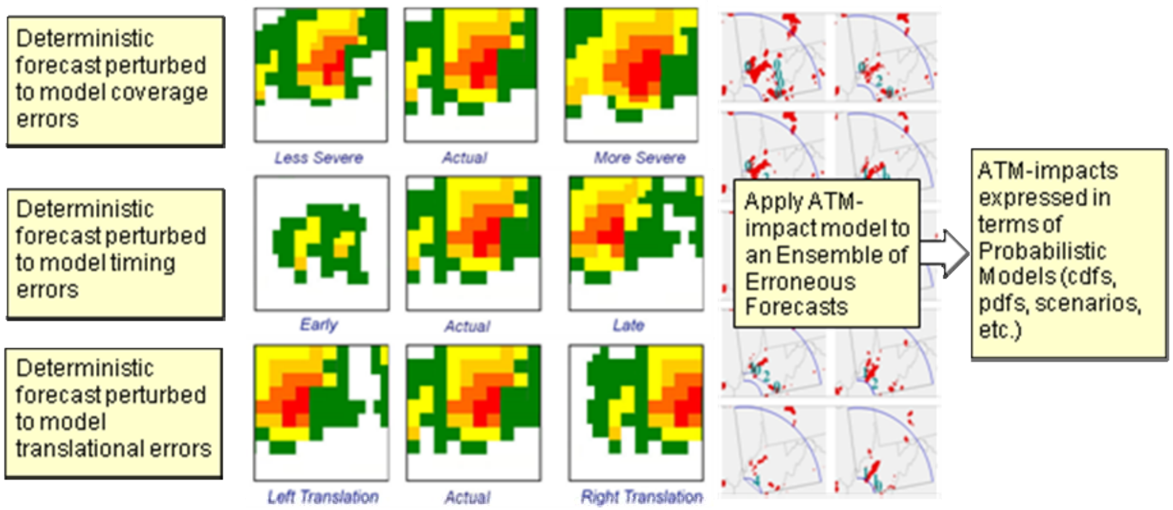


Figure B-10 Weather forecast errors characterized in terms of coverage, timing, and translational errors create an ensemble of weather constraints for a probabilistic ATM-impact assessment.

B-1.12 Sensitivity of NAS-wide ATM Performance to Weather Forecasting Uncertainty

Planners need to understand sensitivity of ATM performance to the weather forecasting uncertainty in order to make research and development decisions. The ATM performance improvement (benefit) is determined by comparing the performance sensitivity and the contemplated forecasting uncertainty reduction.

The ATM performance sensitivity to the weather forecasting uncertainty is difficult to understand for several reasons. First, there are challenges to modeling the ATM response to weather constraints. For instance, ATM performance can be characterized in a variety of ways, and likewise weather includes a variety of phenomena and no two scenarios are exactly alike. Second, not only must the ATM response to weather be modeled, but the ATM response to weather forecasts must also be modeled. Also, weather forecasting improvements may reduce uncertainty in a variety of ways. For instance, the forecasting may be improved for the short-term, but not the long-term. For these and other reasons, ATM performance sensitivity to the weather forecasting uncertainty is difficult to model and evaluate.

ATM performance has several nonlinear dependencies on independent variables such as the weather. Therefore simulation is typically required to model ATM performance. Of course, the simulation must include effects of the weather and its forecast in order to model the sensitivity to the weather forecasting uncertainty. For instance, such effects might include vectoring, rerouting and ground hold decision making models in response to weather forecasts. Such simulations have been constructed at a regional level [HB95,BH98, KPP07] and NAS wide level [RBH06, KD07].

The ATM performance simulations require weather forecasts of varying accuracy in order to evaluate the sensitivity to forecasting uncertainty. This uncertainty variation can be modeled using different approaches. For instance, two broad, and well developed, types of solution to this simulation problem are covariance propagation and Monte Carlo methods [Ge74]. In this problem, covariance propagation varies the forecast uncertainty while Monte Carlo varies the forecast itself. Of course, the covariance propagation requires that the simulation take as input the forecast uncertainty, and not merely the forecast itself. On the other hand, the Monte Carlo method requires a large number of weather forecasts. This can be accomplished with a forecast ensemble, or with forecasts from several different days.

In many problems, simple bounding cases which provide worst and best possible results are quite useful to help guide further research and planning. This is conveniently available for weather forecasts in the form of the persistence (i.e., the current weather is the forecast) and perfect (i.e., the future weather is the forecast) weather forecasts.

For example, in Figure B-11 persistence and perfect convection forecasts were used to compare the effect of the convection forecast with two ATM capabilities: trajectory-based operations traffic flow decision making where the delays and reroutes are assigned to specific flights rather than to flows, and agile decision making where flights can be rerouted or delayed minutes prior to departure [HR07]. For this scenario, these results indicate that NAS performance was most sensitive to the trajectory-based versus flow-based operations. The trajectory-based operations case significantly moved the NAS performance tradeoff curve to lower levels of congestion and delay, compared to the flow-based operations. TFM agility was the next most significant factor influencing ATM performance. The agile TFM moved the NAS performance to lower levels of congestion and delay, compared to the non agile TFM case. Also, the non agile, flow-based operations was the best approximation of the NAS performance as measured by ETMS and ASPM data sources. Finally, the convection forecast uncertainties were the least significant factors influencing ATM performance. Improving these forecasts resulted in second order NAS performance improvement compared to the other factors. These results, however, may not hold for other types of NAS weather or traffic days, which should be explored in future research.

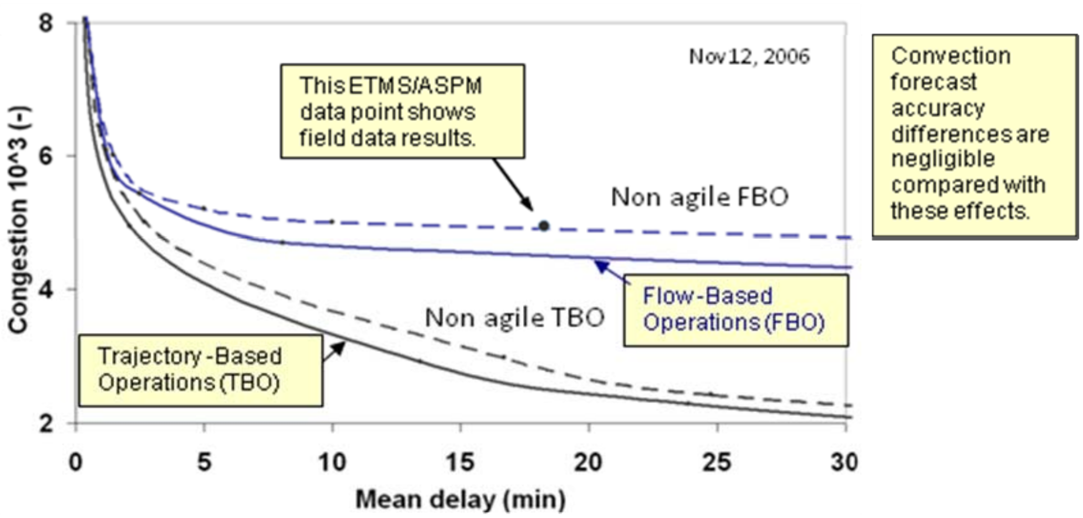


Figure B-11 NAS performance sensitivities of trajectory-based and flow-based operations performance improvements and agile versus non agile decision making.

B-1.13 Use of Probabilistic Convective Weather Forecasts to Assess Pilot Deviation Probability

Probabilistic weather forecasts for convection are being developed today and for NextGen. For instance, the operational 0-6 hour National Convective Weather Forecast (NCWF-6) product provides up to 6-hour forecasts of the probability of convection. Efforts have been made to determine how to use this forecast in ATM automation where probabilities of convective need to be translated to ATM impact. One approach is to determine a correlation between aircraft position and NCWF-6 convective probability values, at the appropriate flight level and relative distance above the echo top [SSM07]. Using the derived correlation, a decision-maker could assess the NCWF-6 probability that aircraft are willing to traverse, and in turn, the risk associated with traveling in the vicinity of forecasted NCWF-6 probability contours. The Probability Cut-off Parameter (PCP) is the maximum NCWF-6 probability contour which correlates with a majority of aircraft positions based on historical analysis. With a 1-hour NCWF-6 forecast, the 80th percentile value (PCP) for all aircraft flying through the probability field across the continental US is around 35% using four months of flight track and weather data [SSM07]. PCP values differ for longer forecast times. Also, PCP values can be established for a local scope, at center and sector levels [SAG09]. Figure 13 shows the method to create the PCP. A flight traversed an NCWF-6 forecast and the contours it coincided with are recorded. These data can then be aggregated for many flights. The bottom of Figure B-12 shows an aggregation of many flights of similar aircraft to develop a PCP for aircraft type. Future research must address how storm echo tops can be included in the analysis of probabilistic weather forecasts and PCP analysis.

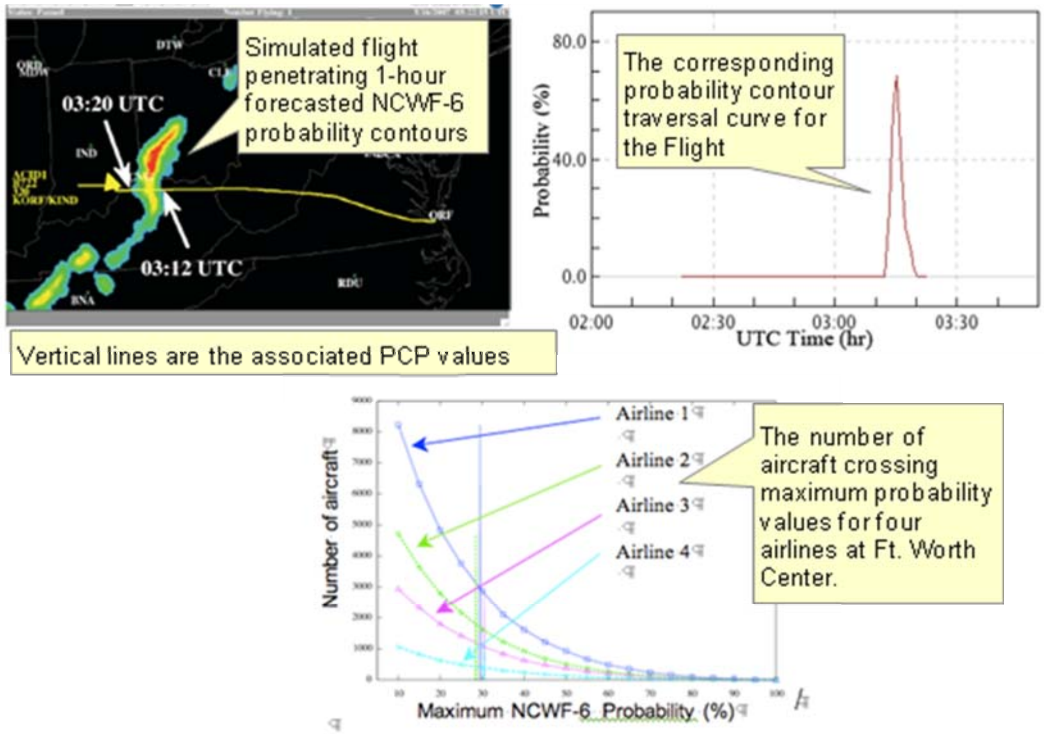


Figure B-12 Transforming a probabilistic NCWF-6 forecast into probability of penetration.

B-1.14 Integrated Forecast Quality Assessment with ATM Impacts for Aviation Operational Applications

The ATM planning process uses specific weather information to develop strategic traffic flow plans. Plans often reroute traffic when hazardous convective weather occurs within the NAS. In order to better understand the application of convective weather forecasts into the ATM planning process, convective forecast products are objectively evaluated at key strategic decision points throughout the day.

An example of how forecasts can be evaluated in the context of ATM strategic planning processes is illustrated in Figure B-13. A sector-based verification approach along with the ATM strategic planning decision points and a measure of weather impact across the NAS [KMM07, MLL08] can be used to evaluate convective weather forecast quality in an operational context. The fundamental unit of measure is applied to super high sectors – the volumes that are used for strategic air traffic planning of en route air traffic. In Figure B-13, a squall line is moving into the Tennessee Valley. The goal is to correctly transform the forecast into sector impacts quantified by the ATM impact model that applies, for instance CWAM model [CRD07, SWG08]. The ATM-impact model may have a flow plan and decision points as an input in order to determine the demand flow direction and quantity. In this example, the northern polygons were false alarms – areas where events were forecast, but did not occur. Convection occurring over the southeast, ahead of the squall line, was not captured by the forecast, and the sectors were considered missed events.

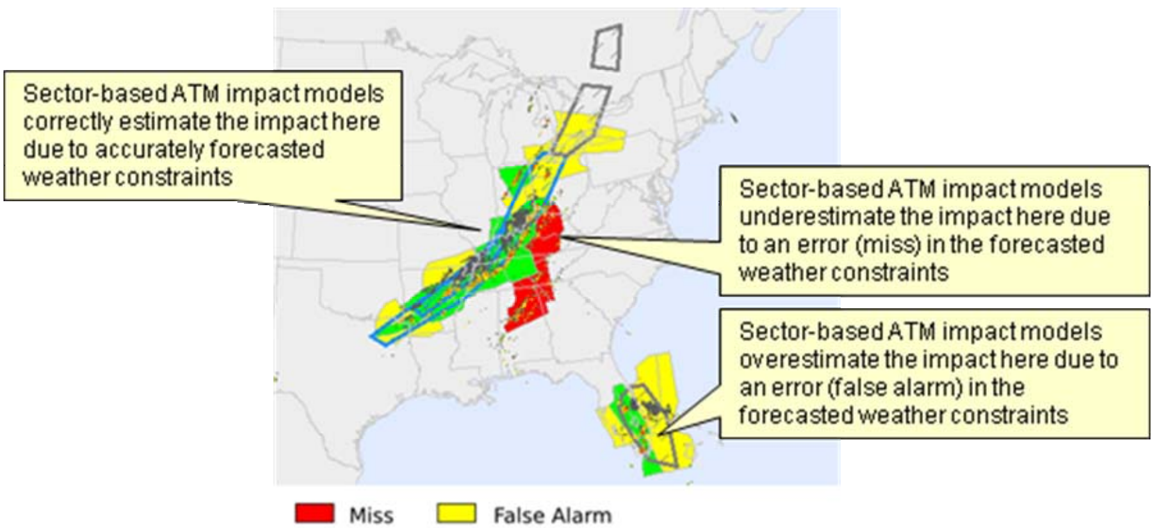
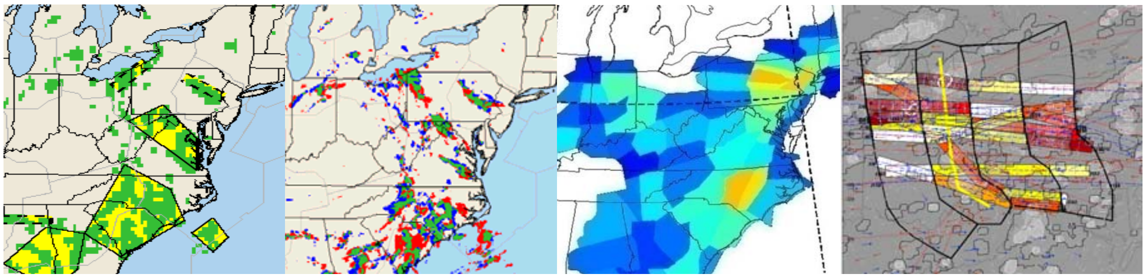


Figure B-13 Sector-based verification of a 2-hour forecast and observations (impacted sectors are color-coded to depict the verification results).

In NextGen, accurate and consistent weather information will be the foundation of the 4-D Wx SAS for ATM operations. User-specific evaluation of weather forecast quality plays a significant role in providing accurate and consistent weather information to the 4-D Wx SAS. ATM impact models must be tied into the evaluation of weather forecast quality in a way that the ATM impact is accurately predicted in measures that are meaningful to the ATM application.

B-1.15 Conditioning ATM Impact Models into User-relevant Metrics

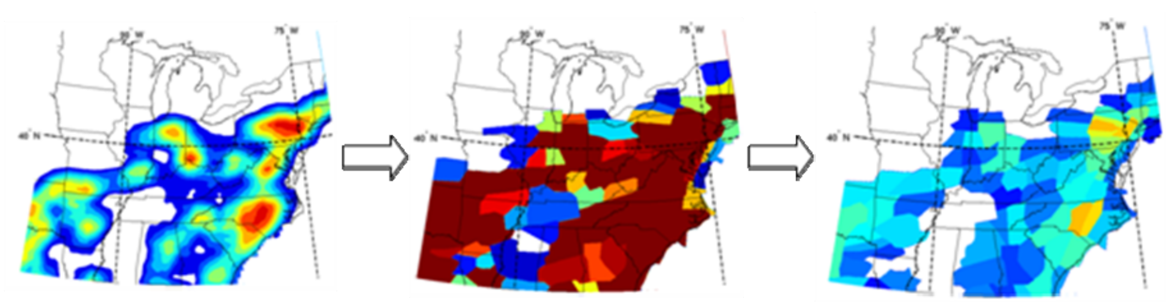
NextGen ATM planners and automated DSTs need useful weather information for efficiently planning, managing, and scheduling the flow of air traffic across the NAS. Significant efforts are currently underway to provide improved forecasts of convective weather for traffic flow managers to help them increase air space usage efficiency during times of convective weather impacts. However, due to the increased workload created by convective weather impacting congested air traffic routes and other factors, increased forecast performance does not always translate directly into more efficient operations. Weather forecasts need to be processed in a way that accounts for the ATM strategic planning procedures making weather information easily digestible for ATM DSTs and their users, in the particular format that is required (e.g., as shown in Figure B-14). In order to translate the weather forecasts into useful information for ATM planners, weather forecasts need to be calibrated, not with respect to meteorological criteria, but with respect to operational planning criteria. Since the airlines participate in the ATM process through Collaborative Decision Making (CDM) processes [BCH08], calibrated ATM-impacts must be expressed in meaningful terms to the airlines (dispatch and ATC coordinators) as well as to the ANSP. When planning and scheduling flows of air traffic to cross the NAS, one must project flight schedules and trajectories and weather forecast information into an ATM impact model to arrive at delay estimates (arrival and airborne delays), cancellation estimates, and cost estimates.



(a) Convective Forecast (b) Pixel-based impact (c) Sector-based impact (d) Route-based impact

Figure B-14 Convective forecast transformed into ATM impact in various formats.

TFM planning requires accurate, consistent, and calibrated impacts, as illustrated in Figure B-15. For instance, weather information (un-calibrated and operationally calibrated) must be ingested into ATM impact models that properly account for sector-to-sector queuing in order to measure delay costs associated with the weather forecast and expected demand on sectors. When operationally calibrated weather information is introduced into ATM impact models, costs must be close to those cost associated with 'perfect' knowledge of the weather [MKL09]. In NextGen, post-process analysis can be used to adjust the bias on ATM impact models so that future ATM impacts best model actual costs. Ultimately, improving the transformation of weather information into ATM impacts will reduce air traffic delay costs. In NextGen, it will be critical that the impacts of weather information be calibrated with respect to ATM operational decisions for effective planning and automated decision support.



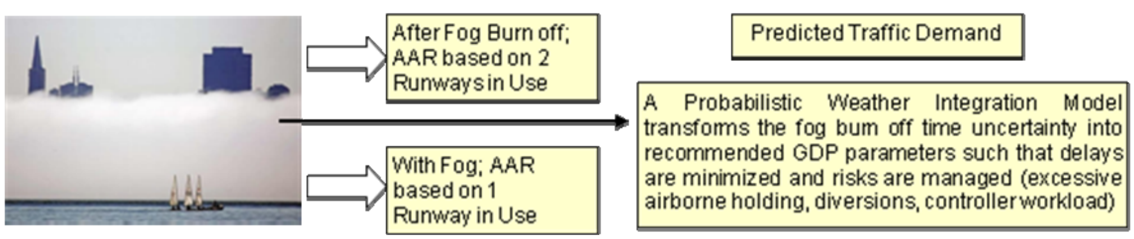
(a) Original Convective Forecast (b) ATM Impact Uncalibrated (c) ATM Impact Calibrated

Figure B-15 Convective forecasts for use by automated ATM planners (impacted sectors are red for high impact and blue no impact).

B-1.16 Integration of the Probabilistic Fog Burn Off Forecast into TFM Decision Making

Convective weather forecasts in the en route environment include uncertainty in multiple dimensions, including time, space, and severity. Attempts at integrating probabilistic weather forecasts into operational decision making in order to address these uncertainties has proven to be challenging – it requires complex models to integrate probabilistic weather forecasts with TFM decision making. The situation at San Francisco (SFO) International Airport provides an opportunity to explore the integration of probabilistic weather forecasts into TFM decision making in a less complex scenario [CW03]. This case involves a forecast of a single weather parameter – the marine stratus (fog) burn off time – at a fixed geographical location (the SFO approach zone). Traffic managers initiate a Ground Delay Program (GDP) to reduce the inflow of aircraft when fog at SFO lingers well into the morning arrival rush, thereby reducing the AAR in half (because only one runway can be used instead of two). One must rate the confidence of each of several forecasts, and use empirical errors of historical forecasts in order to create a probabilistic forecast in terms of a cumulative distribution function (CDF) of clearing time [CIR06].

To address the ATM impact (Figure B-16), a weather translation model must integrate SFO's probabilistic fog burn off forecast in with GDP algorithms [Cl09]. One model uses a Monte-Carlo simulation approach to find the optimal GDP parameters based on objectives of minimizing unnecessary delay and managing the risk of airborne holding [CW09]. The model samples multiple times from the CDF of the forecast of stratus clearing time, calculating the key measures for each possible GDP end time and scope under consideration. The mean value of each metric is calculated over all clearing time samples for each GDP parameters scenario, providing the expected value of each metric given the uncertainty in the clearing time. An objective function uses these key metrics to select the GDP parameters that minimize cost. This model places a high importance on managing the risk of excessive holding if the stratus clears later than anticipated. This is addressed by using an objective function that permits low probabilities of ATM risk, and quickly increases to heavily penalize risky end time decisions.



(a) For Burn off Time Estimate (b) ATM Impact (c) TFM Plan

Figure B-16 Integration of a Probabilistic Forecast of Stratus Clearing with TFM.

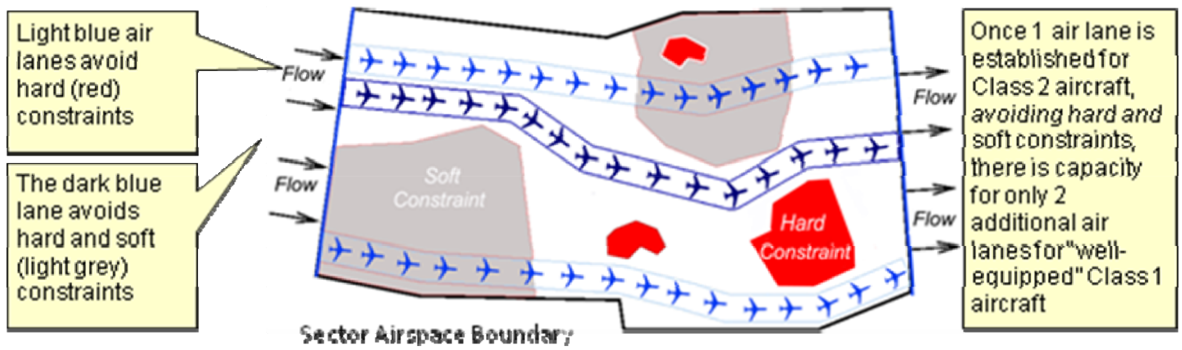
The planning, implementing, and controlling a GDP under uncertainty in stratus clearance time at SFO is both stochastic and dynamic in nature. Decisions related to airport rates, scope, and flight departure delays require revision in response to updated forecasts. Towards this, a parallel body of research is underway to develop an algorithm for setting AARs and allocating slots to flights, and dynamically revising those decisions based on updated forecasts [MHG09]. The primary input to the algorithm is a set of capacity scenarios and their probabilities, generated from forecasts. Given a distribution of stratus clearing time, one algorithm applies a stochastic optimization model [BHO03] to decide on optimum AARs, following which a slot allocation algorithm is applied to assign landing slots to airlines [HBM07]. After airlines perform substitutions and cancellations, the revised schedule and updated forecasts are fed back to the algorithm, which is re-applied in response to changing conditions.

Stochastic dynamic optimization models that simultaneously decide AARs and delays of individual flights require more than just capacity scenarios as input [MH07]. Typically these models apply a wait-and-see policy where certain decisions are delayed until updated information on airport capacity becomes available. Such models could be applied in NextGen if weather forecasts provide a capacity scenario tree whose branching points provide information on when to expect updates in forecasts and the conditional probabilities of scenarios associated with those updates.

B-1.17 Mincut Algorithms given Hard/Soft Constraints to determine Maximum Capacity

While the continuous version of the maximum flow problem [M90, KMP07] is suitable for estimating the maximum throughput across an en route airspace given a traffic flow pattern [SWG08], it assumes that weather hazards are classified in a binary way: traversable or not (hazardous or not). The assumption is that all hazards are hard constraints. However, weather hazards, including the "types" of convection, turbulence, icing, and other weather effects may more generally be classified into hard and soft constraints. Hard constraints are formed by weather hazards that no aircraft can safely fly through (e.g., severe convection, turbulence or in-flight icing). Soft constraints are formed by weather hazards which some pilots or airlines decide to fly through while others do not (e.g., moderate turbulence or icing); these can be characterized as user "business rules". As illustrated in Figure B-17, one can consider two aircraft "classes": Class 1 aircraft that avoid both hard and soft constraints, and Class 2 aircraft that avoid hard constraints but are willing to fly through soft constraints.

(a) Flight Level Turbulence Data (b) Hard and Soft Constraints Model



(c) Some aircraft avoid hard constraints and other aircraft avoid hard and soft constraints.

Figure B-17 Capacity computation for two classes of aircraft among hard and soft constraints.

The problem that arises within this mathematical weather to TFM translation model is that of multi-commodity flow, in which the goal is to determine if there exists a set of air lanes, each with an associated Class of aircraft (the "commodity"), such that each air lane satisfies all constraints from the weather types that impact the Class, and such that the air lanes yield a set of flows that satisfy the demand, or some fraction of the demand. We quantify the capacity of the resulting region of interest in terms of what fraction f of demand is satisfiable, given the multiple types of constraints for various classes of aircraft. The fraction f may be less than 1, indicating that the constraints result in reduced capacity below demand level, or it may be greater than 1, indicating that there is excess capacity available. The problem becomes more complex as both the hard and soft constraint boundaries and the likelihood that airlines will pass through certain hard and soft constraints is modeled with probabilities.

B-1.18 ATM Impact of Turbulence

Unexpected turbulence may injure crew and passengers, and potentially can damage aircraft. The hazard results from several different atmospheric phenomena including jet stream interaction, shear, mountain wave generation, and convection. Two distinct types of turbulence are of concern – Clear Air Turbulence (CAT) and Convective Induced Turbulence (CIT). Turbulence within convection is addressed by avoiding convective storms.

The ATM impact (Figure B-18) [KlK09] results from pilots desiring to avoid or exit turbulent conditions for safety reasons. This may happen tactically or strategically. Alerting to potential turbulence is important so that the cabin can be properly secured prior to an encounter. Exiting an unplanned encounter requires information to identify an acceptable exit strategy (that is, climb or descend to airspace clear of turbulence, or avoid by changing horizontal flight path to a region clear of turbulence). The exit strategy can be determined tactically, essentially as an aircraft is experiencing turbulence, or is warned that it is about to enter it, or strategically, with sufficient planning time to enter into a region of potential turbulence or avoid it altogether. Given a turbulence forecast for advanced warning of potential Moderate-or-Greater (MoG) or of Severe-or-Greater (SoG) turbulence, a pilot or dispatcher can decide to flight plan into a region of potential MoG turbulence if acceptable to the pilot or airlines (a pilot decision or airline policy decision), or in the case of potential SoG, the region should be avoided. This process varies by airline, type of certification, aircraft current altitude, and other factors.

Turbulence is capable of producing both workload and airspace utilization impacts. Tactical information about actual turbulence encounters are conveyed through Pilot Reports (PIREPs or AIREPs). PIREPs are broadcast to controllers and then relayed to other pilots. Today, this occurs by voice communications; in NextGen this process is expected to be automated for many aircraft through electronic PIREPs (e-PIREPs). Processing of PIREPs increases pilot, flight dispatch, and controller workload but does not, strictly speaking, close airspace. MoG turbulence tends to close en route airspace given that passenger comfort and safety is a high priority for many airlines. However, there are some types of aircraft that may fly through MoG turbulence, for instance, cargo aircraft, ferry flights, or some business jets. Forecasted or reported SoG turbulence is an immediate safety hazard which closes airspace and, if encountered, may require diversion due to the likelihood of passenger/pilot injuries and/or required aircraft inspections.

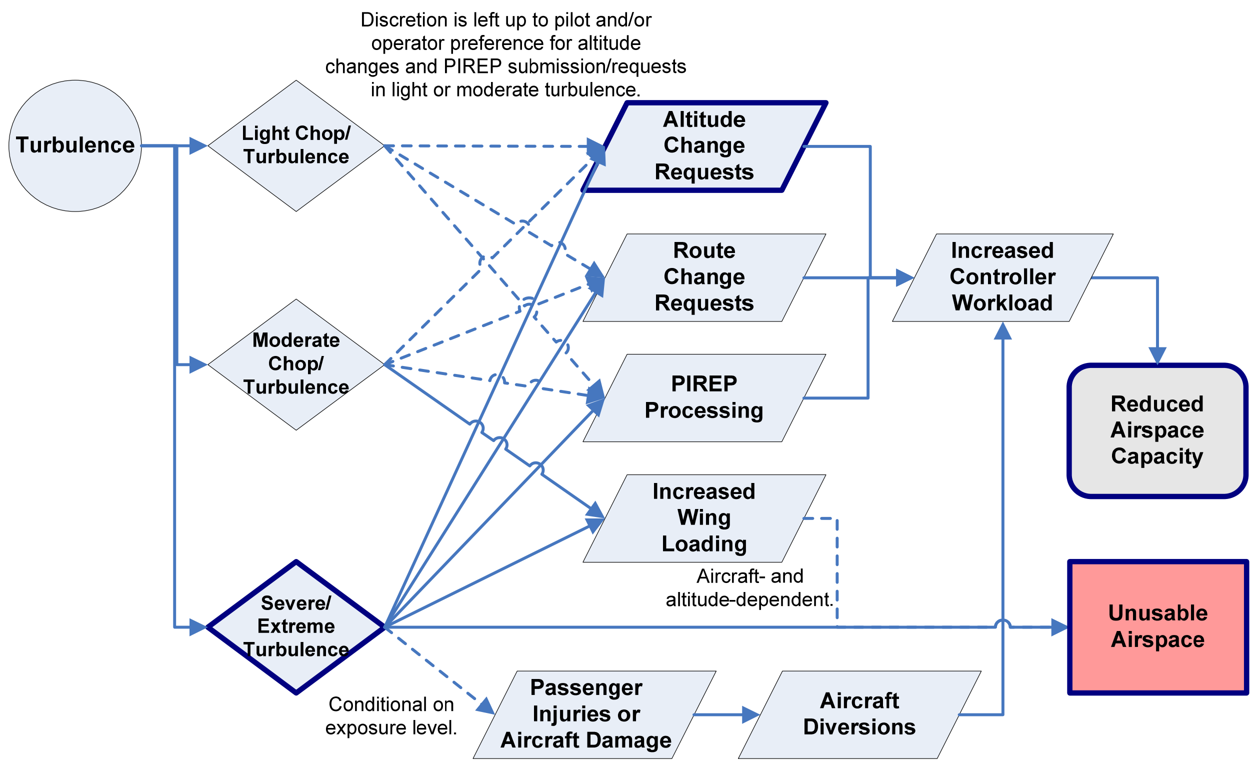


Figure B-18 Causality diagram for turbulence.

Traffic flow impacts are 4D and temporally sensitive because of the dynamic and random nature of turbulence. Current turbulence forecasts predict the potential for turbulence in a given region of airspace, altitude, at a given time in the future. NWP algorithms use coarse grids that cannot directly model and detect the existence of the “subscale” occurrence of turbulence. While fine grids may offer hope for detailed analysis in small airspace studies (e.g., accident investigations), the ability to have a NAS-wide description of exactly where the boundary of the turbulence hazards reside (space and time) is beyond current technology and perhaps may not be achieved in NextGen. Thus, in NextGen, 4D representations of hard constraints for turbulence (SoG level – where no aircraft should enter) and soft constraints for turbulence (MoG level – where some pilots and airlines may choose to go through) will be based on probabilistic information for the potential for where MoG and SoG turbulence may exist. DSTs for dispatchers and controllers must then be designed in NextGen to reason about the risk of entering into turbulence, rather than avoiding a well-defined region of turbulence. It is possible in NextGen that a tactical e-PIREP feedback process of quickly communicating to pilots and controllers where turbulence hazards actually exist will complement long term strategic forecasts of the potential for turbulence to exist.

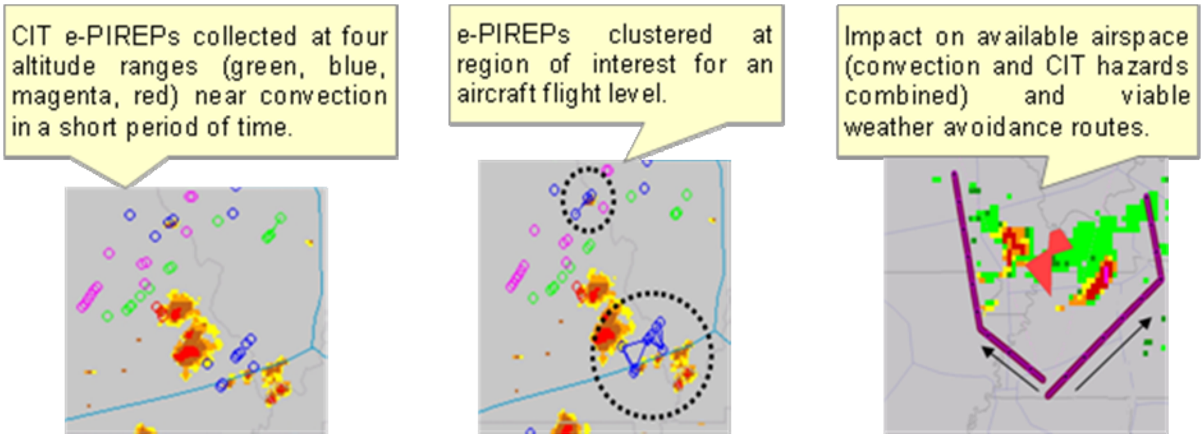
B-1.19 Tactical Feedback of Automated Turbulence electronic Pilot Reports

Currently turbulence encounters are reported from cockpit crews either verbally or by text data link. PIREPs are subjective, late – transmitted only when pilot or controller workload permits, and not easily disseminated to all users. Pilots need to know how turbulence will affect their aircraft in order to make route change decisions. Different aircraft respond to turbulence differently, therefore considerable inference is required on the part of crews to transform turbulence PIREPs from larger or smaller aircraft into the hazard to their own aircraft.

NextGen will likely automate the process of collecting and distributing turbulence (as well as other) PIREP information. Automated e-PIREPs, where human judgment on the magnitude of the turbulence encounter is replaced by an automatic measurement of the turbulence, will automatically and frequently report PIREPs by data link to ATC and to nearby aircraft. Essentially, all e-PIREP equipped aircraft become sensors in the sky for turbulence.

With a collection of e-PIREP information reported at a wide variety of flight levels (null as well as hazard reports), turbulence information can be data linked directly to nearby aircraft or collected and distributed via a centralized database (e.g., NNEW) [KRB09]. Given turbulence data at or above a given threshold (note: the threshold differs based on aircraft type, velocity, altitude, and weight), crews can determine which regions of airspace may be a hazard and which are safe to traverse. Clusters of point e-PIREP data classified as hazardous can be identified (Figure B-19), as well as clusters of clear air data (null or low magnitude reports). Thus, hazardous airspace as well as airspace clear of turbulence can be communicated to nearby aircraft that are soon to pass into such airspace. Since turbulence is a transient hazard, this process needs to be automated, a datalink needs to quickly communicate information to nearby aircraft, and the process must repeat throughout the day for detecting CIT and CAT hazards.

Current turbulence forecasts predict the potential for turbulence in a given region of airspace, altitude, at a given time in the future. NWP algorithms use coarse grids that cannot directly model and detect the existence of the “subscale” occurrence of turbulence. The ability to have a description of exactly where the boundary of the turbulence hazard resides (space and time) is beyond current technology and perhaps may not be achieved in NextGen. However, the tactical feedback process of where turbulence hazards actually exist will complement long term strategic forecasts of the potential for turbulence to exist.



(a) Data Collection (b) Data Clustering (c) Hazard Impact Model

Figure B-19 Feedback of e-PIREP CIT turbulence data transformed into hazard regions.

B-1.20 ATM Impact of Winter Weather at Airports

The accumulation of ice on aircraft prior to take off is a significant safety hazard affecting aircraft. Research [RCM00] indicates that the icing hazard for aircraft directly corresponds to the amount of water in the snow, rather than visibility – the traditional metric used to determine de-icing and take off decisions. Results from field tests of de-icing fluids have identified the liquid-equivalent snowfall rate as the most important factor determining the holdover time (time until a fluid fails to protect against further ice build-up) [RVC99].

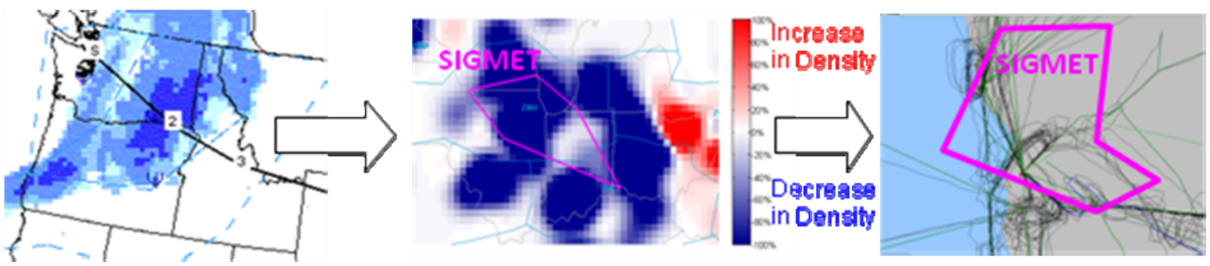
Furthermore, winter weather also impacts other areas of the airport, e.g. roads into and out of the airport, parking areas and transportation to the terminals. This adds to the difficulty of loading passengers and cargo for travel.

The ATM impact of decisions made regarding aircraft de-icing holdover times, de-icing fluid types, and application procedures have yet to be defined and integrated into a NextGen gate-to-gate concept of operations. From initial field evaluations using stand-alone DSTs, significant impacts to an airport occur from de-icing operations [RCM00], including airport ground congestion, decreased arrival rates, and decreased departure rates. Metrics affecting severity of impacts include precise timing of the snow event start and stop times, characterization of snowfall in terms of Liquid Water Equivalent (LWE), optimal deicer mix and temperature to maximize holdover times, and precise timing of the sequence of events from pushback, to de-icing, taxi, and takeoff to prevent additional de-icing. NextGen integration needs further decision support requirements for winter weather impact in order to optimize gate-to-gate performance.

B-1.21 ATM Impact of In-Flight Icing

In-flight icing impacts air traffic flow in complex ways. For aircraft not certified for icing conditions, all known or forecast icing is prohibited airspace and considered a “hard” constraint – these aircraft are not allowed to fly into such an airspace. A SIGMET issued by the National Weather Service (NWS) is considered a hard constraint for all aircraft. Today, SIGMETs are typically valid for up to 4 hours and usually affect a large volume of airspace. Some situations have icing severity and aircraft equipage combined to define a "soft" constraint – some aircraft may penetrate the icing volume for limited exposure times.

In-flight icing is typically a low altitude hazard, generally less than FL200. Major ATM impacts, therefore, are seen for low-end General Aviation (GA) and for all aircraft in the arrival/departure and terminal phases of flight. National ATM impact can be significant when icing affects large airport metroplexes. Figure B-20 illustrates some of the air traffic responses due to SIGMETs issued for severe icing [KrK09]. The traffic density is significantly decreased by a SIGMET when compared to the same day a week before and a week after – the effect is strongest if the SIGMET has a lower altitude that reaches ground level. Holding patterns are established outside of the SIGMET volume to allow aircraft to descend below the SIGMET prior to arrival if the SIGMET does not extend to ground level. Other impacts include increased ground delays until the SIGMET is released, cancellations of flights scheduled to take of when the SIGMET is active, and aircraft forced to fly above or below the SIGMET altitude ranges, thus increasing densities above and below the SIGMET volume and increasing controller workload for those altitudes.



(a) Icing Forecast (b) Decrease in density of Traffic (c) Holding and Delays Impact

Figure B-20 In-flight icing causes significant ATM impacts.

NextGen traffic flow impacts will be 4D and temporally sensitive. In NextGen, flight data objects representing aircraft and traffic flows will integrate with 4D representations of hard and soft constraints due to current and forecast icing conditions. NextGen icing forecasts will be automatically generated. The SIGMET for NextGen will likely be a 4D airspace that is shaped by the 4D forecasted icing volumetric icing phenomenon. Icing decision support can then be provided to flight crews, air traffic managers and controllers, dispatchers, and automated DSTs in the same spatial and temporal context. A 4D gridded format will be highly consistent with planned NNEW formats. Future products needed to fully address ATM impacts include calibrated icing probability and icing severity. Further, a better understanding and mathematical model of the in-flight icing ATM impact in both the terminal and en route environments is needed.

B-1.22 ATM Impacts Derived From Probabilistic Forecasts for Ceiling and Visibility and Obstructions to Visibility

The Ceiling and Visibility (C&V), and Obstructions to Visibility (OTV) impacts differ depending on the flight regime (terminal, en route, ground operations) and type of aircraft operation (Part 91 vs. Part 135 or Part 121). Reduced visibility and ceiling rank 3rd and 4th behind convection and winds as factors reducing terminal capacity [NWS04a, NWS04b]. For the en route NAS, ATM impact for IFR equipped aircraft results from reduced AARs and increased MIT restrictions that originate from the impacts of OTV on terminal airspace and airport ground areas. This impact can greatly reduce air route capacity and may propagate from sector to sector as passback MIT restrictions. OTV impact on terminal arrival and departure operations (see Figure B-21) include restrictions on VFR operations, increased MIT requirements on final approach, increased missed approach potential, higher workload for pilots and controllers (e.g., PIREP communications), and restrictions on use of Land And Hold Short Operations (LAHSO). Impacts result from ground fog, low ceiling, low visibility due to precipitation, and smoke and haze. These conditions are further influenced by day/night effects and by viewing angle relative to solar angle. For ground operations, the OTV impacts come from ground fog, low visibility due to precipitation, blowing snow, plus day/night and viewing angle effects as above. For non-IFR equipped GA aircraft, the OTV impact to ATM is minimal; however, the safety impact to inadvertent penetration into IMC during VFR operations is significant.

A number of techniques for probabilistic forecasting of C&V and OTV occurrence are in limited operational use today, but significant improvements in forecast skill, longer-duration forecasts, expansion to NAS-wide coverage, and better linkage to the specific forecast needs of individual terminal areas are required to meet critical NextGen needs. Similarly, models for translation of C&V weather forecasts into ATM impacts are only in limited use, and there exists no real-time system linking state-of-the-art NAS-wide probabilistic C&V forecasts with a calibrated, terminal-specific ATM impact model. So, the core OTV forecast technology, plus translation to ATM impact and decision support dealing with uncertainty, are NextGen technology gaps. The linkage, testing and implementation of these technologies is a critical and achievable NextGen requirement.

NAS decision support systems need realistic system-wide impact assessment models (e.g., [RH07, HR08]) that use current and forecast probabilistic OTV-impacted AARs at individual terminals to forecast resulting composite air route MIT restrictions. The assessment models must represent the system-wide impacts of reduced AARs, ground holds, and departure delays at remote airports where OTV conditions are not present.

B-1.23 Improved Wind Forecasts to predict Runway Configuration Changes

The airport configuration is a primary factor in various airport characteristics such as arrival and departure capacities (AARs) and ADRs) and terminal area traffic patterns. Since the airport configuration is largely dependent on airport wind conditions, an ATM-impact model must translate the wind conditions (and other factors) into AAR, ADR, and other impacts. Today there is poor dissemination throughout the NAS of the airport configurations in use at each airport at any given time, with very little known about expected future configuration changes. AARs, ADRs, and terminal traffic patterns are central to a variety of ATM decisions, such as setting arrival restrictions to avoid airborne holding as well as the effects certain airport configurations have on nearby airport traffic flows and configurations. Consequently, as uncertainty from wind conditions translates into uncertainty about the current or future airport configuration, this results in traffic management decisions that underutilize or overload airports, resulting in unnecessary or inefficient delays.

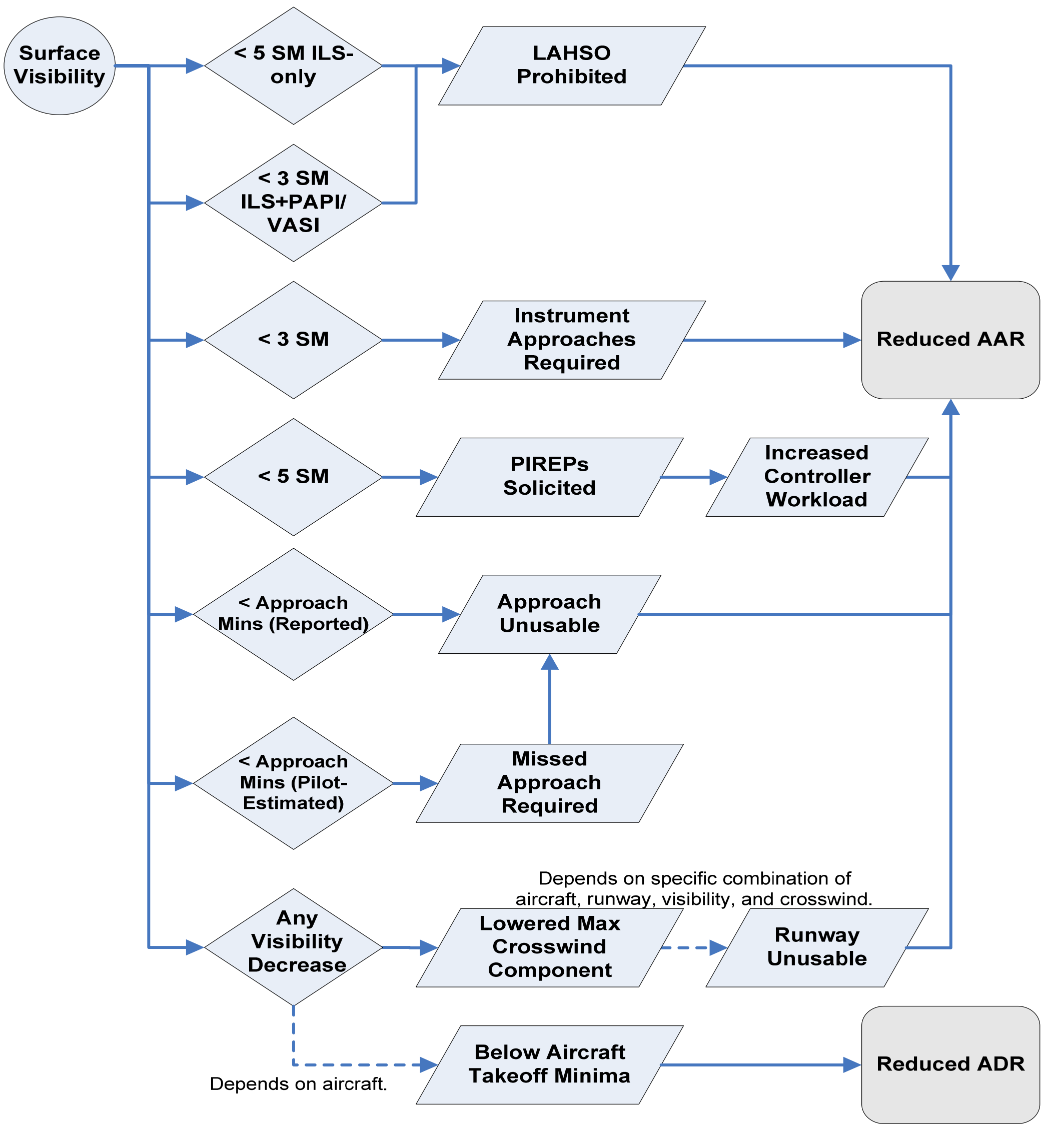


Figure B-21 Causality Diagram for Terminal C&V.

In order to build a model for translating wind conditions into ATM impacts, both meteorological and ATM modeling need to be addressed. The wind speed and direction is essential in determining which runways are feasible. Terminal Aerodrome Forecasts (TAFs) do not currently predict wind conditions precisely enough or accurately enough to enable airport configuration prediction. NextGen weather forecast systems must correct this in order to assimilate weather into DSTs for airport surface operations as well as TFM decision making. Accurately predicting wind conditions at an airport is difficult, and viable automated methods are only now emerging due to recent scientific advances and gains in computer performance. Furthermore, TAFs are intended primarily to provide information for filing flight plans, so they are not required to include certain changes in wind speed or direction that may cause a change in airport configuration.

As for modeling the ATM impact, there is also research needed to establish the relationship between how controllers choose between viable configurations to meet the arrival and departure demands of an airport. Controllers usually have 30 minutes or more leeway in the time at which runway usage can be changed while maintaining safety. This leeway is generally used to choose a time at which to implement a runway configuration change so as to minimize inefficiencies associated with making the change. The timing of the arrival and departure traffic demand, weather (winds as well as possibly convective weather constraints), and other factors need to be modeled. Furthermore, there is generally a preferred configuration that will be used if it is feasible for a sufficiently long period of time. There is a need to build a mathematical model that relates these factors to the forecasted weather (and traffic) conditions.

B-1.24 Improved Wind Forecasts to facilitate Wake Vortex Decision Support

Turbulence associated with aircraft wake vortices pose a potential hazard to other aircraft, especially lighter aircraft following at low altitude. This risk is mitigated by increased separation standards when wake turbulence avoidance is a concern. Historically, these separation standards were established under the assumption that little or no information is available in near real time with regard to the location, severity, or movement of wake vortices. As a result, they are designed conservatively, presuming the existence of a significant wake threat following each Heavy aircraft, and atmospheric conditions that would allow the wake turbulence to persist at a severe intensity for a relatively long duration (several minutes) in a location that encroaches on the flight path of the trailing aircraft.

Knowledge of wake vortex characteristics and behavior in near real time allows the opportunity to safely reduce existing separation standards to increase throughput, particularly within the terminal airspace [LMC03]. Early attempts to develop operational systems to mitigate wake impact focused on detection of vortices, with concurrent meteorological sensing to anticipate wake behavior, particularly wake dissipation rate and vertical displacement [HCB00]. Ground-based systems (e.g. Lidar) have proven extremely effective in local (on-airport) detection; their primary weakness is limited detection range in inclement weather, and they are relatively expensive. Furthermore, prediction of wake behavior based on meteorological measurements of atmospheric stability produced mixed results.

More recent efforts have focused on wind dependent solutions [LTL05, LTD07, RC08]. A very short term wind forecast (20 minutes) is sufficient to determine when persistent transport crosswinds protect specific Closely Spaced Parallel Runways (CSPR) from the threat of a wake vortex moving into the departure flight path, thereby safely allowing reduced separations. Analogous wind dependent solutions currently under investigation for arrival operations have more substantial implications for TFM. Unlike departures, for which a ground queue of aircraft may be immediately available to exploit available capacity, reduced separations for arrivals implies TFM planning to ensure aircraft availability to fill available slots. This puts more rigorous demands on wind forecast performance. First, it requires sufficient forecast lead time to allow for positioning of en route aircraft, which requires additional release of ground held aircraft. Furthermore, the burden of managing the flow of airborne planes (as opposed to a ground queue) requires that the forecast window of opportunity be of sufficient length to provide commensurate benefits, and that the end time of favorable crosswinds be forecast with high reliability to avoid an oversupply of airborne arrivals.

These concepts are illustrated in Figure B-22. (1) The initial forecast of future arrival capacity increase will likely require at least a 1-hour lead time to indicate the potential for increased capacity. (2) When winds are verified as favorable, and the current forecast indicates an expected duration of at least 3 hours of favorable crosswind, ATM can increase upstream throughput, presumably involving the release of additional ground-held aircraft. (3) Additional arrival demand becomes available locally to fully utilize arrival slots made available by reduced separations. Typically this would be expected 60-90 minutes after release of additional aircraft. (4) At some point during the increased capacity window, the wind forecast would indicate an expected end to favorable winds. This would require at least 1 hour lead time to reduce flow of upstream arrivals and absorb existing en route arrivals. (5) Crosswinds no longer favorable for reduced separations. Note that this example represents a minimum acceptable benefits scenario, i.e. a 3-hour wind of favorable crosswinds, during which at least 1.5-2.0 hours could be exploited with a sufficiently increased supply of incoming arrivals. A more aggressive approach to further exploit capacity would be to increase the upstream flow rate immediately upon the initial forecast of favorable conditions occurring within 1 hour. This, of course, adds additional risk of oversupply in the event of an incorrect forecast.

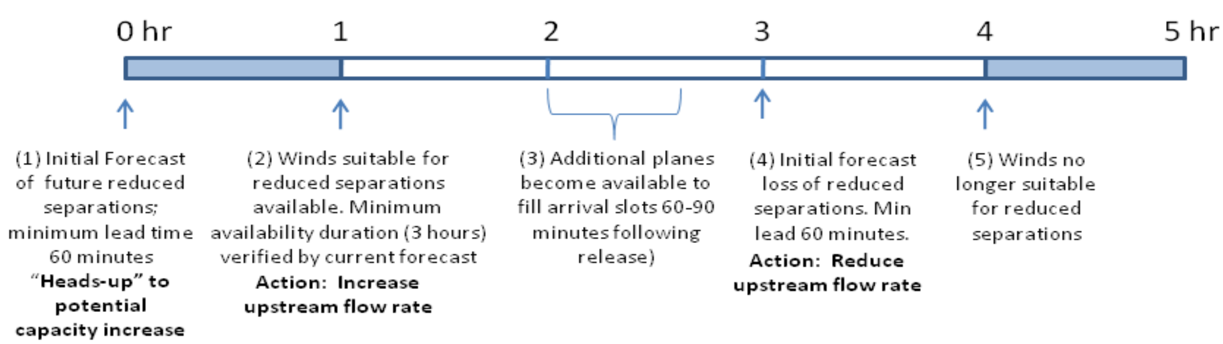


Figure B-22 Conceptual timeline showing traffic flow management in response to reduced wake vortex separations for arrival aircraft.

In NextGen, an increased availability of aircraft meteorological data (e.g. via the Meteorological Data Collection and Reporting System (MDCRS)) and aircraft surveillance technology (e.g. ADS-B) may provide the necessary near real time information for wind dependent solutions without the high cost of more sophisticated ground-based sensors. In particular, flight path observations could be used to validate favorable conditions aloft (nominally up to a few thousand feet) to support the concept. Additionally, continuing advancement in NWP modeling performance and resolution is expected to be of central importance for meeting the wind forecast lead time and precision requirements. Since the capacity impact of wake separation restrictions is highly dependent upon aircraft mix, solutions must also integrate sequence optimization schemes to fully exploit available capacity.

B-1.25 Impact of Winds Aloft on the Compression of Terminal Area Traffic Flows

Strong winds aloft impact an airspace by causing aircraft spacing problems. Generally, when strong winds aloft are present, the wind speed will vary considerably with altitude. This will cause large variations in groundspeeds between aircraft at different altitudes and in trail spacing becomes difficult to maintain. The effect on one flow direction may be very different from the effect in the opposite flow direction, for instance, traffic flying East with the wind will have different effects from traffic flying West into the wind. From an ATM perspective, greater MIT restrictions will be issued to deal with this effect, which controllers refer to as compression. Generally when winds aloft impact the airspace, MIT restrictions have to be increased, and there is also the possibility of impacting performance with a lower AARs with the potential of GDPs and Ground Stops (GS).

Vertical wind information, both observed and forecasted, can be used to manage the impact of compression. Current hourly updated vertical profiles of forecast winds will need to be more frequent in NextGen to facilitate better wind forecasts for this ATM application. The outstanding issue is how to translate this information to determine compression effects on ATM, specifically predicting MIT and any reduced AAR or the need for GDPs or GSs. In NextGen, a larger percentage of traffic will be following Continuous Descent Approaches (CDAs) and tracking Area Navigation (RNAV) routes within a required RNP level, and these procedures will also drive wind forecast accuracy requirements. How the requirements relate to the weather forecast accuracy is an open research question.

B-1.26 Oceanic/Remote Weather Integration

The NextGen Concept of Operations envisions a seamless transition between CONUS, terminal, and oceanic domains. Weather information for oceanic and remote areas will be integrated with ATM at the same level as for CONUS operations. A number of oceanic procedures are already being implemented as wide-spread use of Automatic Dependent Surveillance – Broadcast (ADS-B) expands. For example, airlines are already exploiting the benefits from Dynamic Airborne Reroute Procedures (DARP) which allow airborne aircraft to take advantage of updated atmospheric conditions and cruise-climb more efficiently for better fuel consumption. Oceanic routes integrate with CDAs into gateway terminals to permit idle thrust descents from cruise to short final approach. All of these capabilities depend on timely weather updates on hazards (convection, turbulence, volcanic ash, in-flight icing), winds, and Outside Air Temperature (OAT).

Weather information for remote and oceanic regions is more difficult to create than for the CONUS because data is sparse. This requires creative use of available data from satellites and other limited sources, and is an area of active research. Prototype algorithms have been developed for regional use, but not integrated with ATM procedures.

Studies in the Central East Pacific [GSC06], for instance, demonstrate how wind data can be used to generate wind optimal routes, transitioning away from the fixed Central East Pacific routes to user-preferred routes. While such routing takes advantage of the jet stream, it also must take into account turbulence that can be found near the jet stream, which is an area of future research.

Direct integration of winds and temperature into flight planning systems on the ground, and via data link into flight management systems (FMSs) while airborne, is occurring. Flight plans are optimized prior to departure, and changed as needed en route to take advantage of updated winds and OAT (for cruise-climb). 4D, flight path specific, descriptions of weather hazards (convection, turbulence, volcanic ash, in-flight icing) are needed to complete the NextGen seamless transition to CONUS and terminal operations. 4D hazard information needs to be integrated with winds and temperature effects on flight profiles. Airline dispatchers, oceanic air traffic managers, and pilots can then strategically plan flight profiles and, most importantly, pilots can prepare to react to real-time hazard information prior to an encounter.

B-1.27 Translation of Volcanic Ash Plume Hazards onto Airspace and Airport Impacts

Advanced techniques are needed in NextGen that will detect, forecast, and disseminate information on volcanic ash plume hazards and how the hazards will affect ATM resources to aviation operators and users. Airborne volcanic ash constitutes a recognized threat to aviation that can severely damage jet aircraft engines through erosion, corrosion and congestion. Volcanic ash contamination may render large volumes of airspace unavailable, necessitating costly rerouting contingencies, degrades braking action at affected airports, as well as completely closes contaminated airports [KMP08]. Problematic ash-related aircraft encounters have been reported days after an eruption and thousands of miles from the source. There are a number of technical issues that need to be addressed to identify volumes of airspace that should be avoided.

The weather translation model for volcanic ash plume hazards (Figure B-23) requires further advancement of both science and operational modeling. Science issues for NextGen include:

- Timely detection of eruption and resulting ash cloud
- Discrimination of ash from water/ice and sulfur clouds
- Missed detections and false alarms
- Sensor response function, measurement precision, calibration
- Dispersion models
- What concentration and ash particle size constitute a hazard
- How the concentration and ash particle size determined
- Operational issues for NextGen include:
- Timely advice of the mathematical model for eruption / ash cloud
- Dispersion model development and validation, and

- More automation needed for integration of ATM impact with NextGen systems.

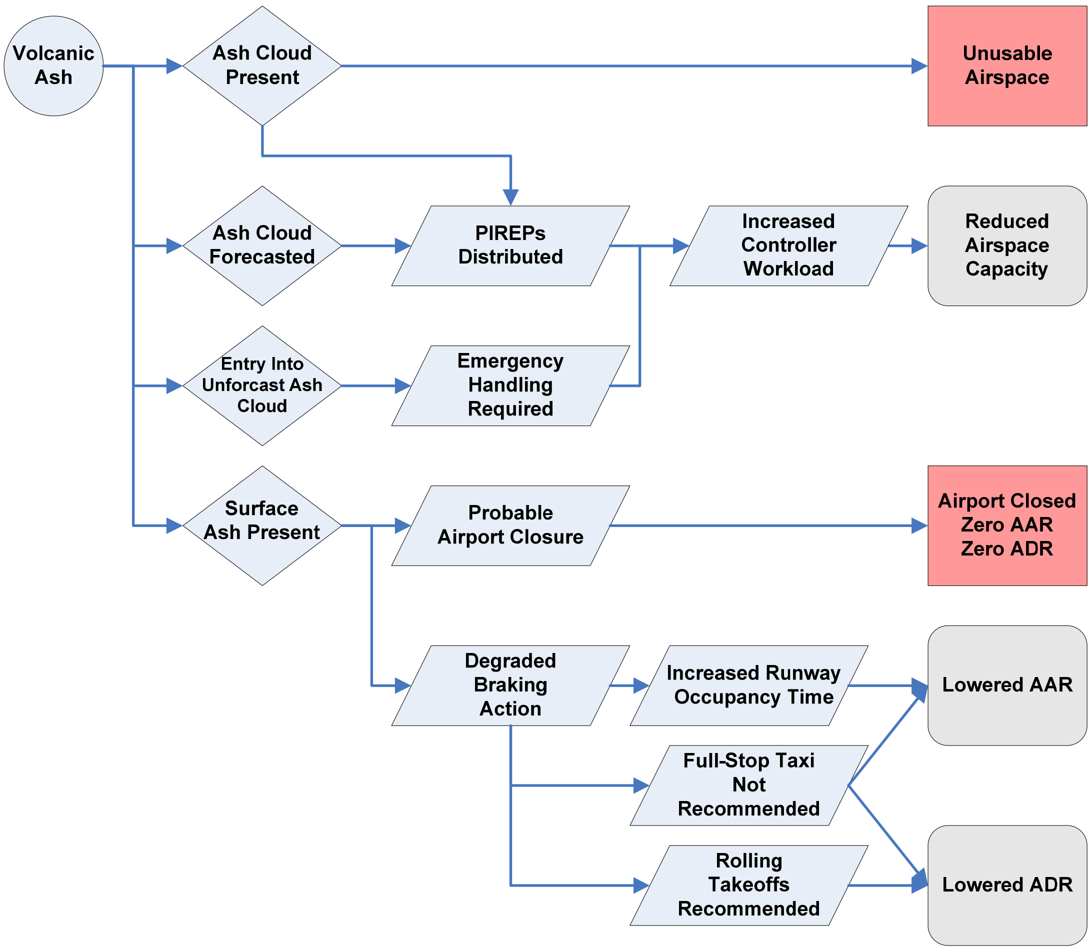


Figure B-23 Causality diagram ATM impacts of volcanic ash.

The ATM impact is so severe that any forecast or actual volcanic ash above a threshold concentration and particle size is considered a hard constraint. A 4D airspace volume defining the hard constraint is required for NextGen. Application of the constraint would be the same as for any 4D weather hazard. It represents a no-fly volume that most likely is deterministic versus probabilistic (pending further research on the above technical issues).

B-1.28 Translation of Atmospheric Effects into Environmental and ATM Impacts

The large increase in air traffic associated with NextGen will have a growing impact on the environment. Environmental impacts will be significant constraints on the capacity and flexibility of NextGen unless these impacts are managed and mitigated [GTA09]. The major environmental effects of aviation are:

- Emission of pollutants affecting local air quality, such as NOx, SOx, CO, and particulate matter;
- Emission of greenhouse gases such as CO_2;
- Aircraft noise; and
- Water pollution via de-icing agents, spilled fuel, etc.

Note that the discussion of fuel consumption in the NextGen Concept of Operations is not an environmental impact but is a surrogate for greenhouse-gas and air-pollution impacts. All of the weather-integration applications discussed here, of course, have an impact on fuel consumption as related to ATM efficiency.

Most of the above environmental impacts are affected by the atmosphere and will require the integration of probabilistic weather forecast elements for proper risk management. The weather elements include, but are not limited to: wind and temperature profiles; probabilistic model output of Atmospheric Impact Variables (AIVs); translation of atmospheric conditions to environmental impact; and translation of environmental impact to ATM impact.

Examples of the translation mechanisms coupling atmospheric conditions to environmental impact include:

- Noise intensity on the ground is affected by wind and temperature via their influence on the strength and directionality of acoustic propagation, and also via their influence on aircraft performance (e.g., climb rates).
- Dispersion and mixing of air pollutants is affected by wind, temperature, and humidity via their impacts on atmospheric mixing and chemistry.
- Generation of greenhouse gases is affected by wind, temperature, and humidity via their impacts on engine performance and fuel consumption.
- Environmental impacts are translated into ATM impacts via several mechanisms, including:
- Mitigation measures such as specialized departure and arrival procedures and routings, as well as restricted periods of operation;
- Routing and altitude assignments that seek to minimize fuel consumption (and possibly contrail formation); and
- Surface and system management that seeks to minimize taxi times and delays on the ground with engines running.

To the degree that the above change the capacity or throughput of airspace or airport elements, then environmental considerations will impact NAS operations.

B-1.29 ATM Impact of Space Weather

There is a growing threat from space weather as aviation's dependence on space and terrestrial networks vulnerable to space weather continues to grow. The threat also exists within the aircraft, affecting communication and navigation abilities for long-haul polar flights. In addition, there is an increasing need to characterize the radiation environment that changes as a consequence of space weather eruptions. Even relatively minor solar storms can affect communications, navigation, and radiation exposure, and this can cause flights to reroute, divert or not even dispatch over polar regions. Thus, an increase in polar flight activity in NextGen will bring about an increase in NAS delays from space weather impacts during times of high solar activity. We can expect an as-yet undefined impact to the net-centric NextGen infrastructure in the CONUS as well. Moreover, the human exposure to space radiation is significantly higher on polar routes, which poses a potential health risk. Finally, the emerging industry of commercial space tourism and commercial resupply and transportation services to the International Space Station will also necessitate the need for increased situational awareness of the space weather environment and its impacts.

Information on space weather is currently sparse and not well applied to aviation applications. Recent popularity of polar routes has driven the requirement to include adding appropriate space weather information into the normal operating procedures of commercial aviation. This requirement also extends all over the globe, as communication and navigation issues in particular reach far beyond the polar regions. The physical units describing these events are not translatable to aviation and net-centric impact. First, impact thresholds for both net-centric operations and communications/navigation systems need to be established in terms of the physical units describing solar events. This is an area of active research. Once thresholds are better understood, solar events can be translated into such ATM impacts as alternative communications and navigation methods required for flight; backup net-centric systems for flights through affected regions; support for airline dispatch and air traffic control decisions to close routes and airspace; and restrictions to human exposure to radiation. Forecasts of solar eruptions and their impact time-of-arrival for the Earth's atmosphere are necessary to mitigate these impacts to aviation in NextGen.

B-1.30 ATM Impact of Weather Constraints on General Aviation Access to the NAS

Although GA aircraft operations make up approximately half of all flight hours in the NAS, quantification of the impact of weather upon their operations in the NAS is complicated due to a number of factors. At one extreme, these GA flights are non-scheduled, and thus cancellation and delay data are not available. When these fights do enter into controlled airspace, then ETMS and other trajectory data sources can be mined to yield statistical models of pilot behavior [DE06] however, it is expected that the results will vary considerably compared to the models that have been emerging to characterize commercial airline pilot behavior. Further, GA aircraft cover a wide spectrum from day VFR-only to extremely weather-capable aircraft matching those in scheduled Part 121 service. This diversity in aircraft capability is matched by that of the pilot qualifications and the airports from which the aircraft operate. This variability will be reflected in the response of these aircraft to weather constraints. These constraints include convective activity, turbulence/wind, flight icing, ground icing, and Ceiling and Visibility (C&V).

One example of this variability is in the behavior of pilots when using datalinked reflectivity data to avoid thunderstorm cells. Some pilots interpret the data tactically and penetrate the convective areas while others interpret it strategically, avoiding the entire region of convective activity [B08]. There is considerable variability in pilot behavior near convective areas, making it difficult to model the diversion probability. Pilot experience and training, as well as aircraft equipment, vary considerably, and these will strongly affect weather avoidance strategies. The evolving nature of onboard weather detection can reasonably be expected to ensure that GA pilot deviation behavior will continue to be nonuniform. Existing simulation methodologies can be rapidly configured to explore pilot response to cockpit weather and traffic displays [HMB06].

Terminal area winds and turbulence will also have varied impacts. The decision of whether or not an aircraft will accept an approach to a given runway can depend more upon pilot skill, runway width, and flow field complexity than upon aircraft type and may be difficult to quantify. This is because most GA aircraft do not have well-defined crosswind limits, although some have a maximum demonstrated crosswind.

En route turbulence will usually result in a request for a higher altitude, although pilots with headwinds may choose to sacrifice ride quality for a higher groundspeed, as headwinds will have a lesser impact at lower altitudes. Orogenic turbulence over major mountain ridges can render some altitudes unusable if downdrafts approach or equal climb rate. Clear air turbulence in the vicinity of jet streams will have similar impacts upon GA jets and air carrier aircraft.

Both in-flight icing and ground icing show high variability in their NAS impacts for GA flights. In addition to having less effective anti-icing provisions, smaller GA aircraft typically operate at altitudes where icing is more frequent, so it is likely that GA aircraft will be more affected by in-flight icing than studies show for larger commercial aircraft [KrK09]. Larger, particularly jet, aircraft will experience icing primarily during ascent or descent from or into terminal areas.

Aircraft are classified as approved or not approved for flight into known icing conditions. This classification does not capture the degree of ice protection possessed by the aircraft. Furthermore, not all aircraft sharing a single type certificate have the same status with regard to icing. This wide spectrum of ice protection is matched by a large variability in pilot strategies to avoid ice. However, regardless of the level of ice protection, pilots will avoid areas of potential or reported icing as much as possible. This can make some altitudes unavailable for holding traffic, resulting in aircraft being spread out over large areas. Most GA airports have limited de-icing services, with hangaring being the most common option. A thin layer of overnight frost can cause cancellation or lengthy delay for all unprotected aircraft, particularly impacting early morning departures.

As for C&V, under Part 91, aircraft may begin an instrument approach even if there are no official visibility measurements or if such measurements are below minimums for the approach. This may lead to a greater probability of missed approach procedures being flown compared to Part 135 and Part 121 operations. Pilots of en route VFR GA aircraft may request IFR clearances in the event of sudden reduction in C&V. Others may require special assistance. Either action adds to ATC workload. New cockpit displays, such as moving map and synthetic vision, have the potential to improve VFR into Instrument Meteorological Conditions (IMC) accident rates but may also increase the proportion of VFR pilots who choose to continue toward the destination rather than diverting or changing to IFR, [JWW06] potentially increasing complexity for controllers managing low altitude IFR operations. Non-towered, non-radar airports are typically “one in – one out” for IFR operations, creating significant delays for both arrivals and departures.

While the number of studies that have been performed to build ATM impact translation models has been increasing over the years, few and possibly none of these have focused on the particular parameters that model GA aircraft in particular, or have quantified the overall impacts to GA pilots in the aggregate.

B-2. Methodologies for ATM Weather Integration

Many of the ATM-impact models will eventually be integrated into DSTs in order to help users reason about the impacts of weather while solving ATM problems. The survey includes approaches for addressing weather-related uncertainty in ATM decision making for strategic look ahead times – risk management processes – as well as approaches that wait until the tactical look ahead times to address deterministic forecasts after the uncertainties diminish. The ATM-weather integration techniques make reference to ATM-impact models as appropriate.

B-2.1 Sequential, Probabilistic Congestion Management for addressing Weather Impacts

Flexibility and adaptability in the presence of severe weather is an essential NextGen characteristic. But even at tactical flow management planning times (0 to 2 hours), weather and traffic forecasts contain significant uncertainties. Sequential, probabilistic congestion management [WG08] describes how to incrementally manage en route airspace congestion in the presence of these uncertainties.

The concept is illustrated in Figure B-24 as a control loop, where congestion management decisions are made continually at regular intervals (e.g., every 15 minutes). The distribution of traffic demand in en route sectors is predicted based on flight plans (or downlinked Flight Management System (FMS) data), track data, wind forecasts, aircraft performance data, and other adapted elements. Several methods of predicting traffic demand distributions have been developed. [WZS05, GS07, WSZ05] Convective weather forecasts, which will include measures of forecast uncertainty, are used to predict the probabilistic capacity of en route sectors. This calculation may include the predicted traffic demand, since the true capacity of sectors is sensitive to the traffic flow patterns and how they interact with the weather. Methods for estimating weather impact on sector capacity have been proposed [KMP07, SWG07, M07], however, none have been developed for estimating the distribution of possible sector capacities based on a probabilistic weather forecast product. The distributions of demand and capacity are convolved to produce a probabilistic congestion forecast, where congestion is simply defined as when demand exceeds capacity.

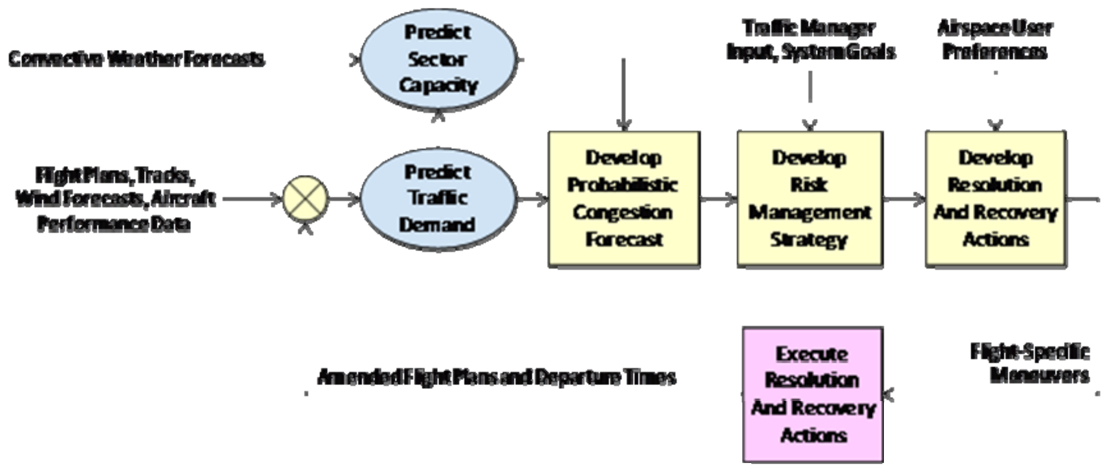


Figure B-24 The sequential, probabilistic congestion management concept as a control loop.

Given a probabilistic congestion forecast, a decision needs to be made. How much control is needed to ensure that the congestion has an acceptable level of risk? This decision is made knowing that the strategy will be modified at the next decision time, and thus it need not be a complete solution to the problem. If too-aggressive action is taken, then some flights will be affected unnecessarily. If insufficient action is taken, then more intrusive maneuvers, such as airborne rerouting, may be required to manage congestion. This is a classic decision-theoretic tradeoff between acting early on uncertain information and waiting for better information. Note that the system goal (congestion risk) and desired types of flight maneuvers can be modified by traffic management personnel at this stage.

Once a congestion management goal has been chosen, specific actions must be developed. If congestion resolution is required, flight-specific maneuvers can be developed in a variety of ways [WG08, TW08, RH06, BS98, SMW07]. If the weather turns out to be less disruptive than predicted, delay recovery actions to undo previous maneuvers may be needed. In both cases, it is anticipated that relatively few aircraft would be maneuvered at any single decision time, as compared to the large-scale traffic flow initiatives commonly used today. At this step, airspace users can collaborate with the ANSP to coordinate resolution or recovery actions with their business needs. This may be via user preferences, or eventually via a 4D trajectory negotiation process. The final step is to execute the actions such that departure times and cleared flight plans, or the agreed-upon 4D trajectory, are updated.

Sequential, probabilistic congestion management can take advantage of probabilistic weather forecasts to reduce weather impact on en route airspace. It would also provide an effective "inner loop" to be used in conjunction with strategic flow management initiatives, based on longer-range weather forecasts [HKD07]. Note that an alternate, multiple-timescale sequential congestion management approach has also been proposed [GSM08]. This method does not employ probabilistic forecasts, but rather relies on adapting to observed weather development.

B-2.2 Sequential Traffic Flow Optimization with Tactical Flight Control Heuristics

A deterministic sequential optimization approach integrates a strategic departure control model with a fast-time simulation environment to reactively control flights subject to system uncertainties, such as imperfect weather and flight intent information [GSM08]. To reduce the computational complexity of the strategic model, only departure delays are assigned, while tactical en route flight control is accomplished through heuristic techniques. These heuristics rely on a shortest path routing algorithm and an airborne holding model that is used only as a control strategy of last resort.

This closed-loop, integrated optimization-simulation system is illustrated in Figure B-25. System inputs consist of user schedules and flight plans, weather data, and airspace adaptation data. The weather forecast inputs are suitable for establishing CWAM WAFs [DE06].

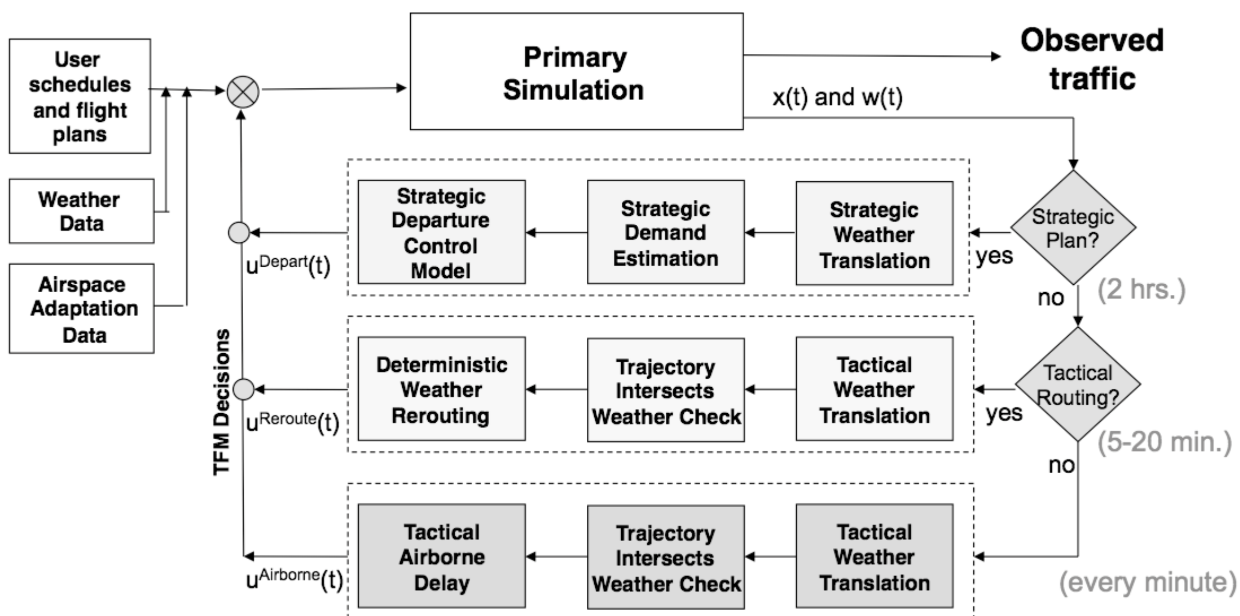


Figure B-25 Sequential optimization with strategic and tactical weather translation.

A Primary Simulation updates state information (e.g., latitude, longitude, speed, altitude, and heading) for all aircraft in the simulation every minute, while updates to the weather forecasts are provided every five minutes. This updated state information is used every two hours to develop and refine deterministic, strategiB-level flow control initiatives, assigning pre-departure delays to flights subject to airport and airspace capacity constraints. The first step in developing these strategiB-level controls is to translate the weather data into reduced sector capacity estimates

[KMP07, M07, SWG08]. Subsequently, the predicted positions of all airborne and scheduled flights over a user defined planning horizon is calculated. The forecasted system demand and capacity estimates are used as inputs for strategic departure control, assigning flight specific pre-departure delays.

Refinements to the strategiB-level traffic flow management plan to account for uncertainties in the demand and capacity estimates are accomplished through two tactical control loops. The first is called at a frequency that ranges between 5 and 30 minutes, and assigns tactical reroutes to flights to ensure that aircraft do not venture into regions of significant convective weather. The variable calling frequency is allowed here to account for the confidence in the weather forecast accuracy. Regions of significant convective weather are defined by CWAM WAFs. The trajectories of all flights over a 100 nmi to 400 nmi look-ahead horizon are checked to determine if any flight intersects a WAF. Flights found to intersect these regions are rerouted. The lowest level control loop that is called every minute is a strategy of last resort to immediately assign airborne delay to any flight that will encounter an en route weather hazard within the next minute.

B-2.3 Airspace Flow Programs to address 4D Probabilistic Weather Constraints

An AFP [Br07, KJP06] is a particular type of Traffic Management Initiative (TMI) that controls traffic flowing into an airspace where demand is predicted to exceed capacity, as illustrated by Figure B-26. A FCA is defined to be the boundary of the region of airspace where demand exceeds capacity – most typically, due to convective weather constraints. Today's AFPs use fixed locations for FCA boundaries used for AFPs, typically a line segment connecting sector boundaries that aircraft cross at they travel toward eastward destinations, and these regions are defined by air traffic control sector boundaries, not the location of the weather constraint itself.

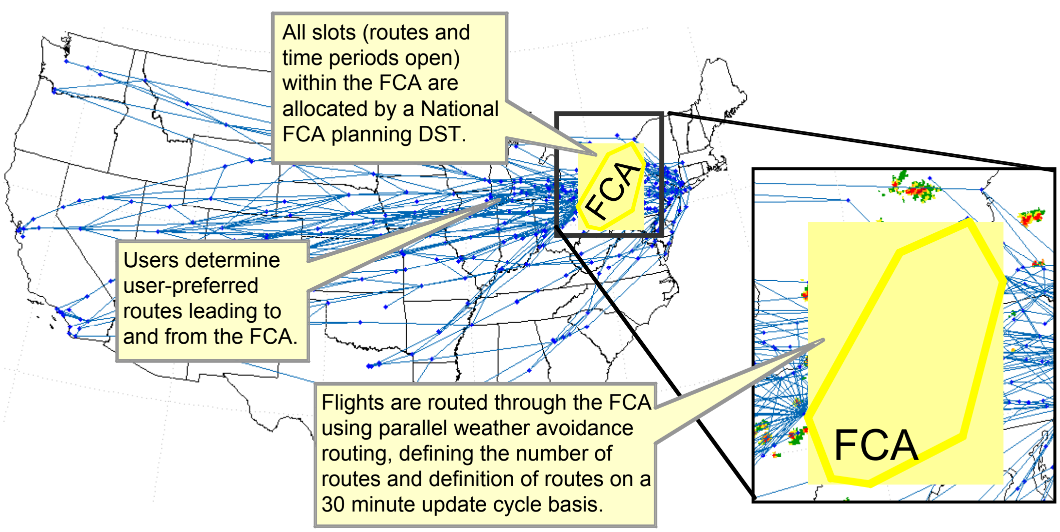


Figure B-26 In an AFP, routes within the FCA are defined by an FCA planning DST to maximize throughput given weather constraints; routes outside the FCA are determined by routing preferences of the user.

In NextGen, the FCA is likely to be a 4D volume that describes the space-time region where weather constraints (not only convection, but severe turbulence and icing regions as well) cause significant ATM impacts. This 4D volume is likely to be derived from weather forecast data from the NextGen 4-D4-D Wx Data Cube and from information about the expected demand at a given time and location that reflects user preferences. The FCA is thus a product of the translation of weather into ATM impact; it requires a capacity estimation technique to define the capacity reduction due to the forecasted weather [CRD07, KMP07, SWG06, SWG07, SWG08]. The AFP is a TMI that responds to the ATM impact in terms of a TFM plan that adjusts periodically (e.g., every 30 minutes) as long as the scheduled demand continues to exceed the FCA capacity.

The AFP for NextGen is able to control a number of factors. Strategically, the AFP controls the takeoff time (ground delay) for aircraft heading to the FCA in order to control the flow rate of traffic entering the FCA. Tactically, the AFP defines the entry points into the FCA as a function of time. As aircraft approach the FCA boundary, the AFP defines safe routes (routes that avoid hazardous convection, turbulence, or icing constriants) across the FCA in order to maximize capacity usage within the FCA region subject to the dynamic 4D weather constraints. One algorithmic solution to the AFP minimizes the sum of all delays experienced by all flights in the AFP [KJP06].

Because the AFP must reason about the effects of weather on airspace capacity for long lookahead times, it is necessary for the AFP to reason about a probabilistic estimate of capacity [MPK06, SB09]. Thus, the FCA boundary is not known precisely, but it represents the general vicinity in 4D where the constrained airspace is likely to occur. As the time horizon shortens (when most aircraft are en route), the exact boundaries of where the FCA must control traffic flow is known more precisely based on deterministic estimates of capacity. Because the routes across the FCA may not be synthesized until flights are within about 1 hour from entry into the FCA, a datalink is required in NextGen to inform air crews of the routing needed for safe and efficient travel across the FCA. Thus, the AFP is an implementation of strategic TFM plans to continuously adjust the flow rate of traffic entering the FCA in order to match demand with the capacity estimates that were initially set using probabilistic techniques and later refined through deterministic means.

B-2.4 Ground Delay Program Planning under Capacity Uncertainty

Uncertainty in capacity forecasts poses significant challenge in planning and controlling a GDP. There are two main decisions associated with any GDP: (1) setting the AAR, and (2) allocating landing slots to flights, and hence, to the airlines who operate those flights.

The AAR is dependent on uncertain weather conditions; it is not known in advance with certainty. Therefore, when a GDP is implemented, a planned AAR (PAAR) must be set based on stochastic information. A “static” stochastic optimization model for deciding optimum PAAR was presented in [BHO03]. There are other variants of such models [KR06, RO93]. The models require an input arrival schedule, a finite set of capacity scenarios, and their probabilities. A scenario represents time-varying profile of airport capacity. A cost-ratio between ground and airborne delay can be adjusted to penalize excessive airborne delays. Given these inputs, the static optimization model [BHO03] generates the optimum PAAR.

Uncertainty in airport capacity is represented by a set of scenarios in stochastic optimization models. Probabilistic weather forecasts are needed. Past research has addressed this issue for specific airports [Wi04]. Research is currently underway to generate probabilistic weather forecasts at airports and en route airspaces. One methodology generates capacity scenarios by analyzing historical observations of AAR [LHM08]. In the future, a combination of probabilistic weather forecasts and empirical data analysis could be used to generate capacity scenarios for airports.

After setting the PAAR, the next step in a GDP is to assign slots to airlines. In today's system, this is done by executing a Ration-by-Schedule (RBS) algorithm, which is based on first-scheduled-first-served principle. Before RBS is applied, certain flights are exempted from the GDP. The primary reason for exempting flights is to mitigate capacity uncertainty. The RBS algorithm, which lexicographically minimizes the maximum delay of included flights [Vo06], has been accepted as the standard for equitable slot allocation. In a recent study, a new algorithm – Equity-based Ration-by-Distance (E-RBD) – was proposed that considers both equity and efficiency factors in slot allocation [HBM07].

A GDP is a stochastic and a dynamic process. Changing conditions at an airport, for instance due to weather constraints, requires revision of GDP parameters and flight delays. In static optimization models [BHO03, KR06, RO93] decisions are made once and are not revised later based on updated information. This deficiency is overcome by dynamic optimization models [MH07, RO94]. However, it is possible to re-apply static models, and revise decisions, whenever updated forecast becomes available. Figure B-27 presents an algorithm for planning a GDP under uncertainty, and dynamically revising decisions in response to updates in the information on demand and capacity. The steps within the algorithm are similar to how GDPs are planned in today's system under the Collaborative Decision Making (CDM) paradigm

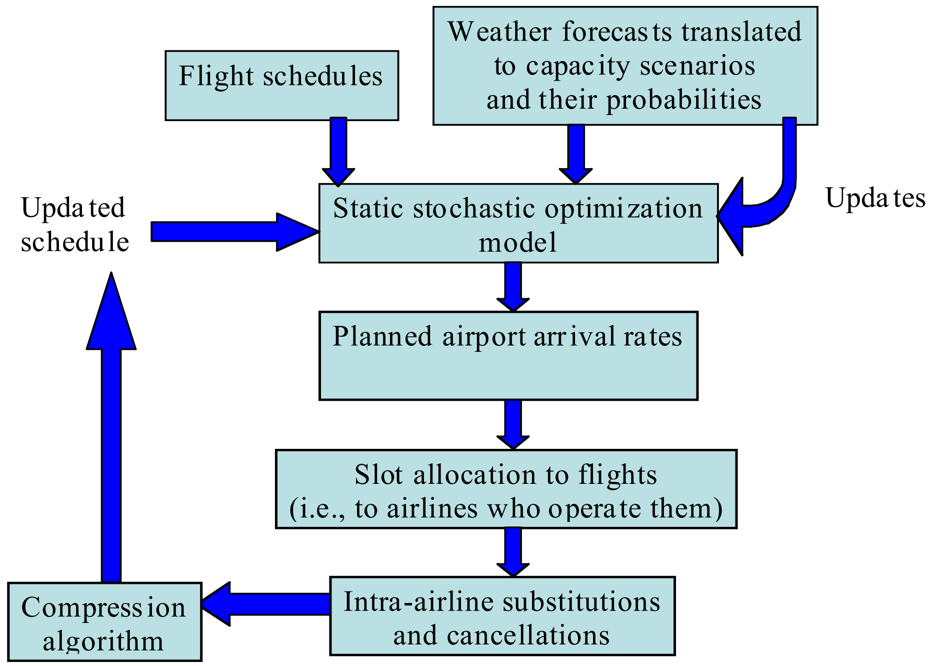


Figure B-27 A dynamic stochastic algorithm for planning and controlling a GDP.

Dynamic stochastic optimization models simultaneously decide PAAR and slot allocation to flights [MH07, RO94]. The dynamic models typically assign scenario-contingent slots to individual flights. These models allow revision of delays based on updated forecasts. Along with a set of capacity scenarios, these models require as input a scenario tree, whose branching points reflect changing AARs. What complicates the applicability of dynamic models is the fact that the branching points in time must be predicted in advance and provided as input to the models. Techniques for generating scenario trees from empirical data were explored in [LHM08]. Performance-wise, however, dynamic models outperform the static models. Application of the dynamic models for GDP planning would require a change in the intra-airline flight substitution process. Unlike in today's system where each flight receives one slot, the dynamic models would assign a portfolio of scenario-specific slots to a single flight. Thus the flight substitutions would also become scenario-specific, and hence, more complex.

Along with capacity uncertainty, there could be uncertainty in flight arrival demand [BVH01]. This could result from flight cancellations, deviation from scheduled or controlled arrival times, and arrivals of un-scheduled flights. Developing models that account for both demand and capacity uncertainty is a potential research topic.

B-2.5 Contingency Planning with Ensemble Weather Forecasts and Probabalistic Decision Trees

Management of the complex interaction between potential weather outcomes and TMIs can be modeled using a collection of potential weather scenarios. These would be retained in an ensemble forecast, which would serve as input to a Probabilistic Decision Tree [DKG04]. Flow planners would make use of this to form a primary plan and contingency flow plans (one for each possible weather scenario) (for instance, strategic two to four hours in the future). This assists in the strategic planning of GDPs, AFPs across FCAs as well as tactical GSs, holding, metering, reroutes, and other plans.

Ensemble weather forecasts aim to represent the spread of possible outcomes of the weather. Since there could be hundreds of different weather scenarios, the secret to this techinque is to group the scenarios by general natural and impact on air traffic. Weather organization (e.g. squall line versus popcorn storms) is one such way to group scenarios into a more managable number. Each representative scenario would have associated with it a likelihood (probability) of occurrence. This technique allows for automated routines to propose hedging strategies. Hedging strategies are a proven way to take a wide range of possible outcomes into account without falling back on an overly conservative (worst-case scenario) strategy. Some weight is given to dire outcomes, but other more optimistic outcomes are considered as well. This leads to a more balanced strategy that peforms well on average; cost savings are incurred with repeated use [HKD07]. Probabilistic forecasts and the use of probabilistic decision trees will have failures on a daily review, but over the long-term will show improvement in operations.

The probabilistic decision tree manages the ATM impacts and probabilities of occurance. As illustrated in Figure B-28, the decision tree is set up to reason about the general dimensions of forecast error that are possible in the future, and how these should be linked to strategic and tactical TMIs that will address those scenarios. The tree is mainly for benefit of the human users. It provides a map of key TMI and flow planning decisions that need to be made. Decision makers and other stakeholders can follow along to see which critical decisions must be made, when, and ATM-impact costs associated with the course of action.

First, the ensemble captures potential variations in weather types that may emerge, and associated probabilities. Errors in timing, coverage, echo tops, and translational errors may be considered in the tree. In order to process such errors, the appropriate weather to ATM impact models must be invoked, requiring potentially a wide range of ATM impact models from capacity estimates, route blockage probabilities, affects of weather on AARs, or other impacts. Associated with each branch of the tree is a set of TMIs that would be used if the future evolves to that state.

For NextGen, the use of probabilistic decision trees to manage traffic in the NAS requires both ATM impact models to mature as well as the understanding of how to best assemble TMIs into a probabilistic decision tree that meet the objectives of a strategic plan of operations. Given that the amount of weather forecasts in an ensemble is likely to be large, and the space-time dimensions of potential uncertainty further expand the number of scenarios, NextGen will require research on how to best manage probabilistic decision trees using computers as the number of possible futures is far larger than humans could cognitively grasp

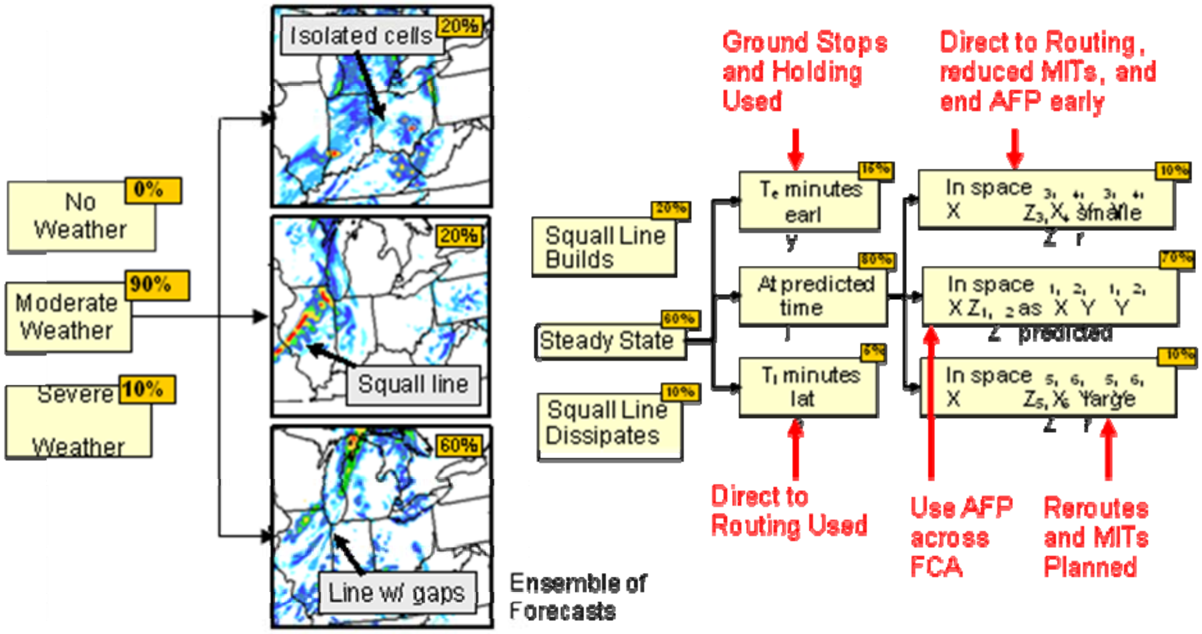


Figure B-28 Probabilistic decision tree reasoning with an ensemble of weather forecasts.

B-2.6 Probabilistic Traffic Flow Management

An important goal of TFM is to ensure that traffic loadings do not exceed system capacities. TFM problems often involve time horizons extending to one or more hours into the future. This strategic TFM problem is inherently stochastic since both the traffic loadings and system capacities are difficult to forecast precisely over such long time horizons [WSZ05]. Strategic TFM solutions need to account for forecasting uncertainties.

The strategic TFM problem is difficult even in the absence of forecasting uncertainties [BS98]. This difficult problem is solved mainly by human operators in today's NAS. A strength of human decision making is its intuitive ability to rapidly assess and approximately account for uncertainties. Such powerful intuition will be a challenge to replace in automated strategic TFM solutions in NextGen. These future TFM solutions hold the promise of significantly improving NAS performance and repeatability, but first they must match the robustness inherent in human decision making.

Any strategic planning activity within the NAS requires forecasts which contain uncertainties since all forecasted quantities are random variables. For instance, surveillance reports, navigation data, communications, user intent and conformance, weather, and the possibility of anomalous events all introduce uncertainty into NAS forecasted quantities. These processes could be modeled and their random variables estimated in a classic covariance propagation [Ge74]. But this is difficult due to the magnitude of the problem and the substantial modeling effort required. Perhaps the biggest drawback to the approach, however, is the difficulty in accounting for the substantial human-in-the-loop decision making that critically affects these processes. In fact, in the absence of such an accounting, the variances of many random variables (e.g., aircraft position) can rapidly grow. In this case distributions flatten and the strategic TFM problem reduces to a non problem due to an absence of information.

An alternative to the classic covariance propagation approach is to identify the key random variables in the strategic TFM problem and model them with aggregate uncertainty models, based on system domain knowledge and historical data. In this rational-empirical approach, one (i) constructs mathematical models describing the random variable uncertainty as a function of the relevant independent variables and (ii) fits these models to the historical data [WSZ05, H07a, HR08, HW08]. This approach also has the advantage that many random variables can be ignored as irrelevant. For instance, though surveillance error should be accounted for in a classic covariance propagation approach, it becomes irrelevant in the aggregate model of traffic loading uncertainty [WSZ05].

In the strategic TFM problem, forecasted traffic loadings and system capacities are the most important random variables that need to be estimated. Since loading and capacity are typically expressed as integers, these random variables can be expressed as discrete distributions, known as probability mass functions (PMFs). Properly constructed, these PMFs faithfully represent the forecast accuracy. They are neither less accurate (wider) nor more accurate (thinner) than the forecast accuracy. Given PMFs that faithfully represent the forecast accuracy, the probabilistic TFM solution can then use them to account for the uncertainties that are unavoidable at the planning stage.

A misconception is that a probabilistic TFM solution is limited to probabilistic, or multiple, solutions. Such solutions would be difficult to implement but are easily avoided. Probabilistic TFM solutions can use probabilistic forecasts to produce a deterministic solution. An obvious approach is to compare the traffic loading and system capacity PMFs to evaluate a congestion cost (e.g., by convolving the PMFs). Such a metric can be forecasted for NAS elements, such as airports and regions of airspace, and for flights. Figure 30 shows an example of the distribution of flight costs in a day [H07a].

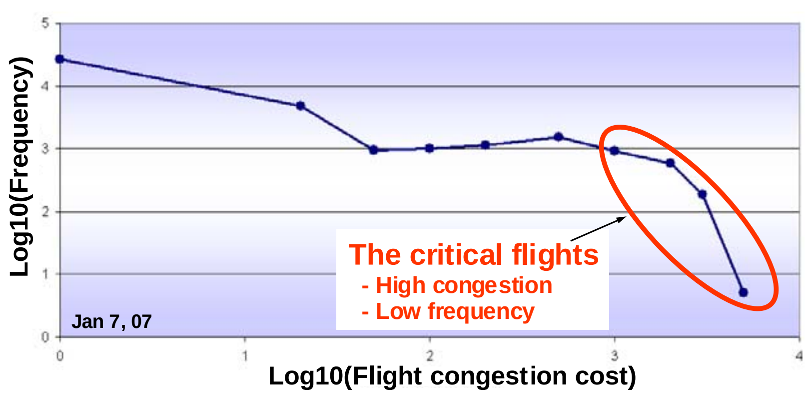


Figure B-29 Example histogram of flight congestion costs.

Such congestion forecasts, by flight or by airspace / airport, are crucial in the probabilistic TFM solution. They can be used to guide flight selection, for delaying or rerouting. And they can be used to manage system congestion to acceptable levels. And this approach is well-suited to the NextGen principles of trajectory-based operations and user involvement.

The specific solution method can take several forms. One is a resource allocation solution involving a combination of rerouting and ground delay. This probabilistic TFM concept has a high maturity level, as it has been defined, analyzed and verified at various levels. Also, it has been simulated for several different types of traffic and weather days, and has been tested in a real-time system testbed [H07a, H07b, H08].

B-2.7 A Heuristic Search for Resolution Actions in Response to Weather Impacts

Uncertainties present in demand, weather, and capacity, create a need to resolve congestion in an efficient and flexible manner. In both the strategic and tactical time frames, the methods utilized to resolve congestion should provide metrics to measure the quality of the proposed solutions. As it is desirable to have flight-specific resolution actions, there are many potential solutions and the challenge is to find a good solution quickly. A Generalized Random Adaptive Search Procedure (GRASP) can address this problem through a computationally-efficient heuristic optimization approach. GRASP finds feasible solutions quickly and evaluates proposed solutions against defined metrics to determine the set of resolution maneuvers that best satisfies the objectives.

Figure B-30 illustrates the decision loop. The process creates an ordered list of flights and then examines each flight individually to determine if it can remain on its original path or if it must be delayed and/or rerouted. Weather information is used to predict sector capacities in and around the congested area, and flight options that violate the congestion resolution goal are less desirable. The flight list is ordered probabilistically, using specified priority criteria such as first-come first-served (FCFS), to determine the likelihood of placement in the sort order. This is useful because it exploits the fact that the chosen prioritization criteria may not fully capture the best situation and therefore minor modification in the ordering may be beneficial [FR95].

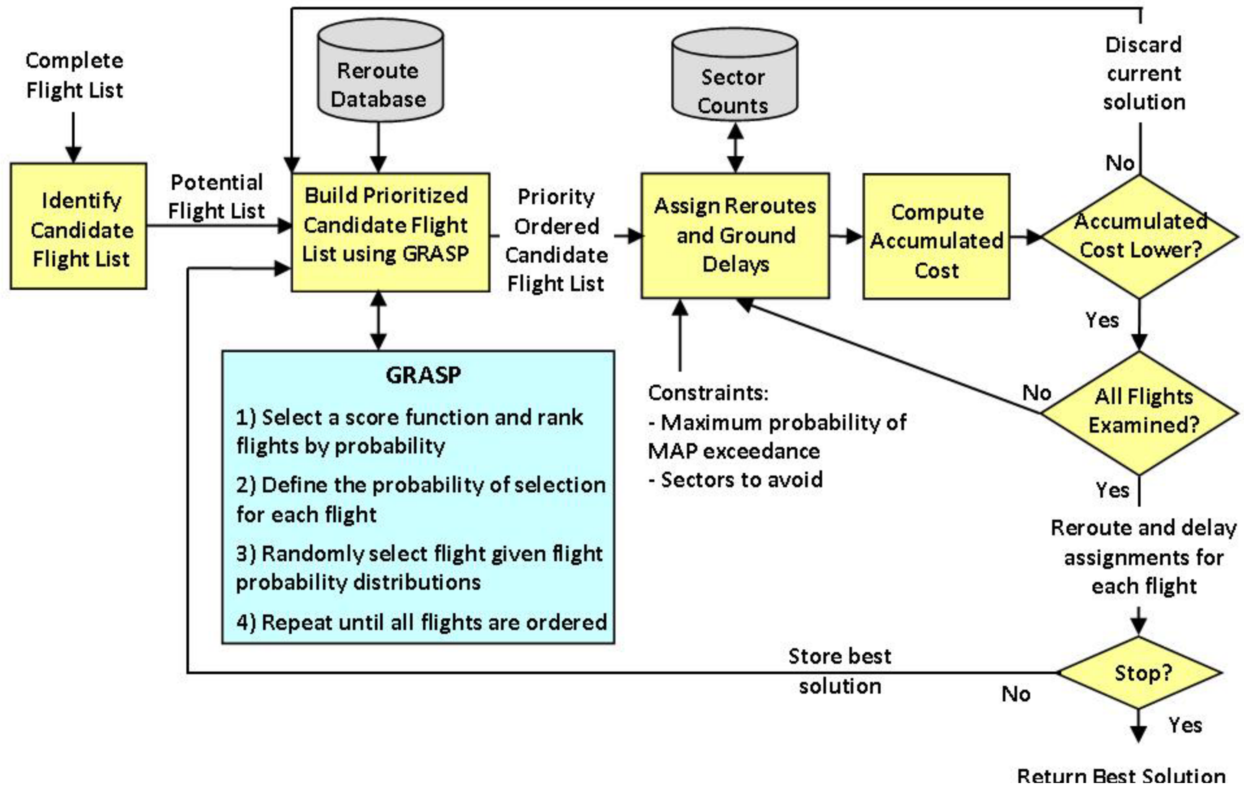


Figure B-30 Congestion management algorithm flow diagram.

Once all flights are examined, an objective function is used to measure solution quality against a variety of goals. Objective functions are formulated to evaluate the quality of the solution as a whole, such as congestion resolution effectiveness, total delay, or the equitable distribution of resolution actions among users. After iterating, the algorithm returns the best solution found.

This process for air traffic congestion provides a flexible and computationally efficient alternative to more traditional heuristic optimization algorithms [MWG06, SMW07]. Given its computational efficiency, GRASP could be employed within a larger decision making process, such as sequential probabilistic congestion management [WG08], to optimize the resolution maneuvers at each stage of the decision process.

Another useful application is to evaluate quantitative measures of the impact on a policy objective that result from implementing a given prioritization criteria. For example, by choosing a FCFS prioritization, the impact on delay and equitable distribution can be compared to the results obtained from the choice of an alternative prioritization (e.g., sort flights by the number of congested sectors they currently are planned to traverse). This type of analysis can provide feedback as to which choice of prioritization criteria is desirable, based on the trade-offs obtained in the policy objectives considered.

B-2.8 Integrated Departure Route Planning with Weather Constraints

NextGen will require an Integrated Departure Route Planning (IDRP) capability in order to handle departure traffic efficiently and safely. The IDRP capability must integrate departure route and en route sector congestion information, especially when weather constraints are present and traffic demand must dynamically adjust to predicted downstream capacity fluctuations. This concept also applies to downstream weather constraints such as convection, turbulence, or icing. The IDRP capability reduces the time needed to coordinate and implement TMIs and supporting departure management plans.

A variety of TMIs such as reroutes, MIT restrictions, and GDPs are generated to control the NAS when air traffic demand on specific resources – sectors, routes, and fixes – is predicted to exceed capacity. This is especially crucial when system capacity is reduced by severe weather. In current operations, with limited automation support, traffic managers must mentally integrate the traffic, weather, and airspace resource information and project that information into the future. This process is difficult, time consuming, and inaccurate. In NextGen, in order to maximize airspace capacity while maintaining safety, it is desirable to minimize the impact of TMIs on operations and to implement only those TMIs necessary to maintain system integrity.

Route availability [DRT08] feedback helps traffic managers determine the specific departure routes, altitudes, and departure times that will be affected by significant convective weather, turbulence, or icing. NextGen DSTs will assist users in deciding when departure routes or fixes should be opened or closed and to identify alternative departure routes that are free of weather constraints. DSTs need to help traffic managers answer the questions:

- If a route is impacted by the weather constraint during a particular time window, which and how many aircraft are affected?
- What alternative departure routes are free of weather constraints during a particular time window, and how many aircraft can the route handle?

The IDRP concept (Figure B-31) translates weather constraints into ATM impacts, and thus helps decision makers evaluate and implement different TMIs [MBD08] in response to the projected ATM impacts. The concept takes into account multiple factors that can have significant effects on departure management when weather constraints are present. In evaluating the impact of congestion and downstream weather constraints on departure operations and potential actions to mitigate those impacts, traffic managers must consider filed flight plans and acceptable alternatives, surface departure queues, predicted weather impacts (route availability) along both departure and arrival routes in the terminal area and nearby en route airspace, the current state of departure routes (open, closed, MIT, etc.), predicted congestion and flight times along weather-avoiding reroutes, and the weather forecast uncertainty. By bringing all of these factors into an integrated environment, IDRP can reduce the time needed to make departure management decisions and coordinate their implementation. If it is integrated with surface and arrival management systems, IDRP can improve efficiency over the NAS considerably.

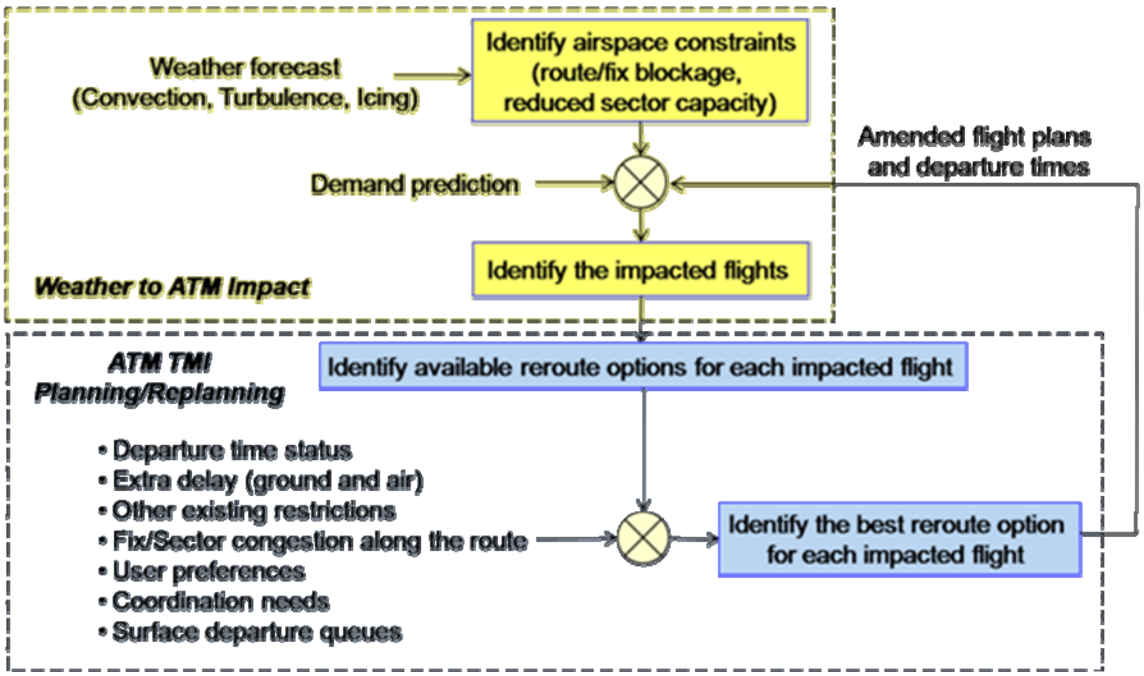


Figure B-31 Integrated Departure Route Planning Concept.

B-2.9 Tactical Flow-based Rerouting

This concept for rerouting air traffic flows around severe weather is for a tactical timeframe (0 to 2 hours out) and requires an ATM-impact model for route blockage, as illustrated by Figure B-32. In this timeframe, weather predictions are relatively good, so the reroutes can be closer to the weather than strategic reroutes and thread through smaller gaps between weather cells. Automated solutions makes tactical rerouting easier, increasing the ability of traffic managers to implement them. Moving this activity from controllers to traffic managers will reduce controller workload, thereby safely increasing airspace capacity during severe weather.

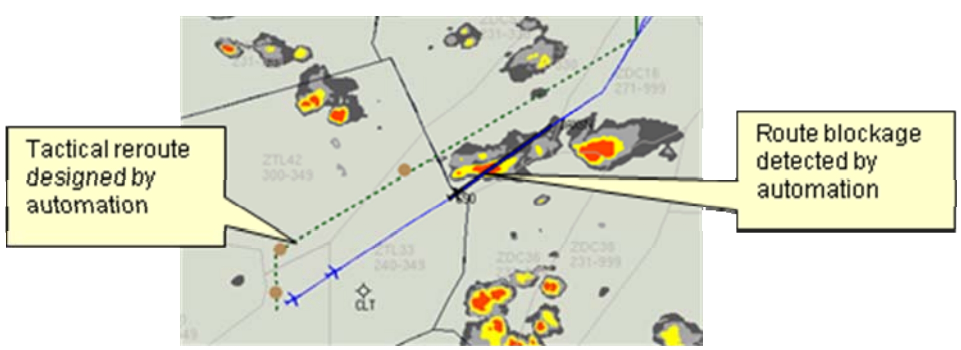


Figure B-32 Example flow reroute.

A Flow-based Tactical Rerouting DST identifies flights that are likely to need deviations from their current routes to avoid severe weather. The flights considered can be limited to the flights in a Flow Evaluation Area (FEA) flight list [CDM04] to narrow the focus to particular flows or areas. To determine severe weather encounters, predicted 4D trajectories are probed against a WAF [DRP08] that is based on a dynamic 4D weather forecast, including echo tops. Parameters are provided to allow the traffic manager to adjust the sensitivity of the probe.

The DST groups the flights identified with WAF encounters into flows according to weather impacted route segment, arrival airport, sectors traversed, or some other manner, and presents those to the traffic manager. The traffic manager can select one or more flows to examine in more detail in a flight list or on a map display, and advance time to view the predicted future situation. The traffic manager can select one or more of the impacted flows and request reroutes from the DST. The DST can then generate reroutes that avoid the WAF. It may achieve this based on historical routes, a network algorithm, or both. A ground delay can also be used with the current route to allow the weather to move off of the route. The resulting clear routes are ranked and filtered based on a number of criteria such as delay, required coordination, consistency with existing traffic flows, sector congestion, and closeness to weather.

Traffic managers determine the best reroutes for each flow. The reroutes go into a list with all the information necessary to implement them, including identification of air traffic managers (external facility or internal area) that need to approve them. After coordination, an air traffic manager in a rerouted flight's controlling facility can accept and implement the reroute.

B-2.10 Tactical On-Demand Coded Departure Routes (CDRs)

This concept for rerouting air traffic flows around severe weather is based on moving today's static, fixed Coded Departure Route (CDR) framework for rerouting traffic on jet routes during severe weather events into a dynamically defined "On Demand" CDR framework [KPM06] for NextGen for routing 4D trajectories in a tactical timeframe (0 to 2 hours out). The method requires an ATM-impact model for route blockage to identify ahead of time when On-Demand CDRs are needed, as previously illustrated by Figure B-32, and the ability to design space-time reroutes between city pairs with a 1-2 hour look ahead time (Figure B-33). The purpose of On-Demand CDRs is to move the rerouting decision as close to the tactical time horizon as possible to eliminate the uncertainty in rerouting – eliminating the potential for several weather outcomes, as is the case in ensemble weather forecasts, and focusing in on one projected weather outcome in the tactical time frame.

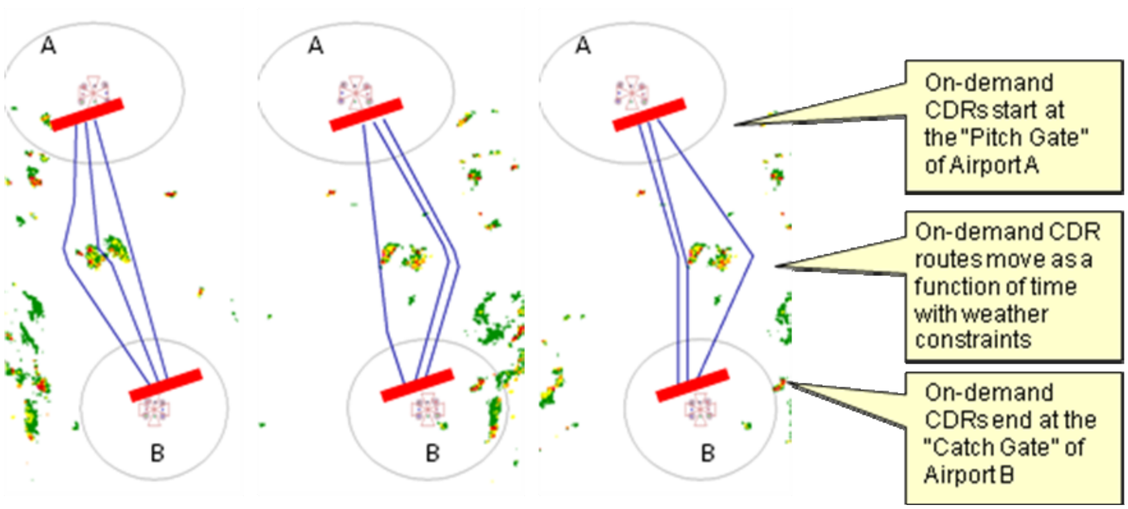


Figure B-33 On-Demand CDRs between pitch and catch gates from Airport A to B.

Today, CDRs are generated far in advance of the day that they are implemented. The routes are maintained in a database and distributed between the ANSP and the users (airlines). If the weather forecast is highly predictable, the ANSP selects the CDR that best solves a weather avoidance problem, given other TFM constraints. For less predictable weather, the ANSP identifies CDRs that could be used to avoid multiple weather constraint scenarios, asks the NAS users to prepare for this full set of contingencies (alternative CDRs), and then assigns the actual route to the flight as it departs. However, today's CDRs often take aircraft far out of the way as they do not shape the weather avoidance route to the actual movement of the weather constraint.

The On-Demand CDR concept dynamically generates CDRs approximately 1-2 hours in advance of take off time based on the latest deterministic weather forecast. The benefit of generating CDRs as needed to meet the constraints imposed by the weather forecast is that the routing solution adapts and best fits both the emergent weather pattern and latest traffic flow requirements. Such weather avoidance routes can be generated with a space-time weather avoidance algorithm [P07] that takes into consideration the weather forecast, CWAM WAF [DE06, CRD07] or other weather avoidance constraints, and relevant human factors (see C-5) and domain knowledge requirements [KPM06]. The weather avoidance routes do not have to be based on today's jet routes and Naviads, since in NextGen, RNAV routing and RNP performance will allow routes to be defined anywhere in the sky

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C. INTEGRATION PROGRAM PLAN

This appendix contains projected budget, benefits, schedule and other activities for the execution of this plan.

C-1. Weather Integration Budget

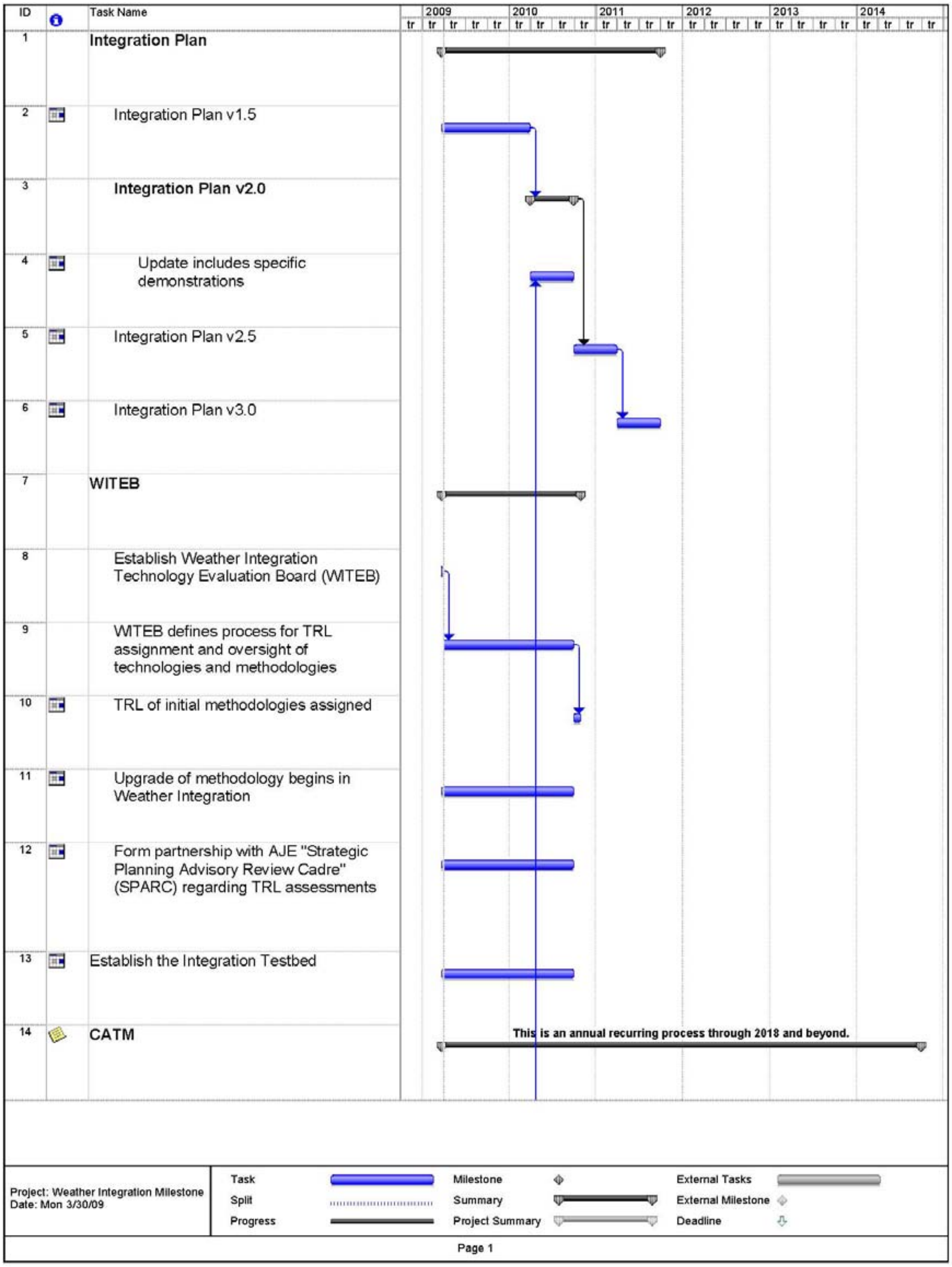
Budget information is under development.

C-2. Weather Integration Benefits

Benefits information is under development.

C-3. Schedule

The schedule shown on the following 4 pages will be revised and updated when the schedules of each of the target capabilities are established.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2011
2012
2013
2014
1 Integration Plan
2 Integration Plan v1.5
3 Integration Plan v2.0
4 Update includes specific demonstrations
5 Integration Plan v2.5
6 Integration Plan v3.0
7 WITEB
8 Establish Weather Integration Technology Evaluation Board (WITEB)
9 WITEB defines process for TRL assignment and oversight of technologies and methodologies
10 TRL of initial methodologies assigned
11 Upgrade of methodology begins in Weather Integration
12 Form partnership with AJE "Strategic Planning Advisory Review Cadre" (SPARC) regarding TRL assessments
13 Establish the Integration Testbed
14 CATM
This is an annual recurring process through 2018 and beyond.
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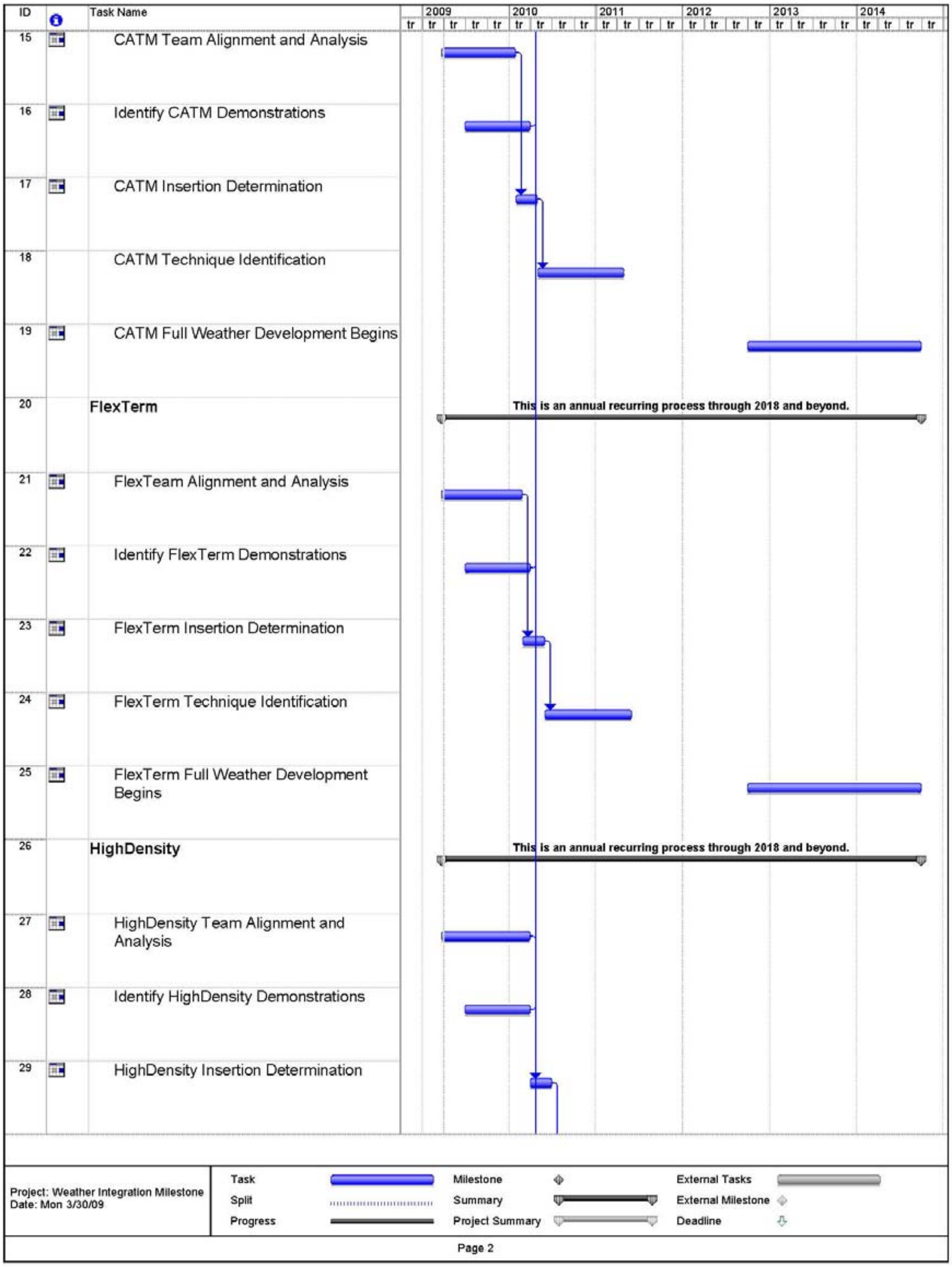
Progress
Milestone
Summary
Project Summary
External Tasks
External Milestone
Deadline
Page 1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2012
2013
2014
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16 Identify CATM Demonstrations
17 CATM Insertion Determination
18 CATM Technique Identification
19 CATM Full Weather Development Begins
20 FlexTerm
This is an annual recurring process through 2018 and beyond.
21 FlexTeam Alignment and Analysis
22 Identify FlexTerm Demonstrations
23 FlexTerm Insertion Determination
24 FlexTerm Technique Identification
25 FlexTerm Full Weather Development Begins
26 HighDensity
This is an annual recurring process through 2018 and beyond.
27 HighDensity Team Alignment and Analysis
28 Identify HighDensity Demonstrations
29 HighDensity Insertion Determination
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Progress
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Project Summary
External Tasks
External Milestone
Deadline
Page 2

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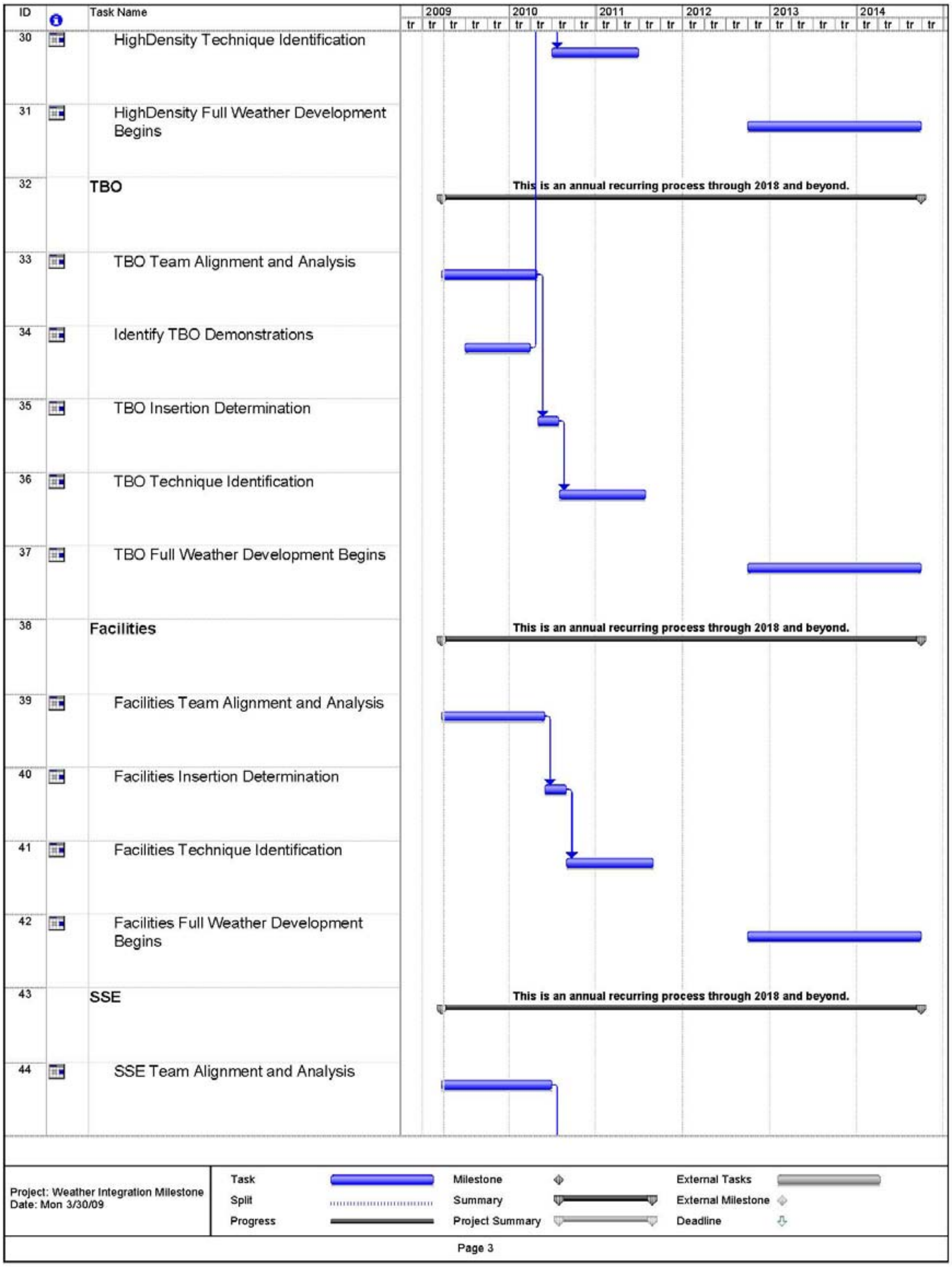
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31 HighDensity Full Weather Development Begins
32 TBO
This is an annual recurring process through 2018 and beyond.
33 TBO Team Alignment and Analysis
34 Identify TBO Demonstrations
35 TBO Insertion Determination
36 TBO Technique Identification
37 TBO Full Weather Development Begins
38 Facilities
This is an annual recurring process through 2018 and beyond.
39 Facilities Team Alignment and Analysis
40 Facilities Insertion Determination
41 Facilities Technique Identification
42 Facilities Full Weather Development Begins
43 SSE
This is an annual recurring process through 2018 and beyond.
44 SSE Team Alignment and Analysis
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Progress
Milestone
Summary
Project Summary
External Tasks
External Milestone
Deadline
Page 3

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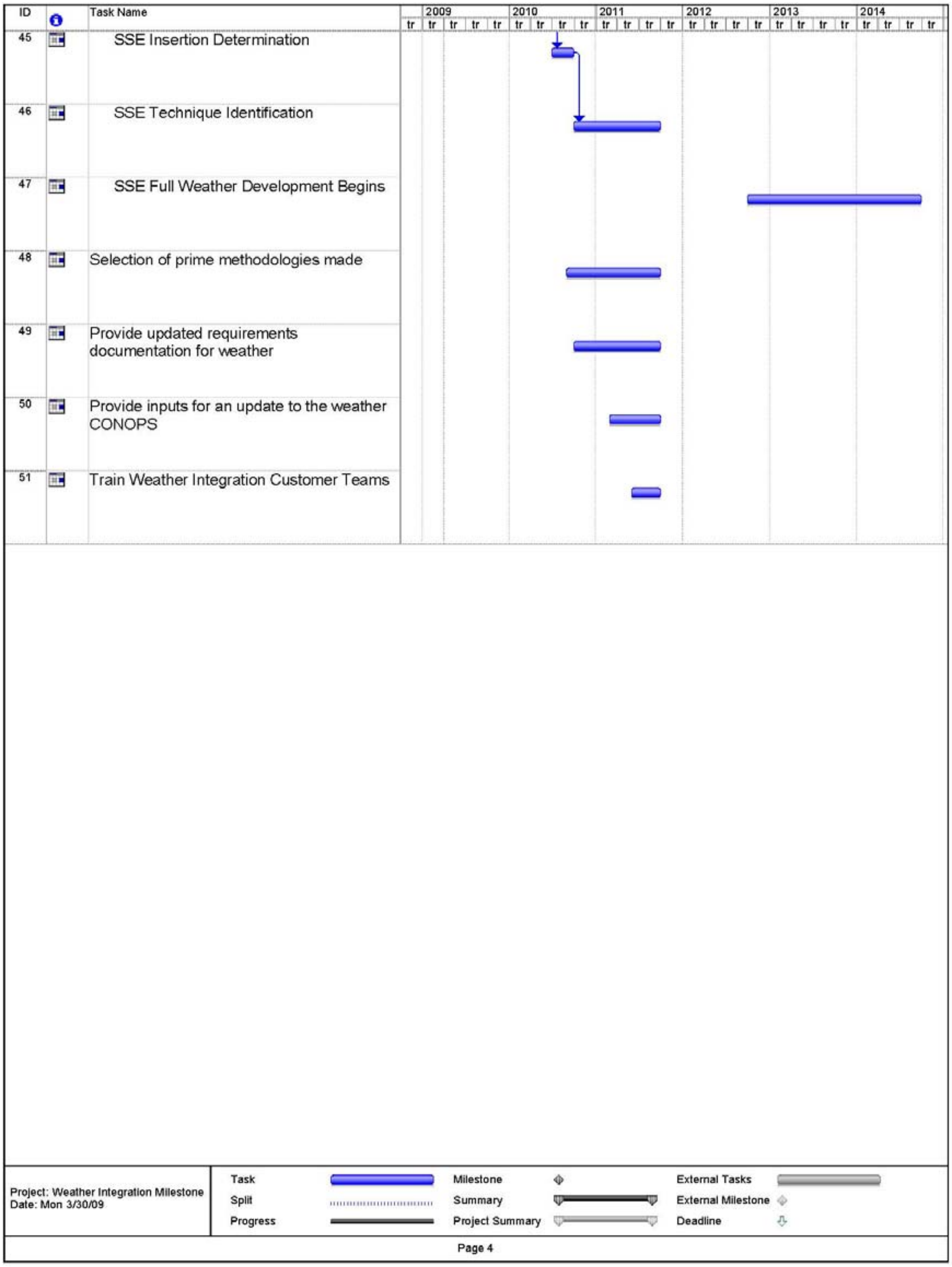
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2010
2011
2012
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2014
45
SSE Insertion Determination
46
SSE Technique Identification
47
SSE Full Weather Development Begins
48
Selection of prime methodologies made
49
Provide updated requirements documentation for weather
50
Provide inputs for an update to the weather CONOPS
51
Train Weather Integration Customer Teams
Project: Weather Integration Milestone
Date: Mon 3/30/09
Task
Split
Progress
Milestone
Summary
Project Summary
External Tasks
External Milestone
Deadline
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C-4. Risk Assessment

C-5. Human Factors Considerations

Human factors considerations must be included in every solution. This section and appropriate paragraphs in Appendices A and B are being expanded as specific solution information is developed.

C-6. Training

C-7. Intellectual Property Rights Considerations

D. INTEGRATION PLAN TRACEABILITY WITH PREVIOUS STUDY GROUPS

D-1. REDAC Recommendations and Response

REDAC Recommendation	Integration Plan Alignment	Comments
Overarching Requirements		
Crosscutting Research Program		
1) Initiate and fund a crosscutting research program in ATM/Weather integration and insure that weather aspects are an integral part of all new ATM initiatives from the beginning.		
Leadership		
2) Establish Senior Leadership over-sight.		
3) Establish REDAC monitoring.		
4) Revitalize joint advisory committee reviews of FAA and NASA joint research such as weather – ATM integration. FAA and NASA should hold joint meetings of their advisory committees and include the identification of current and future cross agency research opportunities in support of integrating advanced aviation weather and air traffic management tools. Furthermore, a Memorandum of Understanding (MOU) or Agreement of Understanding (AOU), between FAA and NASA, and encompassing weather and ATM research, may be needed to clearly elucidate the needed connection between these agencies.		
Requirements Process		
5) Develop requirements for weather ATM integration participation within the AWRP.		
Research Recommendations: Near Term - IOC 2010		
Assessment of Avoidable Delay		
6) Research is needed to identify and quantify avoidable delay. Quantitative research studies of "avoidable" delay, should be conducted each year, based on significant summer or winter storm events, to identify opportunities to reduce delay and to evaluate the performance of weather – ATM integration capabilities as they are developed and		

REDAC Recommendation	Integration Plan Alignment	Comments
fielded.		
7) ATM/TFM/AOC/FOC involvement is needed.		
Translating Weather Data into ATC Impacts		
8) Expand research on the translation of convective weather impacts into ATC impacts so that this information can be used to effectively support decision making. Research should be conducted to address the following elements: a. Improve the models for convective weather impacts, e.g., route blockage and airspace capacity. b. Determine if pilot thresholds for weather conditions that lead to deviations can be reduced, since unexpected deviations around storm regions in high density airspace can lead to prolonged, unnecessary route closures. c. Determine if the data link transfer of ground derived weather and ATC domain information (spatial boundaries acceptable for maneuvering) to the pilot achieve a more consistent pilot response to convective weather. d. Determine if the airspace usage differs between various en route facilities [e.g., the Jacksonville Center (ZJX) appears to have very different procedures for convective weather ATM than many of the ARTCCs in the northeast]. e. Develop models for storm impacts on arrival and departure flows in both en route and terminal airspace.		
Improved Weather Input into Collaborative Traffic Flow Management		
9) Develop a six-eight-ten hour convective forecast for strategic flow management decisions with automatically generated and updated forecasts of flow impacts. This should be a joint program between the AWRP and the TFM R & D programs		

REDAC Recommendation	Integration Plan Alignment	Comments
with involvement by representatives of the CDM Weather Team.		
10) Improve the Traffic Management interaction with AOC/FOC's during weather impacts. Develop collaborative TFM systems that allow operators to better manage risks in meeting their own business objectives. Specifically, collaborative TFM systems should be developed that give operators the following capabilities: - Enable visibility into probabilistic TFM weather mitigation strategies through robust TFM data feeds for integration into their own internal systems via CDMnet and eventually System Wide Information Management (SWIM). - Electronically pre-negotiate multiple trajectory options with Traffic Managers. - Select viable route/altitude/delay options during severe weather impacts. - Integrate and ingest ATC-approved trajectories onto the flight deck for execution consistent with their own corporate infrastructure, business objectives and regulatory requirements. - Expand collaboration to include flight deck capabilities and decision making tools consistent with NextGen and within the corporate infrastructure, business objectives and regulatory requirements of the operator.		

REDAC Recommendation	Integration Plan Alignment	Comments
Weather Information and Pilot Decision Making		
11) Initiate a research program to develop procedures and guidance on the integration of weather and airspace congestion information for preflight and in-flight decision making tools. The program should include the following objectives: Develop appropriate rule sets for weather avoidance decision making in both non congested and, highly congested airspace. Develop ways to incorporate the same rule set into preflight, cockpit, AOC/FOC, and ATM decision support tools. Develop methods to integrate or display current and forecast weather impact to flight profile, airspace congestion information, and weather decision support information in preflight and cockpit systems to enable greater shared situational awareness and improved collaborative decision making. Conduct research on the direct, machine to machine, information transfer among cockpit, AOC/FOC, and ATM computing systems and determine whether this will facilitate consistent and expeditious decision making. This will place the users more “over the loop” than “in the loop” with respect to weather decision making.		
Integrating Weather Impacts with Airport Surface and Terminal Management Systems		
12) Expand the use of route availability tools to integrate airport and terminal area weather data and ATM tools. Expand the deployment of integrated tools, such as route availability, to additional airports and terminal regions to improve NAS performance at the largest airports impacted by convective activity.		

REDAC Recommendation	Integration Plan Alignment	Comments
13) Conduct research on enhancing the Traffic Management Advisor (TMA) to achieve a weather sensitive arrival planning tool.		
14) Integrate RAPT, ITWS, DFM, and TMA with surface management systems to provide a singular terminal management tool spanning departures, arrivals, and surface movement. Consider common use by air traffic and operators for collaborative decisions.		
15) Support CDM and other efforts to provide meaningful and integrated terminal and TRACON specific weather forecast information.		
Research Recommendations: Mid Term - IOC 2015		
Adaptive Integrated ATM Procedures for Incremental Route Planning		
16) Develop Weather Impact Forecasts versus Time (for different planning horizons). Develop weather forecasting capabilities that incorporate representations of the uncertainties associated with different weather phenomenon for different planning horizons. This should be included in the research recommended in Section 6 B, translating weather into ATM impacts.		
17) Develop Adaptive ATM/TFM Procedures. Develop TFM procedures that are adaptive, and that take advantage of changes in uncertainty over time. These procedures should incorporate distributed work strategies that match the focus of control for a specific decision with the person or group that has access to the knowledge, data, motivation and tools necessary to effectively make that decision. Such adaptive procedures require an integrated approach to strategic planning and tactical adaptation.		

REDAC Recommendation	Integration Plan Alignment	Comments
18) Manage at the Flight Level Take advantage of trajectory-based management so that control actions and their impacts can be more directly and precisely localized at the points in the system where they are required to deal with a given scenario. In particular, this means that tools and procedures need to be developed to adaptively manage at the flight level instead of traffic flows, and that the air traffic management user does not need detailed meteorology experience.		
19) Translate weather information and forecasts to parameters relevant to decision support tools. Develop decision support tools that translate the implications of probabilistic weather forecasts into the decision parameters that are relevant to the application of particular TFM procedures and in a way that the air traffic management user does not require significant meteorological training.		
20) Develop human-centered designs. Develop human-centered designs for these decision support tools that enable their users to understand the current state of the relevant parts of the NAS, and that support these users in understanding the basis and implications of recommendations generated by their decision support tools that automatically generate options for users to consider.		

REDAC Recommendation	Integration Plan Alignment	Comments
21) Develop tools and automation enabling operations and implementation. Develop computer-supported communication tools and automated decision support tools that enable effective coordination and collaboration in this distributed work system, and that enable timely implementation of the decisions that are made.		
Weather Impacts and Tactical Trajectory Management		
22) Implement Tactical Trajectory Management with integrated weather information. Develop a highly automated advanced Tactical Trajectory Management (TTM) decision support capability integrated with convective weather and turbulence to decrease controller and pilot workload, and increase safety. This would be a mostly automated system. This capability would assist the controller in a shared severe weather separation responsibility with the pilot.		
23) Investigate the human factors (see C-5) issues (communication, information display, safety nets, cognitive complexity, and mental workload) associated with new paradigms for tactical trajectory management.		

REDAC Recommendation	Integration Plan Alignment	Comments
Airspace Designs for Weather Impacts		
24) Airspace designs should enable route flexibility during adverse weather conditions. If the vision of 4D trajectories is to become a reality, the airspace must be designed to support seamless adjustments of the route of flight in all four dimensions, as required by weather impacts. The development of ATM decision support tools must be done jointly with the weather research community so that decisions will adequately address impacts of adverse weather. Foundational efforts that reach across the disciplines of airspace design, weather translation into ATM impact and ATM decision support are required to achieve effective integration.		
25) Investigate the human factors (see C-5) issues associated with the dynamic reconfiguration of airspace, including issues associated with information display, training, and cognitive complexity.		
Research Recommendations: Far Term - IOC Post 2015		
Advanced Weather-ATM Integration Concepts		
26) Develop methods which combine the use of both probabilistic and deterministic forecasts and observations, to maximize throughput using multiple dynamic flight lanes or “tubes” in weather impacted areas.		
27) Develop methods to transition from a probabilistic trajectory or flight envelope to a 4D trajectory which is useable for separation and safety assurance. Establish an independent bi-annual review of this work to determine the potential benefits and costs to aviation.		
28) Conduct research into replacement of surrogate		

REDAC Recommendation	Integration Plan Alignment	Comments
weather indicators such as radar reflectivity with reflectivity with actual indicators such as turbulence, icing, lightning, or wind shear, and an estimate of ATM impact. For example, radar reflectivity can be translated to ATM impact by estimated airspace pilots will avoid and the associated airspace capacity loss.		
29) Develop methods to use gridded and scenario based probabilistic weather data for ATM decision making. Develop methods to translate deterministic and probabilistic convective forecasts to ATM impact for use in network based capacity estimate models. Determine the reduction in capacity of an airspace region due to convective weather using a network model.		
30) Investigate the human factors (see C-5) issues associated with the integration of such probabilistic modeling into decision support tools.		

REDAC Recommendation	Integration Plan Alignment	Comments
Human Factors Considerations for Integrated Tools		
31) Develop advanced information sharing and display concepts for the design of integrated decision- support tools. Develop strategies for information representation and display that enable people to maintain situation awareness regarding weather and traffic impacts, develop shared mental models, and evaluate inputs to the decision process provided by technology. Of particular importance is the need to conduct research on strategies for representing integrating and displaying probabilistic information about uncertainty regarding weather and traffic constraints and its predicted impacts as a function of look-ahead time. Equally important is the need to research new strategies for risk management that make use of such information. Research on the effective use of probabilistic information by ATC, TFM, and AOC/FOCs is a major challenge that needs to commence in the near term in order to obtain short term benefits and to enable more powerful solutions in the longer term. This research need to consider human factors (see C-5) as well as technology development challenges.		

REDAC Recommendation	Integration Plan Alignment	Comments
32) Develop new approaches and strategies for effective distributed decision making and cooperative problem solving. Develop effective strategies and technologies (decision support and communication tools) to enable distributed decision making to address the interaction of weather and traffic constraints, and to adaptively respond to situations as they evolve. This requires consideration of cognitive complexity, workload, and the ability of people to develop and maintain necessary levels of skill and expertise. It requires consideration of the need to design a resilient system that provides effective safety nets. And it requires system engineering decisions concerning when to design the system to provide coordination as a result of the completion of independent subtasks and when to design the system to support collaboration in order to ensure that important interactions occur. Develop technologies that support cooperative problem solving environments that allow people to work interactively with decision support technologies and with each other to assess situations as they develop, and to interactively generate and evaluate potential solutions.		
33) Develop methods for implementing human-centered designs for decision support tools. Develop effective procedures and technologies to ensure effective communication and coordination in the implementation and adaptation of plans in this widely distributed work system that includes meteorologists, traffic managers, controllers, dispatchers, ramp controllers and pilots.		

REDAC Recommendation	Integration Plan Alignment	Comments
34) Proactively enable new training on integrated tools. The FAA and aviation industry should proactively develop training curricula for controllers, traffic managers, pilots, dispatchers, and weather personnel which cover - The new roles and responsibilities in the use of supporting technologies. - The roles, responsibilities and expectations of other decision makers with whom each group must interface. - The training doctrine, developed in concert with the integrated tools development, leveraging that real-world experience to maximize early benefits and refinements. - The training cadre, deployed to all major new facilities as the tools are deployed to both assist in training and to maximize early benefits and identify problems. The resulting procedures and rules must be translated into controlling documents such as the Federal Air Regulations (FARs), the Airman Information Manual (AIM), Air Traffic Manuals, Flight Manuals, and Aircraft Manuals.		

REDAC Recommendation	Integration Plan Alignment	Comments
35) Identify best weather practices of air traffic facilities and train these practices system wide. Identify facilities with superior performance and develop best practices guidance for use by other facilities. Do not limit benchmarking to NAS facilities only. Seek global examples and new visions of innovative weather management techniques. Develop and train ARTCC and TRACON ATC and TFM staff on "best practices" during the introduction and first five years of all new weather and weather-ATM integrated tools. Establish metrics which compare alternative processes.		
Implications on Airline Operations Centers		
36) Ensure strong industry participation in CDM and NextGen concept development and implementation and consider expanding industry participation on review boards. Industry must have voice and buy-in to future developments to ensure that internal corporate infrastructure and business systems can support, blend with and interact effectively with the NAS service provider systems. Joint development of these systems is possibly the key component of a successful future capability.		

REDAC Recommendation	Integration Plan Alignment	Comments
Implications on FAA and NextGen Enterprise Architectures		
37) Ensure that direct ATM automation-weather integration is a key focus of the development of OEP/NAS Enterprise Architecture operational and technical views for the transition to NextGen. To achieve the capacity and safety goals for NextGen, weather and ATM automation developments must become aligned and focused to define the operational and system views for the evolution to highly automated weather impact analysis and solution-generation system, where the human operators are no longer the "glue" for trajectory level decisions. This is a necessary and fundamental shift from today where weather display and human interpretations the norm. The resultant operational and technical views must be reflected in the OEP and companion NAS EA in order to enable timely investment decision on deploying these needed integrated automation-weather capabilities. This information must also be (constantly) coordinated with NextGen concept and EA development to ensure consistency.		

REDAC Recommendation	Integration Plan Alignment	Comments
Implications on FAA Aviation Weather Research Program		
38) Support for the AWRP should be increased beyond previous levels. Support for the AWRP should be increased to enable further improvements in the 0-8 hour forecast time frame, and to allow the weather research community to enter into joint collaborations with the automation research community in integration of weather information into ATM DSS. Additionally, the FAA ATO-P organization should reexamine the R&D goals for AWRP in light of the needs of NextGen. Support for the National Ceiling and Visibility Program should be restored. Related efforts to support and benefit individual sectors of the industry should be prioritized and addressed. For example: 1. Development of the Helicopter Emergency Medical Evacuation System (HEMS) tool. 2. Rewriting FAR 121 limitations regarding Ceiling and Visibility such as FAR 121.619 (also known as the “1, 2, 3 Rule” for alternate fuel specifications		
39) Conduct research to develop improved methods of sensing turbulence taking advantage of a multi-sensor approach using radar, profilers, anemometers, satellite imagery, GPS, and instrumented aircraft to improve the forecasting and now casting of convective and non-convective turbulence.		

3

D-2. Integration Plan Alignment with Weather ATM Integration Conference Recommendations

Wx ATM Integration Conference Recommendation	Integration Plan Alignment	Comments
NextGen Weather Group		
Policy Issues		
1) Develop an information paper that describes the 4-D Wx SAS and 4D Wx Data Cube and their relationship.		
2) A dedicated team needs to focus on the scope and content of the 4-D Wx SAS.		
Research and Development		
3) Encourage industry to participate in NextGen Weather IOC development team efforts to identify domain authority, standards, catalogs, ontologies, etc.		
4) Work with non-federal organizations to identify how to incorporate their sensor information into the 4D Wx Data Cube.		
Simulations and Demonstrations		
5) Accomplish a demonstration to see if we can collect additional weather data from on-board and ground sensors and transfer it to government system(s) in a net-centric manner.		
6) Have the NEO, Aircraft, and Weather Working Groups sponsor a team to identify options of how we get information into the cockpit		
Performance Metrics		
7) Have weather SMEs review how the reliability of the cube can be demonstrated to operational users		
8) Task the Airport and Air Navigation Services Working Groups to set DST quality and reliability as they identify new tools that will be developed.		

Wx ATM Integration Conference Recommendation	Integration Plan Alignment	Comments
Airport Operations Group		
Policy Initiatives		
9) Data sharing agreements need to be reviewed and updated. Effective communication and information/data sharing, across all levels, is critical.		
10) Weather information needs to be translated into impact information specific to user needs.		
11) Operational users need to be involved in the entire requirements process		
12) Use liquid equivalent water instead of visibility to determine deicing needs and holdover times.		
Research and Development		
13) Legacy system integration is very important. Prioritize legacy system value according to NextGen requirements		
14) Improve runway forecasts accuracy and reliability. Address runway sensors that are non-representative of actual conditions.		
15) Need to take into account an integrated approach to weather impacts on airport parking, terminal and ramp areas, surface maneuvering of all vehicles, as well as aircraft. Develop and validate a requirements matrix to address user needs for weather as integrated with various surface movement operations.		
Simulations and Demonstrations		
16) Investigate use of the “Theory of Serious Games” for simulation development.		
17) Demonstrate integrated weather for winter operations at ORD		
18) Derive and validate metrics from operational users. Determine metrics of value from operational personnel		

Wx ATM Integration Conference Recommendation	Integration Plan Alignment	Comments
Trajectory Operations Based Group		
Policy Issues		
19) Establish a weather data standard that is compliant with ICAO standards and use this standard in TBO.		
20) Bring stakeholders together early in the development of TBO implementation roadmap to ensure weather integration at the inception. Do not follow the path of treating weather as an "add-on" in later phases of TBO development, as this will delay or negate the value of a fully-integrated solution that assimilates weather information.		
21) Establish policy that allows flexible trajectory re-negotiation as weather information is updated throughout the NAS.		
22) There is a need to establish policies that encourage NextGen users to incorporate capabilities that meet or exceed new performance-based standards. Develop an agency policy for user performance capabilities in parallel with policy that supports incentives across all stakeholders to meet or exceed performance standards.		
23) Develop agency policy that is adaptive to system performance increases as equipage evolves.		
24) Support efforts (including funding) devoted to the development of the single authoritative source concept, implementation, human factors (see C-5) and governance to enable NextGen TBO.		

Wx ATM Integration Conference Recommendation	Integration Plan Alignment	Comments
25) Existing policies are inadequate to support TBO including a number of factors such as the use of probabilistic weather forecasts, conflict resolution and data sharing. Develop policy for the use of probabilistic weather as it pertains to decision support tools and NextGen system users.		
26) Develop appropriate precedence and procedures to determine proper course of action an operator must make when conflicting weather information is presented.		
27) Make ATM data available to the research community at large to facilitate research and development efforts supporting NextGen.		
28) Find ways to test and implement new science and innovation into the NAS in an expedient manner to incorporate the latest technology.		
29) Carefully consider the affects of implementing NextGen concepts in terms of organizational changes. Identify “cross boundary” issues that affect more than one organization, and determine whether a new division of responsibilities is necessary prior to implementing NextGen concepts and systems.		
30) Define a transition strategy, but do not perpetuate traditional organizational responsibilities and relationships unless they clearly benefit the governance and operation of NextGen.		
31) There is a need to establish a certification or validation process for weather information that will be used in TBO. Develop a certification or validation process for weather information and forecasts used in the 4-D Wx SAS that test for reliability and recognized safety and traffic flow management conventions.		

Wx ATM Integration Conference Recommendation	Integration Plan Alignment	Comments
Research and Development		
32) Human reaction, response and risk of product use that contain integrated weather must be examined. Human factors (see C-5) research is needed to quantify the effects of inherent human conservatism and caution and the effect of inconsistent forecast skill on operational decision making.		
33) Conduct human factors (see C-5) research to understand how controllers will handle air traffic in a TBO world – specifically their reactions to weather that affects sector loading, controller workload, transition to dynamic sectors and delegation of separation responsibilities to the flight deck.		
34) Continue research to quantify predictions of pilot/controller actions when faced with current weather impacts.		
35) Understand the human-machine interface role for each stakeholder, including weather information integrated into a single display. Related research should eventually embrace the transition to complex technological systems designed for use with NextGen constructs.		
36) There is a need for research into how forecast uncertainty can be ‘partitioned’ into spatial and temporal elements as a possible way to quantify and reduce risk and impact of uncertainty and forecast errors.		
37) There is a need to determine who has the authority to take the risk and what are the allowed levels of action for both systemic approaches Traffic Management Initiative and individual trajectory negotiations (e.g., go/no go, red/green, or shades such as red/yellow/green, etc.).		
38) A weather translation model could be developed to select different convective forecast and now-cast products and assess how they help achieve a more accurate airspace capacity estimate – separately and as an ensemble forecast.		

Wx ATM Integration Conference Recommendation	Integration Plan Alignment	Comments
Additional research would be needed to determine how to validate and to determine the granularity (e.g., ARTCC/Sector/Flow/Airway/Gate/Fix).		
39) There is a need for operationally relevant research that translates and integrates weather forecast probability into language (e.g., triggers or sliding scales or time smears, etc.) that can be used by ATM tools.		
40) There is an overall need to determine weather performance requirements/characteristics for all stakeholders and decision support tools. There is a need to conduct applications research to identify and then match the performance of the weather information with user functional needs for TBO		
41) There is a need to conduct research that identifies the weather performance requirements for the entire environment in which TBO-based systems act (e.g., TBO performance changing triggers, how they change and by how much).		
42) There is research needed to quantify how to develop higher fidelity and standardized trajectory predictions with lower fidelity weather (i.e., what is good enough weather for a trajectory prediction and how does such fidelity change from operation to operation).		
43) There needs to be research conducted to determine if there are significant benefits (consistent with 5.2.6) in obtaining more accurate weather forecasts. There is a further need to identify tools, models (e.g., Numerical Weather Prediction), techniques, etc., that validate and measure the real or perceived improvements.		
44) There is a need to conduct TBO and weather research (e.g., time-based research) that overlaps with airport surface movement and weather research to understand and categorize wheels off departure/wheel on arrival times. This could be enhanced through the combined use of ground vehicles and aircraft sensors to determine position.		

Wx ATM Integration Conference Recommendation	Integration Plan Alignment	Comments
45) Research is needed to establish a set of agreed-upon thresholds that are not based on operations as described earlier, but based on aircraft performance and requirements for safe operation for weather phenomena such as icing for deicing, lightning for refueling, etc. Similar issues as previously identified emerge, such as what are the risk factors, who have authority to take the risk, levels of action (go/no go) or can there be shades (red/yellow/green).		
46) In the first (departure) or final (arrival) stages of TBO, research is needed to quantify the affects of weather on aircraft performance in 4DT SDO with regard to trajectory and arrival times in space and the ability to penetrate weather when there are the fewest options available for safe flight.		
47) Research is needed to understand the capabilities of the aircraft with respect to weather factors to reduce the uncertainty of meeting TBO objectives. In the worst-case weather scenarios, research is needed to define airspace which cannot be accessed based on high weather impact phenomena.		
48) In the (legacy) en route portion of TBO, research is needed to quantify the effects of aircraft trajectory performance based on convective (especially) and other (e.g., icing) weather characteristics. There is a need to know what aspects (echo tops, storm tops, cloud/visibility tops, turbulence, vertical impact altitudes, etc) most significantly affect aircraft performance from meeting time and space TBO objectives. There is a need to determine how much equipage and differing agency operations (civil vs. military) will play a role in meeting this objective.		
49) Research is needed to identify how weather forecast uncertainty and associated operational risks change over the entire course of the trajectory		
50) There is a need to conduct fundamental weather research regarding specific weather phenomena, over specific areas, occurring or lasting over a		

Wx ATM Integration Conference Recommendation	Integration Plan Alignment	Comments
range of times, and achieving and/or maintaining specific levels of magnitude that can impact TBO		
51) Applications research is additionally needed to identify important weather thresholds that trigger trajectory-based operation changes.		
Simulations and Demonstrations		
52) CDM between all decision makers (pilots, dispatchers, controllers) needs to be simulated under varied weather conditions and varied TBO activities to quantify relative workload on each, quantify response differences/reactions, and to quantify the relative flexibility (or not) to combined operations/impacting weather scenarios.		
53) Conduct simulations to explore information overload		
54) Simulations are needed to quantify TBO sensitivity to weather. This should include modeling or simulating the value of DST's over a range of weather fidelity or outcomes		
55) This also includes the simulation of weather probability translation upon TBO constructs (i.e., how each probability 'level' is translated and weighted within the DST components).		
56) The value of the integrated weather needs to be simulated and measured in terms of the metrics highlighted in question 6 or from a cost/benefit perspective. In this regard, the value of continued 'improvement' in weather information fidelity needs to be modeled against real or perceived 'improvement' in DST outputs.		
57) Simulations of NAS users operating in a mixed equipage mode need to be conducted to determine consequences and relative sensitivity of continued mixed equipage towards achieving TBO objectives.		
58) The cost/benefit of optimal or minimal equipage needs to be simulated		
59) There needs to be simulations performed that		

Wx ATM Integration Conference Recommendation	Integration Plan Alignment	Comments
describe the cost to benefit of further improvements in weather products and forecasts beyond those so matched in informational integrity to TBO constructs. In this regard, there may be, for example trending routines that could be designed that allow more frequent weather updates to be time-based averaged before integrating.		
60) Simulate value of integrated weather with TBO by simulating various NAS performance measures (e.g., route timing, fuel savings, operational options, etc.) to determine sensitivity to weather.		
61) An approach to initial transition in general is to capture the experience of successful recent trials (e.g., ADS-B in Alaska) and extrapolate or leverage to achieve perceived NextGen benefits.		
62) There is a need to demonstrate both tactical and strategic use of probabilistic convective impacts under various levels of uncertainty		
63) There is a need to demonstrate the operational effectiveness of weather integrated DST's under various levels of uncertainty.		
64) There is a need to demonstrate operational value (tactical) to using predicted convection locations rather than planning based on current convection locations		
65) For more strategic assessment, there is a need to demonstrate effective risk management both for strategic TFM approaches and at the individual flight or trajectory level		
66) In the spirit of leveraging from current operations, demonstrations could be designed to use existing systems and begin rolling in new 'numeric' systems for integration of convective uncertainty forecasting.		
67) There is a need to demonstrate automation of dispatcher/controller/pilot/traffic manager actions – especially to demonstrate the optimization of routing around a weather obstruction. This could be demonstrated using a variety of weather information to determine the most optimal set for		

Wx ATM Integration Conference Recommendation	Integration Plan Alignment	Comments
final integration.		
68) There is a need to separately demonstrate then integrate the value of specific weather information – not just convection – as integrated into automated tools. The demonstrations needs to be separate for each stakeholder – cockpit, AOC/FOC, ATC, etc		
69) There is a need to demonstrate a sufficient number of off-nominal (bad weather) scenarios to test the boundaries of NextGen system adaptability		
70) There needs to be demonstrations that incorporate scenario-based research initiatives to help quantify, in a more strategic way, the potential risks prior to entering into these more tactical scenarios		
71) Related to both tactical and strategic focus, there needs to be follow-on demonstrations to illustrate what kinds of safety nets (i.e., fall back or alternative operations) are available when weather reaches such triggers (tactically) – or in a more strategic sense, at what point is the commitment made to continue a TBO given an availability of alternate (operational) options that will exist in the future.		
72) There needs to be various demonstrations that highlight the relative effects of weather forecast errors with trajectory prediction studies. This could be performed using canned wind forecasts having increasing degrees of error.		
73) There is a need to demonstrate the viability of the 4D Wx Data Cube and 4-D Wx SAS and to show the risks (costs/safety) associated with *not* having “NextGen Weather”.		
74) Trajectories in the NAS should ultimately satisfy two objectives: - Separation from other trajectories by the minimum separation standard of the occupied airspace. Satisfaction of this objective is generally best defined by the ANSP. - The user-preferred trajectory provides optimum		

Wx ATM Integration Conference Recommendation	Integration Plan Alignment	Comments
cost and satisfaction of other operator defined objectives such as safety of flight, passenger comfort and emissions. These are generally objectives best defined by the system user.		
Super Density Operations		
Policy Issues		
75) Re-examine the ADS-B 'IN' timeline. It may need to be accelerated if we are going to more fully realize NextGen benefits, including NextGen Weather integration, by 2025.		
Research and Development		
76) Perform analysis/research to determine SDO weather and weather translation requirements for NextGen. Near-term efforts should include: - Analyze all NextGen SDO operational improvements to see how weather impacts them - Analyze sensitivity of NextGen SDO procedures and decision support tools to winds aloft in order to establish weather observation and forecast requirements - Determine how SDO differ with location (e.g., major airports, Metroplexes) in order to better understand their unique NextGen requirements		
77) Send weather integration researchers into the field to learn current deterministic SDO strategies, so that they are better able to develop more strategic SDO weather integration concepts/capabilities.		
Simulations and Demonstrations		
78) Establish a mechanism to solve SDO problems (through joint community involvement). This could include the use of integration laboratories (to include weather integration) and computer simulations to better understand the problems we need to address in implementing NextGen.		

8

E. CURRENT ATM TOOLS

Tool		Description	Tool Weather Interaction	Current Plans	Future Plans
AIR TRAFIC MANAGEMENT					
TFM-S **TDS** **CCSD** **WSD**	(Replaced ETMS) Includes: Traffic Situation Display, Common Constraint System Display, Web Situation Display	It is the principal component of the TFM infrastructure used by the FAA and NAS stakeholders to predict demand, identify constraints, mitigate delays and maintain common situation awareness. TFMS is based on an open architecture platform supporting the integration of TFM subsystems, facilitating integration with other domains, and supporting responses to new initiatives. In addition to improving development bandwidth, TFMS establishes a platform that is sustainable and scalable for the next decade and beyond.		TFMS displays certain weather products (CCFP, NCWF, and WSI Radar mosaic) onto the Traffic Situation Display function of the TFMS.	TFM-S will incorporate CIWS in 2011. NextGen Weather Processor WP2 will replace CIWS's function in 2017.
FSM GDP AFP GS	Flight Schedule Monitor Includes: Ground Delay Program, Airspace Flow Program, and Ground Stops	FSM creates a common situational awareness among all users and service providers in the National Airspace System. All parties need to be aware of NAS constraints in order to make collaborative air traffic decisions. Designed to effectively interact with existing FAA systems, FSM displays the Aggregate Demand List (ADL) information for both airport and airspace data elements for its users, which means everyone is looking at the same picture.	NONE	FAA and airlines use FSM to monitor demand through receipt of FSM demand pictures of airports updated every 5 minutes. FSM constructs "what if" scenarios for best options (i.e., best parameters) prior to making a GDP, AFP, or GS decision.	Software upgrades with no weather integration through 2025
TMA	Traffic Management Advisor	Traffic Management Advisor (TMA) analyses traffic approaching an airport from hundreds of miles away and can calculate scheduled arrival times in order to maximize arrival capacity.	NONE	Current plans are for multi-center integration of TMA and for weather integration so TMA can work re-routes due to convection.	TBD
ARMT	Airport Resource Management Tool	The ARMT gathers additional flight information from the Atlanta Common Automated Radar Terminal System (CARTS) IIIE and the manual scanning of bar coded paper flight strips at the Atlanta Airport Traffic Control Tower (ATCT). This manual bar code scanning is used to produce a near real-time recording of taxi clearance and takeoff clearance times. The ARMT also captures the traffic flow management (TFM) constraints, airport configuration and weather conditions currently in effect. The ARMT prototype system is also in the Potomac TRACON and the Chicago TRACON.	ARMT captures the weather conditions currently in effect.	Begin decommissioning of ARMT in 2010 with complete decommissioning in 2017. The purpose of decommissioning is so that it can be incorporated into the Tower Flight Data Manager.	TBD
SEVEN	System Enhancements for Versatile Electronic Negotiation (Under development by CDM FCT workgroup)	Allows NAS customers to submit a prioritized list of alternative routing options for their flights. SEVEN provides traffic managers with a tool that algorithmically takes these customer preferences into consideration as it assigns reroutes and delays to flights subject to traffic flow constraints	Weather is not a function of the tool at this time, SEVEN's goal is for an impact value of weather on normal traffic flows.	Phase 1 will be deployed in a selected geographic area for testing/evaluation. Phase 2 will expand Phase 1 functions throughout the NAS 2011 timeframe. (Phase 1 functionality still not fully defined.)	TBD
IDRP	Integrated Departure Route Planning (under development MITRE/MIT-LL)	IDRP takes the benefits identified from RAPT and integrating active traffic into the DST.	MITRE working with MIT/LL are working to develop a new weather model that can provide a 3D display of convection and its impact on traffic flows.	Deployment date not defined	TBD
EFPT	Enroute Flow Planning Tool (under development MITRE/MIT-LL)	Builds on the development of RAPT and the work being done on IDRP applied to enroute airspace. Once an area of weather is selected and timeframe to evaluate aircraft through the area can be selected and options for reroutes are given.	MITRE working with MIT/LL are working to develop a new weather model that can provide a 3D display of convection and its impact on traffic flows.	Deployment date not defined	TBD

Tool		Description	Tool Weather Interaction	Current Plans	Future Plans
	Future Traffic Display	Under development by Volpe 2010 - 2011 timeframe. A function of the TFMS system giving the traffic manager the ability to move the traffic along its filed flight path and view the systems impact.	NONE	TBD	TBD
Reroute Impact Tool		Under development by Volpe 2010 - 2011 timeframe. A function of the TFMS system giving the traffic manager the ability to view and evaluate the impact of reroutes on NAS sectors	NONE	TBD	TBD
DSP	Departure Spacing Program (ZNHY, N90 and Towers only)	DSP enables air traffic controllers to work more efficiently with traffic management coordinators to better use existing capacity for departing aircraft by reducing departure sequencing delays and minimizing terminal-area ground, airspace and telephone congestion. DSP also reduces the need for voice communication between air traffic control facilities by providing dynamic flight plan information and reports, via data transfer through the DSP network, to air traffic control towers, terminal radar approach control facilities and air route traffic control centers.	NONE	TBD	TBD
KVDT	Keyboard Video Display Terminal	A tool which allows air traffic controllers to amend flight plans	NONE	TBD	TBD
DSR	Display System Replacement	Provides controller workstation displays and input/output devices and a communications infrastructure to connect the DSR with external processing elements of the en route air traffic control automation system.	Since this is a display system only, any weather integration will be associated with the ERAM system that it supports.	Currently in a technology refresh 2005 - 2020 with and end of service of 2022.	TBD
ERAM	En Route Automated Modernization	ERAM will replace HOST and will increase capacity and improve efficiency in the nation's skies. En route controllers will be able to track 1,900 aircraft at a time, instead of the current 1,100. Coverage will also extend beyond facility boundaries, enabling controllers to handle additional traffic more efficiently, made possible by processing data from 64 radars instead of the current 24. Controllers will be able to share and coordinate information seamlessly between centers, making the use of three-mile (rather than five-mile) separation. Flight plan processing will also improve, and hand-offs performed when planes divert from their planned course will be done automatically rather than manually. This will improve operational efficiency during weather and congestion.	ERAM will be delivered in multiple releases and varying capability improvements will occur with each release.	Weather data integration: Air traffic controllers will use information from weather systems to help pilots route away from storms, avoid turbulence, and give passengers smoother flights.	TBD
URET	User Request Evaluation Tool	combines real-time flight plan and radar track data with site adaptation, aircraft performance characteristics, and winds and temperatures aloft to construct four dimensional flight profiles, or trajectories, for pre-departure and active flights. For active flights, it also adapts itself to the observed behavior of the aircraft, dynamically adjusting predicted speeds, climb rates, and descent rates based on the performance of each individual flight as it is tracked through en route airspace, all to maintain aircraft trajectories to get the best possible prediction of future aircraft positions. URET uses its predicted trajectories to continuously detect potential aircraft conflicts up to 20 minutes into the future and to provide strategic notification to the appropriate sector. URET enables controllers to "look ahead" for potential conflicts through "what if" trial planning of possible flight path amendments. URET enables controllers to accommodate user-preferred, off-airway routing to enable aircraft to fly more efficient routes, which reduce time and fuel consumption.	TBD	RUC Winds and Temperature	The future plans call for integrating URET into ERAM.
NTML	National Traffic Management Log	The National Traffic Management Log (NTML) was developed to provide a single system for automated logging, coordination, and dissemination of traffic management initiatives throughout the National Airspace System.	NONE	TBD	TBD

Tool		Description	Tool Weather Interaction	Current Plans	Future Plans
VSCS	Voice Switching and Communications System	VSCS allows air traffic controllers to establish all air-to-ground and ground-to-ground communications with pilots and other air traffic controllers. The system offers unprecedented voice quality, touch-screen technology, dynamic reconfiguration capabilities to meet changing needs, and an operational availability of 0.9999999.	NONE	TBD	TBD
ESIS Displays	Enhanced Status Information System	ESIS is a display system which is coupled with NTML to provide controllers and NAS managers with pertinent information	NONE	TBD	TBD
ERIDS	En Route Information Display System	ERIDS provide real-time access to air traffic control information not currently available from the Host Computer System (HCS) and makes this auxiliary information readily available to controllers. ERIDS is installed at various positions, including the Traffic Management Units (TMU), Center Weather Service Units (CWSU), and ARTCC Monitor and Control (M&C) Centers. ERIDS is integrated into the display system consoles at each sector, uses the center's airspace configuration for sector assignments, and allows changes in sector assignments. ERIDS displays graphic and text data products, including air traffic control documents, Notices to Airmen (NOTAMS), and general information.	NONE	TBD	TBD
IDS – 4	Information Distribution System, Model 4	Integrates several National Airspace System (NAS) data weather sensors and operational data onto a single display platform. The information is used by several thousand air traffic controllers.	IDS is a general weather information display.	Decomissioning of IDS-4 (Systems Atlanta Information Display System - SAIDS) is scheduled for 2009 - 2015.	TFDM (Tower Flight Data Management System) will be replacing the SAIDS and IDS-4 system beginning in 2010 and will continue through 2030.
HOST		Facility located at the ARTCC which operates user application software, as well as certain peer network layer protocols required to communicate with adjacent ATN routers.	Host displays NEXRAD weather data.	TBD	TBD
STARS	Standard Terminal Automation Replacement System	STARS is a joint Federal Aviation Administration (FAA) and Department of Defense (DoD) program to replace capacity-constrained, older technology systems at FAA and DoD terminal radar approach control facilities and associated towers. Controllers use STARS to provide air traffic control services to pilots in the airspace immediately around many major airports. These air traffic control services include the separation and sequencing of air traffic, the provision of traffic alerts and weather advisories, and radar vectoring for departing and arriving traffic.	Displays are specially developed for air traffic control and are capable of displaying six distinct levels of weather data	Currently in 49 FAA facilities and 50 DOD facilities, FAA is evaluating future deployment based on possibly combining smaller facilities.	TBD
WEATHER TOOLS					
RAPT	Route Availability Planning Tool	The Route Availability Planning Tool (RAPT) addresses an urgent need to increase the airport departure capacity in convective weather. In busy metroplexes such as New York, airways are tightly clustered and the proximity of adjacent arrival flows means that deviations around thunderstorms by departures cause serious disruptions to arrivals. As a result the departure flows are often shut down. The RAPT is a weather-assimilated decision support tool (DST) that supports the development and execution of departure management plans that more fully utilize the available departure capacity during Severe Weather Avoidance Plans (SWAP).	The RAPT integrates 3-dimensional (3-D) convective weather forecasts from the Corridor Integrated Weather System (CIWS) with the National Airspace System (NAS) airspace structure information (including aircraft trajectory information) to predict the availability of the filed departure route and, specifically designated coded alternative departure routes for an aircraft. Specifically the RAPT algorithms are dependent on CIWS convective	Test and evaluation in NY metropolitan area	Using CIWS weather information to determine route availability and using automation to select best flight/flights to operate on the available route. i.e. Working to improve the modeling capabilities.

Tool		**Description**	**Tool Weather Interaction**	**Current Plans**	**Future Plans**
			and echo tops forecast products.		
ITWS	Integrated Terminal Weather System	The Integrated Terminal Weather System (ITWS) is a recent technology that helps make air traffic flow more efficient in periods of adverse weather at NAS pacing airports. The ITWS is an air traffic management (ATM) tool that provides terminal air traffic managers and controllers plus airline dispatchers with highly accurate, easily understood and immediately useable graphical weather information and hazard alerts on a single, integrated color display. The ITWS provides aviation-oriented weather products via situation displays to air traffic control (ATC) personnel in Airport Traffic Control Tower (ATCT), Terminal Radar Approach Control (TRACON), and some Air Route Traffic Control Center (ARTCC) facilities, as well as in the FAA's Air Traffic Control System Command Center (ATCSCC). These products are immediately usable without further meteorological interpretation. In addition, the ITWS subsumes the functionality of Terminal Weather Information for Pilots (TWIP) [from TDWR] and provides depictions of impacting weather to jetliner flight decks via a communications service provider (ARINC).	The ITWS uses highly sophisticated meteorological algorithms to integrate and analyze data from multiple FAA and National Weather Service (NWS) sources, including data from the Terminal Doppler Weather Radar (TDWR), Airport Surveillance Radar Model 9 (ASR-9) weather channel, the Next Generation Weather Radar (NEXRAD) or WSR-88, the Low-Level Windshear Alert System (LLWAS), Automated Weather Observing System (AWOS) Data Acquisition System (ADAS), aircraft observations from Meteorological Data Collection and Reporting System (MDCRS), and NWS gridded model data to display current and near-term forecasts of weather conditions and hazards in the terminal area. The ITWS gets 1-minute ASOS data and ground stroke lightning data from ADAS.	TBD	TBD
CIWS	Corridor Integrated Weather System	CIWS is a web-based, Nation-wide operational decision support tool to improve traffic flow management. It is envisioned that the CIWS will be implemented at the FAA's Tech Center to provide traffic flow managers with comprehensive convective weather information needed for tactical modifications (0-2 hours). CIWS provides information on the current convective weather situation as well as fully automated forecasts of convection and attributes, e.g., Echo Tops, out to 2 hours.	The CIWS collects various data, then processes, generates, displays, and distributes convective (thunderstorm) weather products to traffic managers at the FAA David J. Hurley Air Traffic Control System Command Center (ATCSCC), numerous Air Route Traffic Control Center (ARTCC) facilities, large Terminal Radar Approach Control (TRACON) facilities, and some large airports. By concentrating its	CIWS will be operational through 2017.	CIWS is a developmental prototype for COSPA and will be integrated with the TSD in 2011

Tool		Description	Tool Weather Interaction	Current Plans	Future Plans
			two-hour forecast product over busy National Airspace System (NAS) corridors, CIWS would enable traffic managers to plan for routing/re-routing due to impacts on the airspace from major thunderstorm disruptions. The CIWS receives weather data from multiple sensors (primarily radars) and distributes processed information to NAS traffic managers via situation displays, and later via the System Wide Information Management (SWIM) network.		
WARP	Weather and Radar Processor	The primary purpose of the WARP system is to improve the timeliness and quality of weather information provided to Air Traffic Control (ATC) and Traffic Flow Management (TFM) specialists at the Air Route Traffic Control Center (ARTCC) facilities and at the David J. Hurley Air Traffic Control System Command Center (ATCSCC) in order to support the tactical and strategic decision-making process. WARP has an interface to the Display System Replacement (DSR) in order to provide mosaics of Next Generation Weather Radar (NEXRAD) data to air traffic controllers. It also provides imagery depicting traffic-impacting thunderstorm activity to the traffic management unit (TMU) and weather coordinator on briefing terminals.	The Weather and Radar Processor (WARP) system provides the capability to simultaneously and continuously receive, process, generate, store, and display aviation-related weather information and radar products from external sources and to disseminate this information to other National Airspace System (NAS) subsystems.	TBD	TBD
TOWER					
DBRITE	Digital Bright Radar Indicator Tower Equipment	Provides tower controllers with radar workstation displays and input/output devices and a communications infrastructure to connect the DSR with external processing elements of the en route air traffic control automation system.	NONE	End of Service 2012 replaced by Remote Automated Radar Terminal System Color Display End of service 2014	TBD
TDLS PDC FDIO ATIS	TBD	The Tower Data Link System (TDLS) automates tower-generated information for transmission to aircraft via data link. The TDLS interfaces with sources of local weather data and flight data and provides pilots with Pre-Departure Clearance (PDC), Digital-Automatic Terminal Information System (D-ATIS), and emulated Flight Data Input/Output (FDIO). The PDC helps tower clearance delivery specialists compose and deliver departure clearances. The Digital Automatic Terminal Information Service (D-ATIS) provides high reliability messages of runway and taxiway instructions, information on avionics equipment, frequency outages, and local weather conditions worldwide. The TDLS data is transmitted in text form via the Aircraft Communication and Reporting System (ACARS) to an ACARS-equipped aircraft for review and acknowledgment by the flight crew.	TBD	TBD	TBD
IDS-4 (5)	(see above)	TBD	TBD	TBD	TBD
DSM	TBD	TBD	TBD	TBD	TBD
AMASS	TBD	The Airport Movement Area Safety System	TBD	TBD	TBD

Tool		Description	Tool Weather Interaction	Current Plans	Future Plans
		(AMASS) with Airport Surface Detection Equipment (ASDE) provides controllers with automatically generated visual and aural alerts of potential runway incursions and other potential unsafe conditions. AMASS includes the Terminal Automation Interface Unit (TAIU) that processes arrival flight data from the Terminal Approach Control (TRACON) automation system and beacon target data from the Airport Surveillance Radar (ASR) and generates a track. The track is compared with the movement of aircraft and ground vehicles on the airport surface based upon surveillance data from the Airport Surface Detection Equipment (ASDE-3). AMASS adds to the ASDE-3 by presenting alarms to the tower controllers when evasive action is required. AMASS integrates and displays data from ASDE-3 and the ASR. The FAA has installed AMASS at the nation's top 34 airports.			
ETVS	TBD	The ETVS (installed in the ATCT) provides the air traffic control (ATC) operational ground-to-ground (G/G) voice communications intra-connectivity between controllers within an ATCT (intercom), interconnectivity between controllers in separate ATCTs (interphone), and interconnectivity between ATCT controllers and TRACON controllers/Air Route Traffic Control Center (ARTCC) controllers/Flight Service Station (FSS) specialists/David J. Hurley Air Traffic Control System Command Center (ATCSCC) specialists. Air-to-ground (A/G) radio connectivity between ATCT controllers and pilots is also supported by the ETVS.	TBD	TBD	TBD
TOWER WEATHER					
	Wind and Wind Shear Equipment	TBD	TBD	TBD	TBD
ASOS / AWOS	Automated Surface Observation System /Automated Weather Observation System	The Automated Surface Observing Systems (ASOS) program is a joint effort of the National Weather Service (NWS), the Federal Aviation Administration (FAA), and the Department of Defense (DOD). The ASOS systems serves as the nation's primary surface weather observing network. ASOS is designed to support weather forecast activities and aviation operations and, at the same time, support the needs of the meteorological, hydrological, and climatological research communities.	REPORTS BASIC WEATHER ELEMENTS: Sky condition: cloud height and amount (clear, scattered, broken, overcast) up to 12,000 feet Visibility (to at least 10 statute miles) Basic present weather information: type and intensity for rain, snow, and freezing rain Obstructions to vision: fog, haze Pressure: sea-level pressure, altimeter setting Ambient temperature, dew point temperature Wind: direction, speed and character (gusts, squalls) Precipitation accumulation Selected significant remarks including-	With the largest and most modern complement of weather sensors, ASOS has significantly expanded the information available to forecasters and the aviation community. The ASOS network has more than doubled the number of full-time surface weather observing locations. ASOS works non-stop, updating observations every minute, 24 hours a day, every day of the year.	TBD

Tool		Description	Tool Weather Interaction	Current Plans	Future Plans
			variable cloud height, variable visibility, precipitation beginning/ending times, rapid pressure changes, pressure change tendency, wind shift, peak wind.		
RVR	Runway Visual Range	Runway Visual Range (RVR) systems provide support to precision landing and takeoff operations in the NAS. RVR is a system that will measure visibility, background luminance, and runway light intensity to determine the distance a pilot should be able to see down the runway. RVRs consist of visibility sensor, ambient light sensor, runway light intensity monitor, and processing units. The RVR interfaces with the ASOS system as well which enhance safety, increase system capacity, and improve maintenance with in CONUS.	TBD	TBD	TBD
TDWR	Terminal Doppler Weather Radar	The Terminal Doppler Weather Radar (TDWR) system detects hazardous weather conditions such as wind-shear, micro-bursts and gust fronts, tornadoes, winds, heavy precipitation (inferring thunderstorms at an airport). This weather information is generated by the Radar Product Generator (RPG) and provided to air traffic on displays at terminal facilities. In addition, a TDWR provides alerts (both aural and textual) of detection wind shear/microburst activity in the approach/departure corridors. The TDWR also provides a 10- and 20-minute prediction of gust front location and movement using a Machine Intelligent Gust Front Algorithm (MIGFA).	TBD	TBD	TBD
METAR	TBD	TBD	TBD	TBD	TBD
OPERATORS					
	Flight Planning Systems	TBD	TBD	TBD	TBD
	Flight Following Systems Includes: CCSD, Flight Explorer (vendor tools), Internet Weather	TBD	TBD	TBD	TBD
AIRCRAFT					
FMS	Flight Management System	A flight management system is a fundamental part of a modern aircraft in that it controls the navigation. The flight management system (FMS) is the avionics that holds the flight plan, and allows the pilot to modify as required in flight. The FMS uses various sensors to determine the aircraft's position. Given the position and the flight plan, the FMS guides the aircraft along the flight plan. The FMS is normally controlled through a small screen and a keyboard. The FMS sends the flight plan for display on the electronic flight instrument system (EFIS), Navigation Display (ND) or Multi-Function Display (MFD).	TBD	TBD	TBD
RADAR					
MDCRS	Meteorological Data Collection and Reporting System	The system collects and organizes up to 28,000 real-time, automated position and weather reports per day from participating aircraft. The data is then forwarded in BUFR format to the National Weather Service World Area Forecasting Center in Maryland, USA, where it's used as input for their predictive weather models.	TBD	TBD	TBD
EFB	Electronic Flight Bag	It is an electronic information management device that helps flight crews perform flight management	TBD	TBD	TBD

Tool		Description	Tool Weather Interaction	Current Plans	Future Plans
		tasks more easily and efficiently with less paper. It is a general purpose computing platform intended to reduce, or replace, paper-based reference material often found in the Pilot's carry-on Flight Bag, including the Aircraft Operating Manual, Aircrew Operating Manual, and Navigational Charts (including moving map for air and ground operations). In addition, the EFB can host purpose-built software applications to automate other functions normally conducted by hand, such as performance take-off calculations.			

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F. ACRONYMS

ACRONYM	DEFINITION
2D	Two Dimension
3D	Three Dimension
4D	Four Dimension
4-D Wx Data Cube	Four Dimension Weather Data Cube
4-D Wx SAS	Four Dimension Weather Single Authoritative Source
4DT	Four Dimension Trajectory
A/DMT	Arrival / Departure Management Tool
AACR	Automated Airspace Congestion Resolution
AAR	Airport Arrival Rate
ACP	Airspace Congestion Predictor
ADDS	Aviation Digital Data Service
ADR	Airport Departure Rate
ADS	Automatic Dependent Surveillance
ADS-B	Automatic Dependent Surveillance Broadcast
AFP	Airspace Flow Program
AGL	Above Ground Level
AIRMET	Airman’s Meteorological Information
AIV	Atmospheric Impact Variable
AIXM	Aeronautical Information Exchange Model
AJN	FAA Operations Organization
ANS	Aviation Network Service
ANSP	Air Navigation Service Provider
AOC	Air Operations Center
API	Application Programming Interface
ARR	Arrival
ARTCC	Air Route Traffic Control Center
ASOS	Automated Surface Observing System
ASPM	Aviation System Performance Metrics

ASR-8/9/11	Airport Surveillance Radar Models 8, 9, and 11
ASR-WSP	Airport Surveillance Radar Weather System Processor
ATC	Air Traffic Control
ATCSCC	Air Traffic Control System Command Center
ATCT	Air Traffic Control Tower
ATIS	Automated Terminal Information System
ATL	Hartsfield-Jackson Atlanta International Airport
ATM	Air Traffic Management
ATM-WIP	Air Traffic Management – Weather Integration Process
AWO	Aviation Weather Office
AWOS	Automated Weather Observing System
AWRP	Aviation Weather Research Program
AWSS	Automated Weather Sensor System
BA	Big Airspace
C&V	Ceiling and Visibility
CAASD	Center for Advanced Aviation System Development
CAT	Clear Air Turbulence
CAT I	Facility providing operation down to 200 feet decision height and runway visual range not less than 2600 feet.
CAT II	Facility providing operation down to 100 feet decision height and runway visual range not less than 1200 feet.
CAT III	Facility providing operation possibly down to no decision height and no runway visual range. Can possibly use auto pilot for landing.
CATM / C-ATM	Collaborative Air Traffic Management
CATM-T	Collaborative Air Traffic Management Technologies
CAVS	Cockpit Display of Traffic Information Assisted Visual Separation
CbTA	Control by Time of Arrival
CCFP	Collaborative Convective Forecast Product
CD	Concept Development
CDA	Continuous Descent Arrival
CDF / cdf	Cumulative Distribution Function
CDM	Collaborative Decision Making

CDR	Coded Departure Route
CDTI	Cockpit Display of Traffic Information
CE	Concept Exploration
CIP	Current Icing Product
CIT	Convective Induced Turbulence
CIWS	Corridor Integrated Weather System
CO	Carbon Monoxide
CO2	Carbon Dioxide
COI	Communities of Interest
ConOps	Concept of Operations
CONUS	Continental United States
CoSPA	Consolidated Storm Prediction for Aviation
CSC	Computer Sciences Corporation
CSPR	Closely Spaced Parallel Runways
CTA	Controlled Time of Arrival
CWAM	Convective Weather Avoidance Model
DARP	Dynamic Airborne Reroute Procedures
DASI	Digital Altimeter Setting Indicator
DEP	Departure
DFM	Departure Flow Management
DFW	Dallas Fort Worth International Airport
DME	Distance Measuring Equipment
DOC	Department of Commerce
DOD	Department of Defense
DOT	Department of Transportation
DST	Decision Support Tool
EDCT	Expected Departure Clearance Time
EN	Enabler
ERAM	En Route Automation Modernization
E-RBD	Equity-based Ration-by-Distance
ETE	Estimated Time Enroute

ETMS	Enhanced Traffic Management system
E-WITI	En-route Weather Impacted Traffic Index
FAA	Federal Aviation Administration
Facilities	Transform Facilities
FAR	Federal Aviation Regulation
Far-Term	2018 – 2025 (Full NextGen)
FAWB	Federal Aviation Weather Board
FCA	Flow Constrained Area
FCFS	First-Come First-Served
FDIO	Flight Data Input/Output
FDR	Flight Data Report
FEA	Flow Evaluation Area
FET	Flow Evaluation Team
FIP	Forecast Icing Product
FIS-B	Flight Information Service-Broadcast
FL	Flight Level
FlexTerm	Flexibility in the Terminal Environment
FMS	Flight Management System
FOC	Flight Operations Center
FSD	Full System Development
FSM	Flight Schedule Monitor
GA	General Aviation
G-AIRMET	Graphical Airman's Meteorological Information
GBAS	Ground-Based Augmentation System
GDP	Ground Delay Program
GNSS	Global Navigation Satellite System
GPS	Global Positioning Satellite
GRASP	Generalized Random Adaptive Search Procedure
GS	Ground Stop
GSE	Ground Support Equipment
GTG	Graphical Turbulence Guidance

HEMS	Helicopter Emergency Management System
HF	High Frequency
HighDensity	High Density Airports
HITL	Human In The Loop
HPA	High Performance Airspace
HRRR	High Resolution Rapid Refresh
hrs	Hours
I&I	Implementation and Integration
IAH	George Bush Intercontinental Airport
ICAO	International Civil Aviation Organization
ICR	Integrated Collaborative Routing
IDRP	Integrated Departure Route Planning
IDFL	Interactive Dynamic Flight List
IFR	Instrument Flight Rules
ILS	Instrument Landing System
IMC	Instrument Meteorological Conditions
IOC	Interim Operational Capability
IPE	Integrated Program Execution
IPM	Integrated Program Modeling
IR	Infrastructure Roadmap
ITBFM	Integrated Time-Based Flow Management
ITWS	Integrated Terminal Weather System
IWP	Integrated Work Plan
JFK	John F. Kennedy Airport
JMBL	Joint Meteorological and Oceanographic Brokering Language
JMDB	Joint Meteorological and Oceanographic Data Base
JPDO	Joint Planning and Development Office
JPDO WG	Joint Planning and Development Office Working Group
km	Kilometer
LAAS	Local Area Augmentation System
LAHSO	Land And Hold Short Operations

LAX	Los Angeles International Airport
LIDAR	Light Detection and Ranging
LLWAS	Low Level Windshear Alerting System
LOA	Letter of Agreement
LP	Localizer Performance
LPV	Localizer Performance with Vertical Guidance
LR	Lagrangian Relaxation
LWE	Liquid Water Equivalent
M2M	Machine-to-Machine
MAP	Monitor Alert Parameter
mb	Millibar
MDCRS	Meteorological Data Collection and Reporting System
MEA	Minimum En Route Altitude
METAR	Aviation Routine Weather Report (an hourly surface weather observation)
METOC	Meteorological and Oceanographic
Mid-Term	2010 – 2018 (Transition to NextGen)
MIT	Miles in Trail
MIT/LL	Massachusetts Institute of Technology Lincoln Laboratories
MITRE	The MITRE Corporation
MM	Maxflow/Mincut
MoG	Moderate or Greater
MPA	Mixed Performance Airspace
NAS	National Airspace System
NAS EA	National Airspace System Enterprise Architecture
NASA	National Aeronautics and Space Administration
NASEIM	NAS-Wide Environmental Modeling
NAVAID	Navigational Aid
NCWF-6	National Convective Weather Forecast - 6
NCWP-6	National Convective Weather Product - 6
NDFD	National Digital Forecast Database
Near-Term	Current to 2010

NetFM	Network Flow Model
NEXTGEN	Next Generation Air Transportation System
NIP	NextGen Implementation Plan
nm	Nautical Mile
NNEW	Next Generation Air Transportation System Network Enabled Weather
NOAA	National Oceanic and Atmospheric Administration
NOTAM	Notice to Airmen
NOx	Nitrogen Oxides
NWP	Numerical Weather Prediction
NWS	National Weather Service
NWX	National Weather Index
NYC	New York Center Airspace
OAG	Official Airline Guide
OAT	Outside Air Temperature
ODNI	On-Demand NAS Information
OEP	Operational Evolution Partnership
OGC	Open Geospatial Consortium
OI	Operational Improvements
OPD	Optimized Profile Descent
ORD	Chicago O'Hare Airport
OTV	Obstructions to Visibility
PAAR	Planned Arrival
PAR	Periodic Auto-Regressive
PCA	Polar Cap Absorption
PCP	Probability Cut-off Parameter
PD	Prototype Development
PDF / pdf	Probability Density Function
PIC	Aircraft
PIREP	Pilot Report
PMF	Probability Mass Function
POET-R	Research Version of the Post Operations Evaluation Tool

R&D	Research and Development
RAPT	Route Availability Planning Tool
RB	Route Blockage
RBS	Ration-by-Schedule
REDAC	Research Engineering and Development Advisory Committee
RNAV	Area Navigation
RNP	Required Navigation Performance
RPD	Resource Planning Data
RRIA	Reroute Impact Assessment
RTA	Required Time of Arrival
RUC	Rapid Update Cycle
RVR	Runway Visual Range
RWI	Reduced Weather Impact
SAA	Special Activity Airspace
SAAAR	Special Aircraft and Aircrew Authorization Required
SAMS	Special Use Airspace Management System
SAS	Single Authoritative Source
SAWS	Stand Alone Weather Sensor
SBAS	Satellite-Based Augmentation System
SBS	Surveillance Broadcast Services
S-CAOSS	Super Computer Aided Operational Support System
SCG	Stochastic Congestion Grid
SDF	Louisville International-Standiford Airport
SDO	Super Density Operations
SEP	Solar Energetic Particles
SESAR	Single European Sky Air Traffic Management Research
SEVEN	System Enhancement for Versatile Electronic Negotiation
sfc	Surface
SFO	San Francisco International Airport
SID	Sudden Ionospheric Disturbance / Standard Instrument Departure
SIGMET	Significant Meteorological Information

SIT	System-Integrated TMI
SM	Statute Mile
SME	Subject Matter Expert
SOA/IT	Service Oriented Architecture
SoG	Severe or Greater
SOP	Standard Operating Procedure
SOx	Sulfur Oxides
SSE	Safety, Security, and Environmental
STAR	Standard Terminal Arrival
STL	St Louis International Airport
SUA	Special Use Airspace
SWIM	System-Wide Information Management
T Routes	Trajectory Routes
TAF	Terminal Area Forecast
TBD	To Be Determined
TBO	Trajectory Based Operations
TDWR	Terminal Doppler Weather Radar
TFDM	Trajectory Flight Data Management
TFM	Traffic Flow Management
TFMS	Traffic Flow Management System
TM	Traffic Manager
TMA	Traffic Management Advisor
TMC	Traffic Management Coordinator
TMI	Traffic Management Initiative
TMU	Traffic Management Unit
TRACON	Terminal Radar Approach Control
TRL	Technology Readiness Level
TSD	Traffic Situation Display
T-WITI	Terminal Weather Impacted Traffic Index
UAT	Universal Access Transceiver
US	United States

VFR	Visual Flight Rules
VHF	Very High Frequency
VMC	Visual Meteorological Conditions
VOLPE	Volpe Center / Volpe National Transportation Systems Center
WAAF	Weather Avoidance Altitude Field
WAAS	Wide-Area Augmentation System
WAF	Weather Avoidance Field
WAIWG	Weather Air Traffic Management Integration Working Group
WATRS	Western Atlantic Track Route System
WIST-1	Weather Integration Sub Team Number 1
WITI	Weather Impacted Traffic Index
WITI-B	Weather Impacted Traffic Index for Sever Weather
WMO	World Meteorological Organization
WP2	Work Plan 2
WRF	Weather Research and Forecasting Model
WTIC	Weather Technology in the Cockpit
WTMD	Wake Turbulence Mitigation for Departures
WV	Wake Vortex
Wx	Weather
XML	Extensible Markup Language
ZTL	Atlanta Air Route Traffic Control Center

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