8.1 A FRAMEWORK FOR THE DEVELOPMENT OF THE ATM-WEATHER INTEGRATION CONCEPT

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1. INTRODUCTION

Weather accounts for a majority of the air traffic delays within the National Airspace System (NAS) [Federal Aviation Adminstration, 2010]. The task of taking meteorological information (e.g., weather observations and forecasts) and turning it into the impact values needed to devise operationally effective air traffic management (ATM)[1] solutions is left almost completely up to the individual human decision maker today. This means that the accurate assessment of the impact of a forecast weather constraint and the quality of the resultant ATM initiative(s) is dependent in large part on the cognitive capability, skill and experience level of the decision maker [Federal Aviation Administration, 2007]. In some cases, the degree of difficulty of weather-related ATM problems is so great as to render all manual solutions suboptimal, regardless of how skillful and experienced the decision maker might be.

An overarching goal of the Next Generation Air Transportation System (NextGen) is to be able to operate more efficiently in the face of weather constraints. This objective is pursued through a number of improvements, including the reliable identification and use of operationally effective ATM solutions when weather phenomena are affecting, or are forecast to affect, NAS elements.

It is strongly believed that the integration of weather into ATM decision-making processes, or ATM-Weather Integration, is a critical and key enabler of this key NextGen concept.

In the above context, weather integration means that meteorological information is included in the logic of a decision process or decision tool such that the impact of the weather is automatically assessed and taken into account when the ATM decision is made or recommended [Federal Aviation Adminstration, 2010]. By minimizing the need for humans to manually (and, therefore, subjectively) gauge weather effects and constraints, and then decide on a strategy to address those constraints, ATM-Weather Integration enables the most effective ATM solutions to be consistently identified and executed.

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[1] For the purposes of this document, the term air traffic management (ATM) shall be considered a superset of both traffic flow management (TFM) and air traffic control (ATC).

1.1 Background

A number of FAA/research community workshops that explored the topic of ATM-Weather Integration were held between 2000 and 2005, but it was not until the Federal Aviation Administration (FAA) Research, Engineering and Development Advisory Committee (REDAC) tackled the subject in 2006 that weather integration became a priority. The Weather ATM Integration Work Group (WAIWG) was formed by REDAC that summer. It met several times per quarter for just over a year, examined dozens of documents, received 47 briefings and, in October of 2007, reported its results back to the parent body.

Among the key findings listed in the report, WAIWG acknowledged that "…as much as *two-thirds* of weather related delay is potentially avoidable" [Federal Aviation Administration, 2007]. WAIWG promoted the use of "…a risk management approach with *adaptive, incremental decision making*, based on *automatically translating weather forecasts into air traffic impacts*", calling that approach "a major new opportunity for reducing weather related delays in the…NAS" [Federal Aviation Administration, 2007]. WAIWG listed several key recommendations, including one which proposed that the FAA help facilitate a "cross cutting research program, involving public and private sector air traffic management and aviation weather experts, …to exploit these key findings" [Federal Aviation Administration, 2007].

FAA's formal response to the WAIWG report included the creation of a government/industry Weather Integration Team the following year. Among the accomplishments of the Weather Integration Team were versions 1.0 and 2.0 of the ATM-Weather Integration Plan in 2009 and 2010 respectively. Of note, each plan contained high-level conceptual descriptions of the NAS as it might operate with weather fully integrated into a variety of ATM decision support systems, and comprehensive catalogs of current weather integration initiatives and research projects.

1.2 The ATM-Weather Integration Context Diagram

During this same time period, the FAA formed a Weather Community of Interest (COI), whose objective was to bring members of the FAA ATM and weather communities together to agree on a way forward on ATM-Weather Integration. One consequence of the work performed by the members of this team was a growing understanding of several of the core weather integration concepts. A series of white papers were written about some of those key components starting in late 2009. In order to make the emerging notions more widely understood and available, an ATM-Weather Integration Concept Diagram was created in 2010 [Bradford et al., 2011]. The latest iteration of this diagram, informally called the "Ketchup-Mustard (KM) Chart" throughout the industry, is shown as Figure 1-1.

The diagram contains four primary elements. The following section contains a brief description of the makeup and relationships of these elements.

- The first element, *Weather Information*, includes the sources of most of the meteorological data used in the NAS. Note that not all weather information will need to be integrated as specified in the definition and depicted in the diagram. For instance, forecast upper winds are directly ingested by systems such as En Route Automation Modernization (ERAM), which then use them to calculate aircraft trajectories. This type of use of weather information is not considered to be integration, in that the predicted upper wind information is neither translated nor converted into impact.
- For the purposes of ATM-Weather Integration, weather observations and

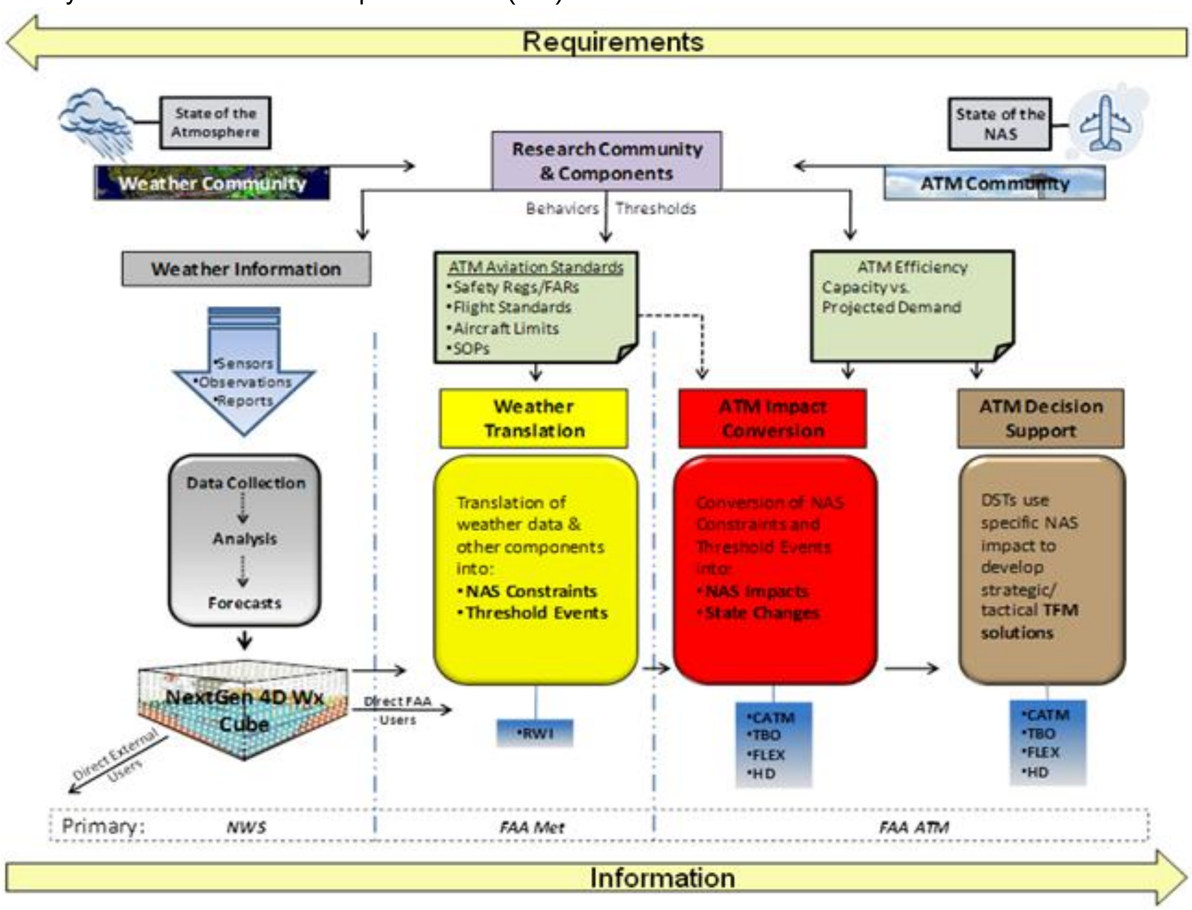

Figure 1-1. The "Ketchup-Mustard Chart."

forecasts from the first element are ingested by automation associated with the second element, *Weather Translation (yellow box)*. Through a framework of filters which apply the effects of such things as safety regulations, operating limitations and standard operating procedures, the weather information is turned (*"translated"*) into one of two weather-related expressions: a NAS constraint or a threshold[2] event. Both are described in terms of non-meteorological parameters that relate to their potential to cause a change in the capacity of the associated NAS element.

  - A NAS constraint is a non-meteorological expression related to the aircraft-specific permeability of the NAS element, usually airspace, in the face of a hazardous weather phenomenon. As such, it can be used to calculate the hypothetical capacity of the affected NAS element.
  - When associated with an airport, a threshold event signals a potential change in minimum spacing between aircraft or airport runway configuration, triggered by one or more key, non-hazardous meteorological parameter values moving through a critical operational threshold (e.g., ceiling height lowers below 300 feet, visibility drops from three miles to one-quarter mile, surface winds shift from east at 10 knots to northwest at 15 knots).

- Translated weather information is, in turn, fed to the third component called *ATM Impact Conversion (red box).* Automation performing this task identifies the individual aircraft making up the projected demand for the affected NAS element, calculates the aircraft-specific, weather-constrained capacity of the affected NAS element and then transforms (*"converts"*) the NAS constraint or threshold event into a NAS impact or state change. In this context, aircraft-specific means that the operational capabilities of individual aircraft in the projected flow relative to the weather constraint or threshold event are used to calculate the impact and, by definition, the resultant projected capacity.

- The fourth component, *ATM Decision Support (brown box)*, takes the impact information from *ATM Impact Conversion* and develops one or more ATM solutions to mitigate the effects of the forecast or actual weather constraint.

The dashed vertical lines are used to designate areas of responsibility, and the primary responsible parties are indicated in the horizontal box in the lower portion of the diagram. The vertical lines are purposely made to look extremely permeable, because ATM-Weather Integration problems cannot be worked out by the weather community alone, or the ATM community in isolation. Rather, there must be joint contributions from both communities on a variety of levels in order for ATM-Weather Integration efforts to succeed.

Finally, it should be noted that, while information flows from left to right in the diagram, as is indicated by the left-right orientation of the light yellow arrow on the bottom of the diagram, requirements by necessity must flow from the ATM community to their weather counterparts, as indicated by the right-left orientation of the upper yellow arrow.

1.3 Levels of Integration

During this period of time, several ongoing research efforts were underway in which various levels of ATM-Weather Integration were being achieved. However, a framework which could be used to classify those varying degrees of integration did not exist. Consequently, the notion of "Levels of ATM-Weather Integration" was proposed and refined in 2011.

There are considered to be five levels of ATM-Weather Integration, ranging from Level Zero (none) to Level Four (full) integration. The currently accepted definitions are depicted in Figure 1-2 and described below.

- A Level Zero classification means that there is no weather integration used in the target ATM system. Weather information and air traffic information are contained in separate, stand-alone systems, and any weather translation, impact conversion and solution creation is done cognitively in the mind of the ATM decision maker. In terms of weather integration, many current FAA ATM systems fall into this category.
- A classification of Level One means that some of the weather information and air traffic information are collocated on the

[2] A threshold event is not related to, nor should be confused with, a runway threshold.

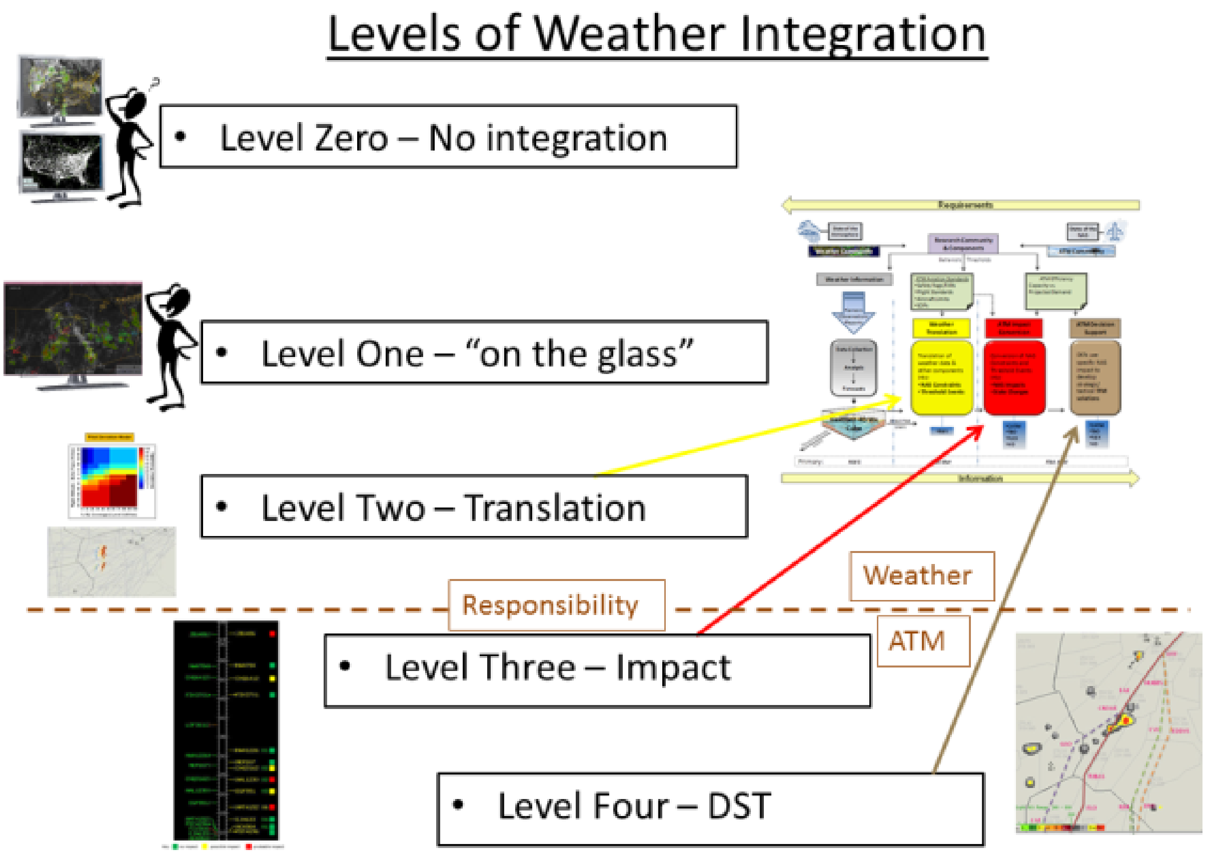

Figure 1-2. Levels of ATM-Weather Integration.

same display. Although weather translation, impact conversion and solution creation are still done cognitively by the ATM decision maker, fewer mental gymnastics are required than if the same information was taken off of two or more separate displays. Corridor Integrated Weather System (CIWS) graphics on the Traffic Flow Management System (TFMS), implemented earlier this year, is an example of Level One Weather Integration.

The remaining three levels, Levels Two through Four, have a direct relationship to the Weather Integration Concept Diagram, and are depicted as such in the diagram.

- Level Two systems automatically output translated weather in the form of NAS constraints or threshold events to the users, who must then cognitively integrate air traffic to determine an "impact" and then mentally devise the best solution for the situation. The most well-known example of an operational Level Two system is the Route Availability Planning Tool (RAPT), currently in operational use in the New York and Chicago Metroplex areas.
- Adding actual or scheduled traffic to a Level Two system results in a Level Three classification. Systems at this level typically use "stoplight" displays to objectively quantify impact to individual flights and/or flows. The prototype Integrated Departure Route Planning (IDRP) tool, which was tested last summer in the New York Metroplex, is considered a Level Three system, in which impact is specified on a flight-by-flight basis. Solutions to the impact, however, are left to the human ATM decision maker.
- Level Four systems not only automatically quantify flight- or flow-specific impacts, they also create solutions optimized against system objectives. A Level Four system provides potential resolutions, typically rank-ordered, to the ATM

decision maker, who takes on a human-over-the-loop role. The prototype Ground Delay Program (GDP) Parameters Selection Model (GPSM) used to optimally model GDPs at San Francisco International Airport may be the only example of a Level Four system in use today.

1.4 Developing the ATM-Weather Integration Concept

To move weather integration from concept to reality, there are a number of technical issues, requirements gaps and misconceptions that require further deliberation and clarification. Included among those topics are the relationship between weather-related functionality and other NextGen components in the future NAS Enterprise Architecture (EA), the notion of weather information and translated weather products as common services, and the idea of a single source of both weather information and translated weather products that will be used in FAA Traffic Flow Management (TFM) decision-making.

The following sections contain more detailed discussions of these and other relevant technical topics. This list of open items should be considered neither exhaustive nor complete.

1.5 Relationship between Weather-Related Services and Functionality and Other NextGen Components

As the name implies, weather integration fundamentally is concerned about the appropriate insertion of meteorological information into ATM processes and tools. The FAA has created comprehensive roadmaps for each major component of its NextGen development effort, including one for the NextGen Solution Set (SS) responsible for weather, Reduced Weather Impact (RWI). What needs increased focus is the integration of information from the RWI roadmaps into those of the major components which are impacted by weather. As such, a visual description of the relationship between future weather-related services and functionality and other major NextGen components does not exist, save for one or two examples created as part of the recent Concept of Integration (CONINT) development work.

1.6 Translated Weather Products as a Common Service

Weather integration implies the creation and use of several tailored products, such as weather translations and impact calculations. To this point, ATM decision support tool (DST) developers creating tools with integrated weather have had to build needed weather translation and impact calculation capabilities into the DST itself. In the NextGen far-term, it is believed that weather translation and impact calculation products will be used by a variety of DSTs, that there will be a common services which will provide the needed information, and that those common services could be housed in a system such as the NextGen Weather Processor (NWP).

1.7 Translated Weather Products – Weather Avoidance Fields (WAFs)

Several questions still exist concerning the translated weather products themselves, such as weather avoidance fields (WAFs[3]). For instance, several different "flavors" of convective WAF have been introduced over the last few years. Little or no guidance exists as to when to use which one, or which WAF methodology might be superior, and in what context. Moreover, it is not clear that the WAF approach is necessarily the only option, or the best one.

Some users have commented that the name WAF causes the affected NAS airspace to be treated as a "no-fly" zone. While this was certainly not the intent of the developers of the WAF, it is easy to see how the name might be misconstrued. Perhaps an alternative designation, such as Weather Induced Capacity Reduction (WICR) area, would more accurately describe the impact of the weather constraint.

1.8 ATM Impact as a Common Service

Just as it seems logical that translated weather products used by a variety of NextGen processes and tools will most likely not be required to be built specifically into every ATM DST, but will be available as a common service, the same is also true of technology which calculates ATM Impact. As part of the recently completed Task N work sponsored by the FAA and conducted by researchers from Embry-Riddle Aeronautical University, Lockheed Martin, ENSCO Corporation and Harris Corporation, in which convective weather information was integrated into the Time-Based Flow Management system (TBFM), a notional Hazardous Weather Conflict Detection Service was created. Its output, used by TBFM to determine when an aircraft was likely to request a

[3] The term "weather avoidance field" was introduced, along with the Convective Weather Avoidance Model (CWAM), by MIT Lincoln Laboratory.

trajectory change due to nearby thunderstorm activity, could also be leveraged by other ATM tools (e.g., ERAM), making it an example of a product that could be potentially deployed as a NextGen common service.

1.9 Source of Weather Information, Products for TFM Decision-Making

Early NextGen weather discussions established the need for a single source of weather information that would be used for TFM decision-making. As the notion has evolved over the years, the initial assigned name (Single Authoritative Source [SAS]) has taken on a negative implication among some number of observers, especially private industry weather providers. This was due in part to numerous unanswered questions about how the SAS would work.

In order to mitigate some of the negative connotations associated with the SAS, it might be helpful to give this notional set of functionalities a less threatening name (e.g., Common Weather for ATM Decisions [CWAD], Common Translation for ATM Decisions [CTAD]) and to try to answer some of the open questions (e.g., locations of CWAD, CTAD functionalities).

1.10 Purpose of Document

The purpose of this document is to propose an ATM-Weather Integration Development Framework to facilitate the effective and efficient development of the concept of weather integration. This framework will build upon the ATM-Weather Integration Concept Diagram but also capture additional key subject areas that should be included in discussion with stakeholders while developing this important NextGen capability.

This document does not propose to make decisions or resolve open questions regarding ATM-Weather Integration. Rather, it suggests that the ATM-Weather Integration Development Framework may be used as the context through which relevant parties can begin to tackle those unresolved issues.

Similar to the way that the original ATM-Weather Integration Concept Diagram and documentation helped clarify the fundamental underlying concepts, it is believed that the ATM-Weather Integration Development Framework and description contained in this document can be used to bring to light and help answer outstanding weather integration issues.

1.11 Document Format

Chapter One introduces the reader to the concept of ATM-Weather Integration, including the original concept and the levels of integration. It then describes the problem that the document is trying to solve.

The ATM-Weather Integration Development Framework is introduced in Chapter Two, and high level descriptions of each of its components help to further elucidate the new material.

Chapter Three provides a systems engineering view of the framework by diving more deeply into the upper two-thirds of the diagram, and examines how ATM-Weather Integration fits into the NAS EA. The new diagram and concepts are used as a means of anchoring the discussion.

Chapter Four provides an operational view of the framework by focusing on the lower third of the diagram. It looks at the role of ATM-Weather Integration in the context of operational decision-making performed by key government and industry personnel in support of flight operations.

Chapter Five presents recommended Next Steps and Chapter Six contains References. Appendix A contains a comprehensive glossary.

2 ATM-WEATHER INTEGRATION DEVELOPMENT FRAMEWORK

ATM-Weather Integration capabilities support cross-domain operations and will be delivered through close coordination across multiple systems. Acquiring weather integration capabilities in the context of the NAS enterprise is complex due to the web of interactions between the many system components and stakeholders. As described in Chapter 1, there are still outstanding technical issues requiring further deliberation and resolution. The ATM-Weather Integration Development Framework is intended as a foundational context in which to bring these issues to light and to help ensure successful development of ATM-Weather Integration capabilities.

2.1 Diagram Overview

Figure 2-1 is the ATM-Weather Integration Development Framework. Building on the original integration concept diagram, this expanded version graphically captures additional key subject areas that should be included in stakeholder discussions with reference to planning, acquiring, and implementing ATM-Weather Integration capabilities for operational decision support systems.

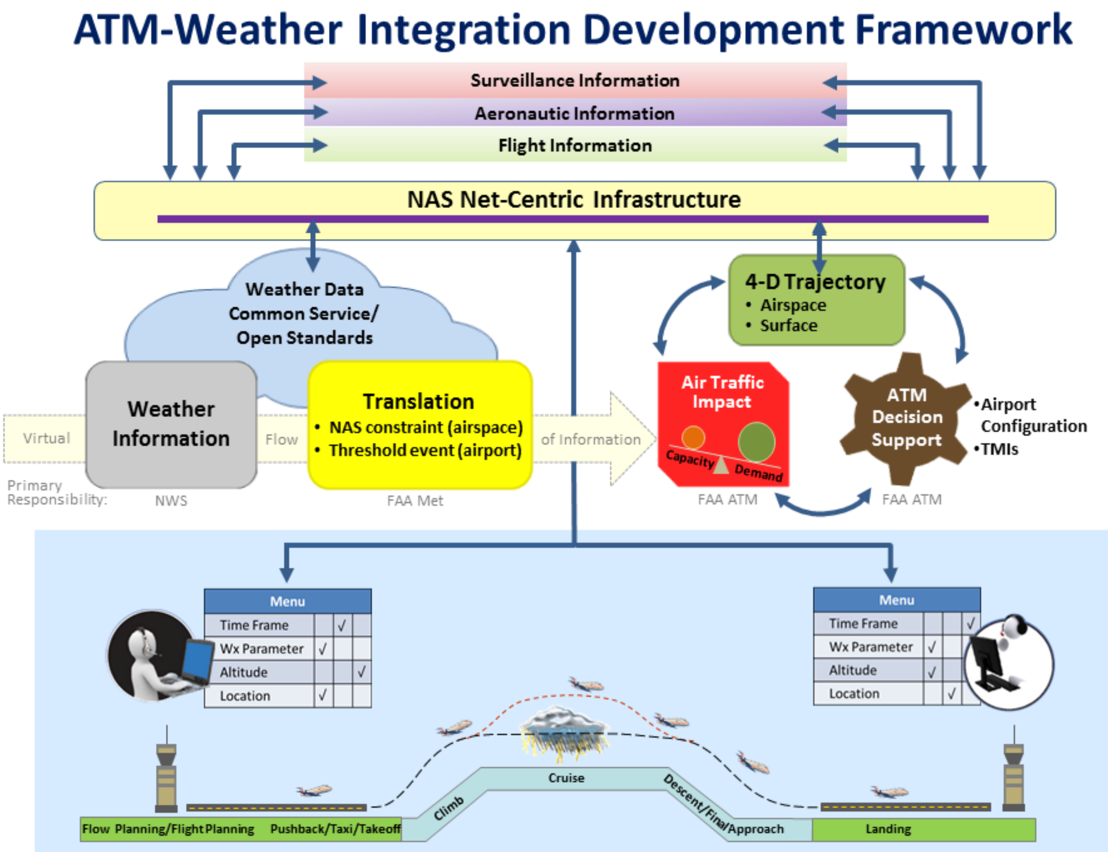

Figure 2-1. The ATM-Weather Integration Development Framework

At the heart of the ATM-Weather Integration Development Framework are the four major components of ATM-Weather Integration described in the original concept — weather information, weather translation, impact conversion, and ATM decision support. Expanding from the core, the enhanced diagram includes additional graphic objects to highlight the exchanges and relationships of weather integration components with other NAS information components (top portion) and NAS operations and related decision-making (bottom portion). The diagram also reflects the NextGen concept of net-centric infrastructure services. The diagram is not system/program-specific and, therefore, only the characteristics of the objects are described, and not the potential implementation systems.

2.2 Weather Information, Translation, and Weather Data Open Standards

Weather information and Translation products will be transmitted through a NAS net-centric infrastructure using Weather Data Open Standards. This dissemination plan provides users and systems with easy access to weather data and delivers tailored weather information through user-defined selection criteria such as weather parameters, space, location, time, forecast timeframe, and refresh rate. It will also significantly reduce system resource requirements and improve system performance of functions that ingest the weather information (e.g., translation engine, capacity estimator, what-if analyzer) while improving the ability to respond to changes in weather situations in a more timely fashion. Figure 2-2 depicts this portion of the ATM-Weather Integration Development Framework.

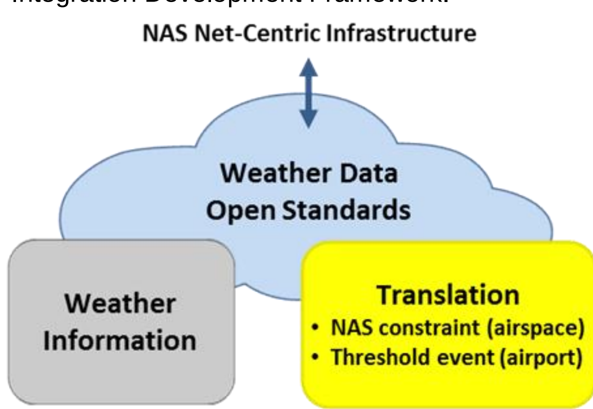

Figure 2-2. Weather Information, Translation and Weather Data Open Standards.

2.2.1 Weather Information

Weather affects flight operations in the air and on the airport surface. It affects both normal NAS operations (e.g., fair weather, wind-driven airport runway configuration changes) and those that take place during off-nominal atmospheric conditions, such as when a lowering ceiling results in the reduction of the airport acceptance rate (AAR) and the issuance of a traffic management Initiative (TMI).

Weather information includes all current observations, interpolated current conditions, and forecasts for various timeframes. It is expected that probabilistic weather forecasts, which are weather forecasts qualified with explicit probabilities, will become increasingly available to better support risk management decisions. Weather conditions of special concern to aviation cover of a wide range of phenomena including turbulence, thunderstorms and other convective weather, in-flight icing, freezing and frozen precipitation on the surface resulting in ground deicing and airport surface contamination, ceiling and visibility, lightning, wind speed and direction (surface and aloft), microbursts and wind shear.

2.2.2 Translation

Weather translation refers to determining the effects of weather conditions on the availability or capacity of NAS resources, which include airspace and airports. These effects are categorized as either NAS constraints or threshold events.

NAS constraints primarily affect en route airspace and the airborne phase of flight. An example of a NAS constraint is a convective WAF. Depending on the severity of the thunderstorms, some pilots are likely to refuse to fly through airspace in which the convective activity is located, making it a region of reduced permeability. A WAF is not a meteorological parameter but is derived (translated) using meteorological parameters, aircraft operating limits and pilot/flight behaviors in the face of hazardous weather. While convective weather receives most of the attention pertaining to the disruption of air travel, it is not the only hazardous weather phenomenon that can produce a NAS constraint. A turbulence chart containing regions of objectively measured or forecast eddy dissipation rate (EDR) values is also a translation of hazardous weather conditions into NAS constraints.

The effect of non-hazardous weather on primarily airports can be dependent on “operational thresholds”, values of various meteorological parameters around which operational changes are triggered. These threshold values may be based on empirical criteria, or established operating standards and regulations that govern airport surface and flight operations. Examples of threshold events include the following:

- Runway Visual Range (RVR) changes from 1800’ (CAT 1) to 1600’ (CAT 2).
- The surface visibility drops from six miles in haze (Visual Meteorological Conditions) to one mile in fog (Instrument Meteorological Conditions).
- Observed overcast cloud base height lowers from 500’ at Atlanta Hartsfield-Jackson International Airport (ATL) (tower cab beneath the clouds with good surface visibility underneath) to 300’ (tower cab in the clouds with limited or no surface visibility).
- The wind direction and speed at ATL shift from southeast at eight knots (east operation) to northwest at 12 knots (west operation).

Weather parameter changes as described in each of the examples above can lead to changes in either or both aircraft operating and ATC procedures, some of which in turn may have an impact on the capacity of the affected airport.

2.2.3 Weather Data Open Standards

To achieve NextGen network-enabled weather, data standards for the distribution of weather information need to be developed and specified. Weather data will need to be compliant with data format standards and its dissemination will be based on specified service standards.

Interoperability of data is a key requirement for NextGen weather data. Data format standards help achieve this by enabling the integration and exchange of heterogeneous weather data from thousands of sources. Data format standards generally involve format descriptions, encoding information, compression characteristics, and limited metadata.

The dissemination of weather data will be through a Service-Oriented Architecture (SOA), which allows different users to access data regardless of their operating system. Service standards specify how a data consumer communicates its specific needs, making it easy for users to query for weather data based on what, where, and when semantics. This is important since weather data is often high-volume and service standards will allow consumers to request only the necessary information. Both data format and service standards will be open standards as opposed to proprietary ones.

2.3 Air Traffic Impact, ATM Decision Support, and 4-D Trajectory

ATM Decision Support (brown gear symbol), 4-D Trajectory (green box), and Air Traffic Impact (red box), shown in Figure 2-3, form a kind of “plan-do-check” decision cycle. Not only does weather affect the capacity of NAS resources (as captured by NAS constraints and airport threshold events), it also affects demand through its impacts on 4-D aircraft trajectories. The changes in 4-D trajectories may be due to airspace user initiatives or due to ATM actions. Any imbalance between capacity and demand necessitates ATM action until the demand surge is absorbed or capacity is restored. Often the ATM action to adjust the demand includes flow contingency management or trajectory management, which then leads to changes in 4-D flight trajectories. The ATM decisions may also involve short-term capacity management actions (e.g., sector configuration, resources assignment). Weather information needs to be assimilated in a coordinated manner between the different tools used for trajectory modeling (both surface and airspace), air traffic impact assessment, and ATM decision support.

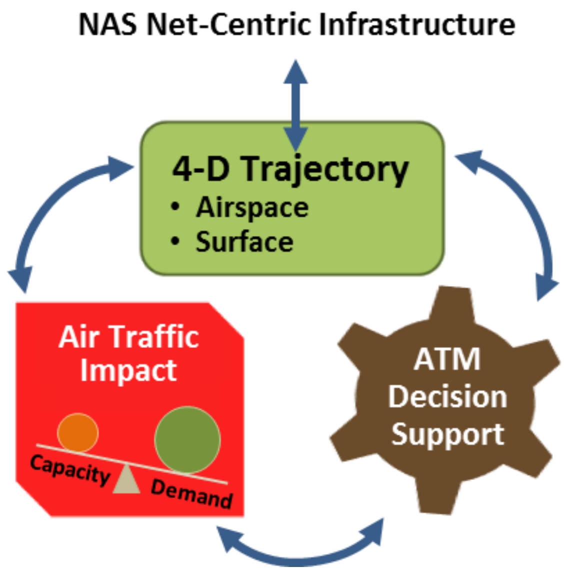

Figure 2-3. Air Traffic Impact, ATM Decision Support and 4-D Trajectory.

As depicted in the red box, the Development Framework graphically emphasizes the evaluation of demand for a NAS element (e.g., fix, waypoint, airport runway) against the weather-constrained capacity of the NAS element. Nominal capacity information is modified by the results of the Translation function. The demand is estimated based on projected trajectories of individual flights aggregated over a specified time interval.

2.3.1 Air Traffic Impact

Air Traffic Impact functionality evaluates the effect of weather on actual or planned air traffic by combining the output of Translation (i.e., the weather-constrained capacity of the NAS element) and the demand for the use of the NAS elements. For example, if a route is completely blocked by convective storms for a period of time, Air Traffic Impact will identify all flights planning to use the route for the affected period (including those still on the surface) and show them as being impacted. It will also calculate the magnitude of the capacity/demand imbalance caused by the route blockage. In addition to those caused by weather, this functionality can ingest other potential constraint information such as Special Activity Airspace (SAA) and runway closure information.

When there is an imbalance, Air Traffic Impact triggers an ATM action, which may be tactical or strategic depending on the timeframe, and may be manual or automated depending on the level of weather integration of the associated tool.

2.3.2 ATM Decision Support

ATM Decision Support refers to the various ATM DSTs and displays available to decision makers. These tools ingest the capacity-demand analysis results from the Air Traffic Impact functionality and then develop plans to mitigate the capacity reduction due to weather. In selecting feasible alternatives, decision support tools take into consideration additional factors such as local environmental regulations and standard operating procedures. When mitigation strategies are presented as a hierarchically-ordered family of possible solutions, the alternatives include types of traffic management actions, the timing of the action, and an associated risk analysis. ATM DSTs are expected to have humans “in-the-loop” (HITL) to verify information and ultimately select the most appropriate actions.

2.3.3 4-D Trajectory

4-D trajectory refers to flight path information in four dimensions: longitude, latitude, altitude, and time. In NextGen, aircraft trajectories will be defined from gate-to-gate including both the airborne trajectory and the surface trajectory (albeit some may consider the surface trajectory to be 3-D because it often has two spatial dimensions). Before departure, the trajectory is estimated using the planned gate departure time, filed flight plan and its amendments. After departure, the trajectory is a combination of observed locations and predicted future positions.

The NextGen Trajectory Based Operations (TBO) concept requires every aircraft that is operating in or managed by the ATM system to be represented by a detailed 4-D trajectory, which will be automatically exchanged between flight operators and air traffic service providers before and throughout the phases of flight.

The significance of the 4-D trajectory to ATM-Weather Integration is that if all aircraft 4-D trajectories are known, the demand for any NAS element can be calculated by summing the number of aircraft passing the element during a specified time. Air Traffic Impact functionality needs this information to determine if demand and capacity are in balance. When an imbalance is detected, ATM DSTs produce mitigation strategies which may alter some number of trajectories. This information in turn is then fed back into Impact functionality, completing the plan-do-check cycle.

2.4 NAS Net-Centric Infrastructure and Other Key NAS Information

ATM-Weather Integration functions will require information exchanges with other aviation functions (in particular, surveillance, aeronautical and flight information functions). These information exchanges are facilitated throughout the NAS using the Net-Centric Infrastructure as shown in Figure 2-4.

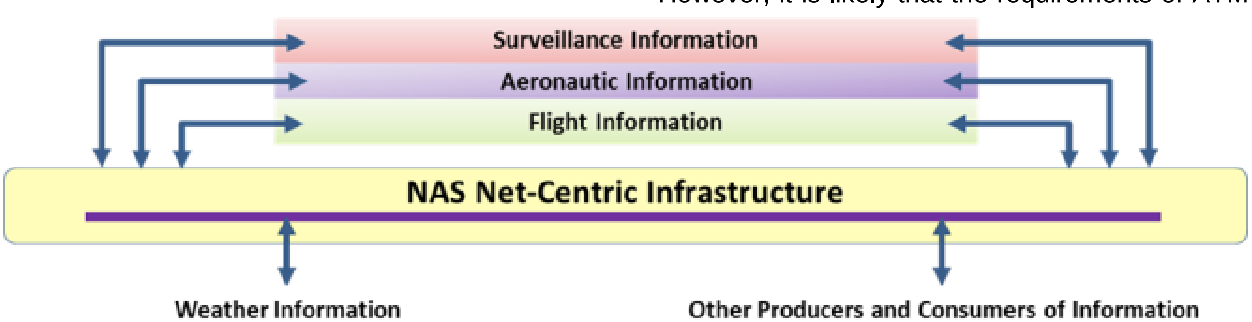

Figure 2-4. NAS Net-Centric Infrastructure and Other Key NAS Information.

2.4.1 NAS Net-Centric Infrastructure

The NextGen CONOPS (JPDO, 2009) envisions an interoperable enterprise network using a Net-Centric Infrastructure (NCI) to enable Net-Centric Operations for the NAS. NCI improves the transmission of air transportation-related information (e.g., weather, surveillance, and aeronautical information) using network methods and technologies. As described in the NextGen CONOPS, NCI is a combination of physical infrastructure and two services: infrastructure services and information services. Infrastructure services focus on providing and managing connectivity for sharing information, while information services focus on directing tailored data to authorized users (including information systems) where and when the information is needed. These two services are built upon an underlying physical global network that supports ground-to-ground, air-to-ground, and air-to-air data communications.

2.4.2 Other Key NAS Information

Certain ATM-Weather Integration functionality requires information from other key NAS information systems, namely surveillance information, aeronautical information, and flight information. The requested information is used by ATM-Weather Integration functionality to determine the degree of constraint (Weather Translation) and projected consequence (Air Traffic Impact) of the weather phenomenon on the NAS element in question, along with feasible solutions to mitigate congestions (ATM decisions)

Most of the data anticipated to be stored in these information systems are those used by ATM systems (e.g., ERAM and TBFM) to perform fundamental tasks such as calculating flight trajectories or identifying specified NAS elements (e.g., 3-D boundaries of a particular SAA). However, it is likely that the requirements of ATM-Weather Integration will result in an expansion of the amount or type of stored information, the frequency of updates and area of dissemination of some types of information. The following is a partial list of some of the information that would be desirable from the perspective of ATM-Weather Integration:

- Flight information such as specific aircraft and flight crew characteristics and operational capabilities in the face of different kinds of adverse weather.
  - An example of this type of information would be an indicator concerning the ability of both the aircraft AND the flight crew to operate in low visibility (e.g., CAT 3) conditions.
- Airspace-related aeronautical information such as predefined airspace configurations, flows, and routes used to address weather constraints or threshold events.
  - This would be useful for modeling future flight trajectories and evaluating alternative weather constraint resolutions.
- Airport-related aeronautical information such as runway or taxiway closures.
  - This would be useful not only to identify a constraint, but also to narrow the solution space that can be considered by decision support tools.
- Surveillance data for both airborne and airport surface operations.
  - Information like this would be essential to model future trajectories and estimate impacts for individual and groups of aircraft.

2.4.3 Operational Decisions

ATM-Weather Integration enhances operational decisions for a wide range of stakeholders including both flight operators and air navigation service providers (ANSPs). The time frames of operational decisions range from long-range planning (eight or more hours) to short-term tactical decisions (0-20 minutes), and span the entire flight operations cycle—flow planning/flight planning, pushback/taxi and takeoff, climb, cruise, descent/final approach and landing (as shown in Figure 2-5). ATM-Weather Integration, in conjunction with net-enabled information sharing, provides tools for timely information sharing and effective collaboration to reach better decisions while responding with agility to dynamic weather situations.

The following list is a small sampling of weather-related decisions based on current operations.

- Low visibility and ceiling leading to reduced airport capacity.
  - Strategic planning starts with consideration of the Terminal Aerodrome Forecast (TAF) to determine if and when low visibility and ceiling will reduce the airport throughput, expressed in terms of the anticipated AAR for arrivals and Airport Departure Rate (ADR) for departures.
  - FAA facilities implement TMIs such as a ground delay program to manage any demand/capacity imbalance.
  - Flight operators use the TAF to ensure regulatory compliance and to plan for possible delays (for example, carrying more fuel for holding, or to proceed to an alternate airport, if required).
- A significant wind shift requiring a change in runway configuration.
  - The TAF is used strategically to anticipate runway configurations throughout the forecast period, and the approximate timeframes within the forecast period when changes to the

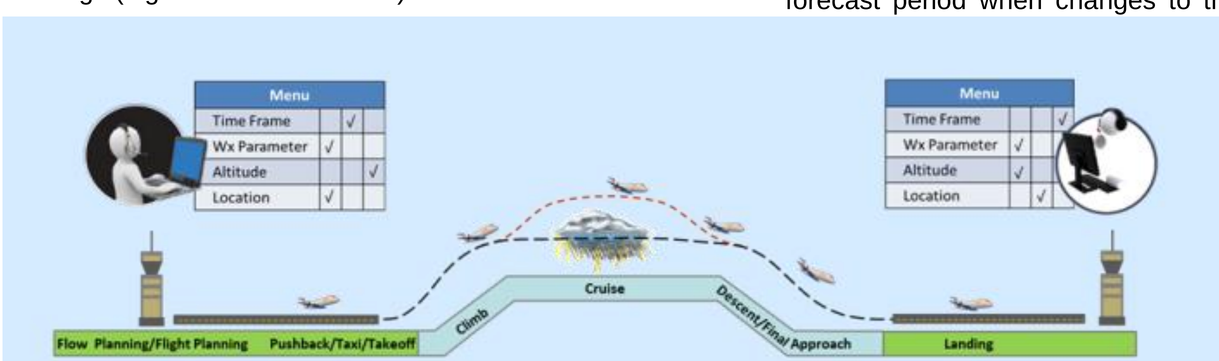

Figure 2-5. Framework for Operational Decisions.

configuration will be necessary.

  - FAA facilities coordinate and identify the time to tactically change configuration with minimal disruption to NAS operations while ensuring flight safety.
  - Flight operators anticipate the airport configuration at arrival based on the TAF, and may add contingency fuel when scheduled time of arrival is at or near the forecasted time of wind shift.
  - Airport surface weather observations (METARs) are continuously monitored by FAA facilities and flight operators to validate the forecast and to ensure the airport is properly configured for existing conditions.

- En route convection limiting available routes and reducing airspace capacity.
  - Reviews of ECFP (Extended Convective Forecast Product), CCFP (Collaborative Convective Outlook Product), SPC (Storm Prediction Center) Convective Outlooks, CIWS and TAFs begin the strategic decision process.
  - FAA facilities implement TMIs (e.g., Airspace Flow Program [AFP] and TBFM Flow Program [TFP]) to manage demand/capacity imbalance.
  - Flight operators pre-plan adding contingency fuel in anticipation of NAS-wide delays.
- Convective activity closing in on an arrival/departure fix.
  - Reviews of information from CCFP, SPC Convective Outlooks and CIWS begin the tactical decision process.
  - FAA facilities adjust current TMIs (e.g., ground stops) to manage demand/capacity imbalances.
  - Flight operators pre-plan adding contingency fuel and plan for NAS-wide delays.

3 A SYSTEMS ENGINEERING VIEW OF THE ATM-WEATHER INTEGRATION DEVELOPMENT FRAMEWORK

The FAA, in a joint effort with the National Weather Service (NWS), is developing NextGen ATM-Weather Integration capabilities for the NAS enterprise. These capabilities will be developed according to a system of systems (SoS) architecture in phases over time and across multiple programs. The SoS will be comprised of both new components (e.g., systems, infrastructure, technology) and existing ones. Acquisition of the SoS is inherently complex due to its distributed nature and evolving relationship between component systems. Because ATM-Weather Integration is a relatively new concept, the acquisition of integration capabilities is further compounded by the challenge of requiring stakeholders from one discipline area (e.g., the FAA ATM community) to understand their relationship with stakeholders in other discipline areas (such as the weather community, pilots, or controllers).

Developing successful weather integration capabilities depends to a large extent on the ATM and weather communities having a clear, common understanding of their interactions. The weather community needs to understand ATM operations and needs, and the ATM community needs to articulate their requirements for, and understand how to leverage, available weather products. The ATM-Weather Integration Development Framework provides a succinct view of the major integration functions and their interactions with other NAS components. It is expected that this framework will facilitate a more transparent, cross-program/system coordination to accomplish the following objectives:

- Produce a vetted, accepted, and cohesive set of Concepts of Operations (CONOPS) for inter-related systems to define NAS enterprise operational capabilities.
- Provide a comprehensive description of ATM-Weather Integration including the entire range of weather-related impacts, from those associated with non-constraining weather phenomena (e.g., surface winds, whose direction directly affects airport runway configuration) to highly constraining ones (e.g., a solid north-south line of thunderstorms across NY Metroplex east-west arrival and departure routes).
- Clearly define the overarching technical requirements (including the allocation of functions within the overall system architecture, as well as data exchange requirements) to ensure appropriate technical provisions are made in the emerging design.

This section illustrates potential uses of the new concept and diagram to manage the technical complexity involved in developing these integration capabilities. It first provides a summary of the current NextGen implementation plan for reducing weather impacts (Section 3.1), followed by a discussion of the relationships of these programs using the diagram (Section 3.2).

3.1 Implementing NextGen ATM-Weather Integration

NextGen ATM-Weather Integration capabilities will be developed within multiple programs/systems and by multiple agencies. Figure 3-1 illustrates the relationships between programs and systems and ATM-Weather Integration capabilities by displaying the former under the ATM-Weather Integration Development Framework.

NextGen weather data will be available through the NextGen 4-D Weather Data Cube (4-D Wx Cube). The NWS is responsible for a majority of the content of the 4-D Wx Cube.

The FAA is developing complementary weather integration capabilities through the Reduced Weather Impact (RWI) Solution Set. RWI is responsible for the NWP, Common Support Services-Weather (CSS-Wx), and the incorporation of weather into multiple ATM decision support systems. Weather integration is currently described or in the process of being described for the following ATM systems/technologies:

- TBFM
- Terminal Flight Data Management (TFDM)
- Collaborative Air Traffic Management Technologies (CATM-T)

Also noted in the figure is System-Wide Information Management (SWIM). SWIM is the NAS-wide information distribution and access mechanism for current and new applications. It is built on top of the FAA Telecommunications Infrastructure (FTI) and uses a SOA approach to integrating applications running on heterogeneous platforms using common standards.

3.2 NextGen Capabilities for Weather Information, Translation, and Weather Data Open Standards

This section describes the systems/programs currently planned for developing the NextGen capabilities for net-enabled weather, which is the lower left portion of Figure 3-1. As discussed earlier, the NextGen weather information will be available through 4-D Wx Cube. Consequently, the 4-D Wx Cube has become a synonym for NextGen weather information. The descriptions are focused on FAA's effort and are based on the current implementation plan for NWP and CSS-Wx in the NextGen RWI solution set.

3.2.1 Weather Information/4-D Wx Cube

The 4D-Wx Cube is a net-centric, virtual data repository of aviation weather data. It provides the content for CSS-Wx with weather data from NWS,

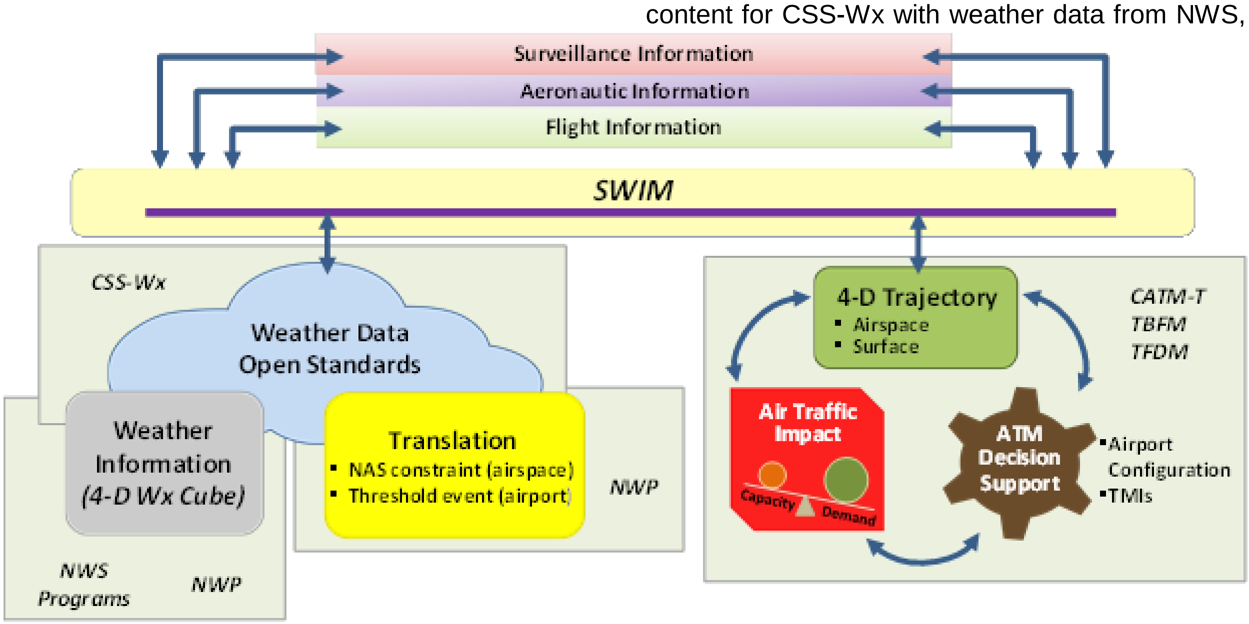

Figure 3-1. NextGen Systems/Programs Currently Planned for ATM-Weather Integration.

FAA, the Department of Defense (DOD) and participating commercial weather data providers. NWS aviation weather products, both existing and planned, will be converted to a web-enabled data format and transmitted to the FAA using a single connection (Day, T., 2010). Weather data published by DOD, FAA and participating commercial vendors will also be available in the same fashion.

The FAA NWP system will contribute to the content of the 4-D Wx Cube by establishing a common weather processing infrastructure responsible to accomplish the following:

- Replace current weather processors: Weather and Radar Processor (WARP) and Radar and Mosaic Processor (RAMP).
- Provide enhanced aviation-specific weather information.

The FAA has been developing enhanced aviation-specific weather information that is easily understandable without special meteorological training, and is readily usable by ATM tools. NWP will subsume two of these products, the Integrated Terminal Weather System (ITWS) and CIWS.

ITWS performs real-time integration of weather data and information from multiple sources (e.g., NWS, FAA, aircraft) and provides wind shear and microburst detection and predictions, storm cell intensity and direction of motion, lightning information and detailed winds in the terminal area, along with a one-hour storm forecast. The graphic and textual display of these products provides an easy-to-use interface.

CIWS is evolved from ITWS and gathers high altitude weather information from many sensors and satellite images to provide integrated weather information along busy jet airways and air traffic corridors. CIWS provides high-resolution three-dimensional (3-D) weather information and forecasts for precipitation and echo tops in the 0-2 hour time frame. The CIWS forecast timeframe will be extended to eight hours in the future through the introduction of CoSPA.

3.2.2 Translation by NWP

NWP is also expected to perform weather translation to characterize weather effects on NAS capacity for both airspace and airports. It will likely be the single source of translated weather information for the NAS. The technology for translation of weather phenomena into airspace constraints is currently more mature than for airports, and no NWP translation for airports is yet planned.

The current plan for NWP's translation capability is to implement the Convective Weather Avoidance Model (CWAM) for NAS-wide use by ANSPs and ATM systems (i.e., TFMS and TBFM). The use of CWAM results in the production of probabilistic, 3-D WAFs identifying regions of airspace that pilots are likely to avoid in the presence of convective weather. This convective weather translation capability will be applied to en route portions and terminal airspaces. The current version of CWAM was developed by MIT Lincoln Laboratory and has been applied to en route airspace. En route CWAM uses CIWS weather data products—vertically integrated liquid and echo top information—along with National Lightning Detection Network (NLDN) data to predict when and where aircraft deviations are likely (DeLaura et al., 2008). The initial operational applications of CWAM for terminal airspace are being planned and will later be extended for NAS-wide application.

3.2.3 Weather Data Open Standards/CSS-Wx

CSS-Wx (formerly the NextGen Network-Enabled Weather [NNEW]) will provide common weather information dissemination to all users throughout the NAS. CSS-Wx extends the SWIM SOA core services by publishing aviation weather information on SWIM. It will provide for filtering of the information by user-specified criteria, enable access to information via web services and, over time, replace legacy weather dissemination systems. CSS-Wx will define standards for weather data formats and services. Data standardization facilitates service standardization, and the CSS-Wx program has been working with the Open Geospatial Consortium (OGC) to develop such standards for aviation weather information. The Weather Information Exchange Model (WXXM) is the proposed OGC standard for the exchange of aeronautical weather information, and it is harmonized with the World Meteorological Organization (WMO). Another major accomplishment of this program is the joint effort with OGC to extend their Web Coverage Service[4]/Web Feature Service[5] (WCS/WFS) to include real-time publish/subscribe capability. Using OGC standards for weather information will provide flexibility in the integration of weather information into ATM decisions, interoperability with government and industry sources including

[4] For gridded data

[5] For non-gridded data

international partners (e.g., EUROCONTROL), and will facilitate a broader shared services strategy that supports multiple domains.

3.3 Incorporation of Weather into ATM Decision Support Tools

This section provides a brief description of the current plan to integrate weather data and translation products into ATM decision support tools (lower-right portion of Figure 3-1). The current plan describes, or will soon describe, the initial incorporation of weather into three ATM DSTs: TBFM, TFDM, and TFMS/CATM-T.

3.3.1 Time-Based Flow Management (TBFM)

TBFM is an existing system that applies time-based metering technologies and methodologies to tactically manage capacity and demand imbalances at U.S. airports. TBFM today plans efficient trajectories and manages traffic from the en route environment down to the runway threshold by specifying Scheduled Times of Arrival (STAs) at key trajectory locations. Controllers are responsible to adjust the trajectories of flights being metered so that their Estimated Times of Arrival (ETAs) match the assigned STAs.

When hazardous weather impinges on airport arrival routes, aircraft deviate from their planned trajectories. The resulting ETA fluctuations cause time-based metering operations to become unsustainable, and TBFM is shut down at the time it would be most effective (Fronzak et al., 2012). Improvements and enhanced capabilities are planned to address the performance gaps and shortcomings of the current TBFM system, and also to support operations envisioned for the NextGen mid-term timeframe and beyond.

3.3.2 Terminal Flight Data Management (TFDM)

TFDM is a new system that will provide surveillance, weather and other data to tower personnel, as well as DSTs to assist in their ATM decision-making activities. TFDM will also consolidate many of the stand-alone, disparate systems and displays presently used in the airport tower cab (Vilas et al., 2009). As a new system, the required weather and impact attributes for TFDM have not yet been fully defined, but the focus of aviation weather needs for this system include both the airport surface and local airspace.

3.3.3 Collaborative Air Traffic Management Technologies (CATM-T)

CATM-T is a NextGen Transformational Program that provides enhancements to TFMS. The present TFMS has evolved through several generations of hardware and software to provide strategic traffic flow management. Additional enhancements are planned to increase integration and interoperability with the overall air traffic management structure. The current implementation plans for these systems/tools suggest varying levels of weather integration. TBFM and CATM-T are Level 2 or above, while TFDM currently appears to be planning for Level 1 integration.

3.4 Applications of the ATM-Weather Integration Development Framework

This section provides examples of applications of the ATM-Weather Integration Development Framework as a reference to foster wider

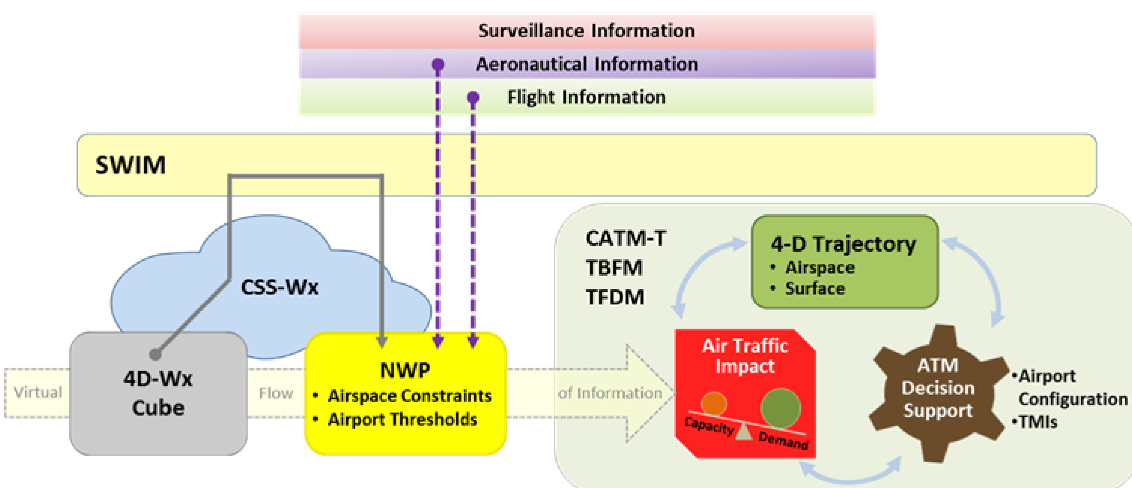

Figure 3-2. Example of Weather Information Flow for Translation.

discussions among all stakeholders on information interface dependencies and functional allocations. It is expected that such discussions will eventually lead to a consensus on operational and architectural concepts and requirements.

3.4.1 Example 1 - Information Interface Dependencies for NWP Translation

Figure 3-2 above amplifies the ATM-Weather Integration Development Framework to illustrate possible flows of information needed by the NWP translation function.

The NWP requires aeronautical information (and possibly flight information), plus appropriate weather information from the 4D-Wx Cube, as inputs to perform the Translation function. Aeronautical information here refers to the physical description and operational status of all NAS components. This information is needed in order to assess if weather events affect the availability or operational status of these resources, and also to ascertain which NAS resources are available for use in potential constraining or threshold weather events. Thus, NWP will depend on aeronautical information such as that from the National Flight Data Center (NFDC) database. In addition, the NWP translation function will require access to all weather information that is necessary to characterize actual or forecast weather phenomena that could produce a NAS constraint or threshold event.

Outputs from the translation function of NWP are descriptions of potentially constrained NAS elements (primarily airspace) or threshold events affecting primarily airport operations. These operationally-relevant characterizations of NAS resources will be used directly by ANSPs or by ATM systems to assess the impact on flows or flights, and to develop mitigation options. TFDM, TBFM, and CATM-T are ATM systems that currently, or will soon, have descriptions of weather integration activities and will have information dependencies on NWP when these systems progress to integration levels of Level 2 and above.

3.4.2 Example 2 – Information Interface Dependencies between ATM Systems and Weather Information Sources

All ATM systems will have the need for weather information but the nature of these dependencies varies according to the functions and their level of weather integration. Figure 3-3 illustrates potential information flows and dependencies.

An ATM system with Level 1 integration essentially only needs access to the weather information itself. In the current architecture, the information feed is via a point-to-point connection with one or more external weather systems. In the future, as illustrated in Figure 3-3, this weather information will be provided by the 4-D Wx Cube, published by CSS-Wx, and then filtered by specified criteria to customize the retrieval of only the data of interest to the using system. This reduces bandwidth and processing requirements.

An ATM system with Level 2 or higher (L-2+ in the diagram) integration will require NWP translation information provided by CSS-Wx. It may also be necessary or beneficial to allow user access to the selected information from the 4-D Wx Cube. This access will be necessary if users are given the

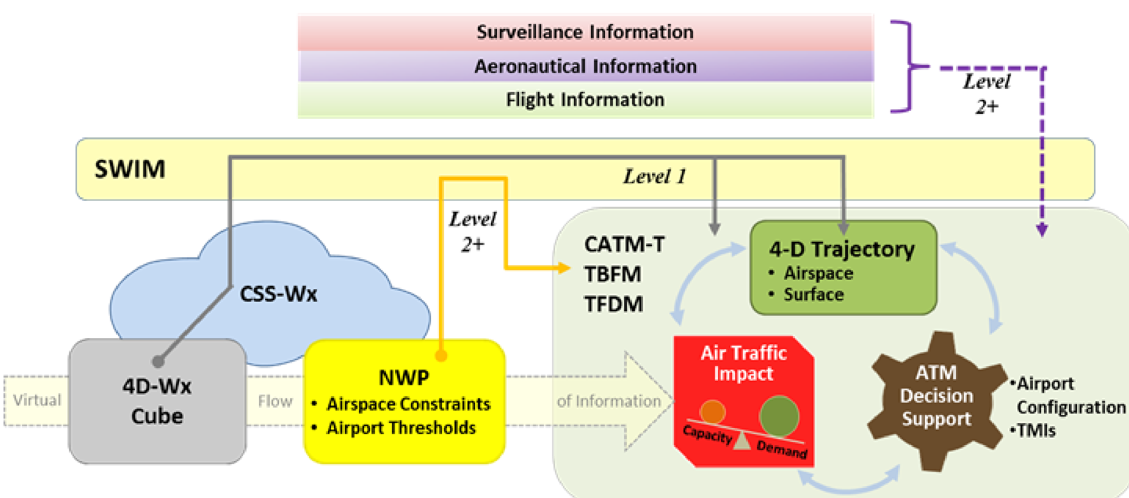

Figure 3-3. Example of Weather Information Flows for ATM Systems.

option to manually modify or override the automated translation result, a capability viewed as potentially leading to increased user acceptance of the translation result.

In addition, ATM systems have a requirement for weather data independent of the ATM-Weather Integration processes. Trajectory modeling performed by ATM systems requires atmospheric conditions of wind, pressure, and temperature. These atmospheric conditions are currently available from a weather system external to the ATM system such as WARP. In the near future,

3.4.3 Example 3 – Consideration of Functional Allocation Alternatives

Emerging technologies and operational procedures allow consideration of advanced mitigation strategies, such as wake turbulence mitigation (WTM), to increase airport capacity. The best way to allocate the required functionality for wake turbulence mitigation remains an open question, but the use of the ATM-Weather Integration Development Framework facilitates discussion and analysis of various options, as illustrated in Figure 3-4.

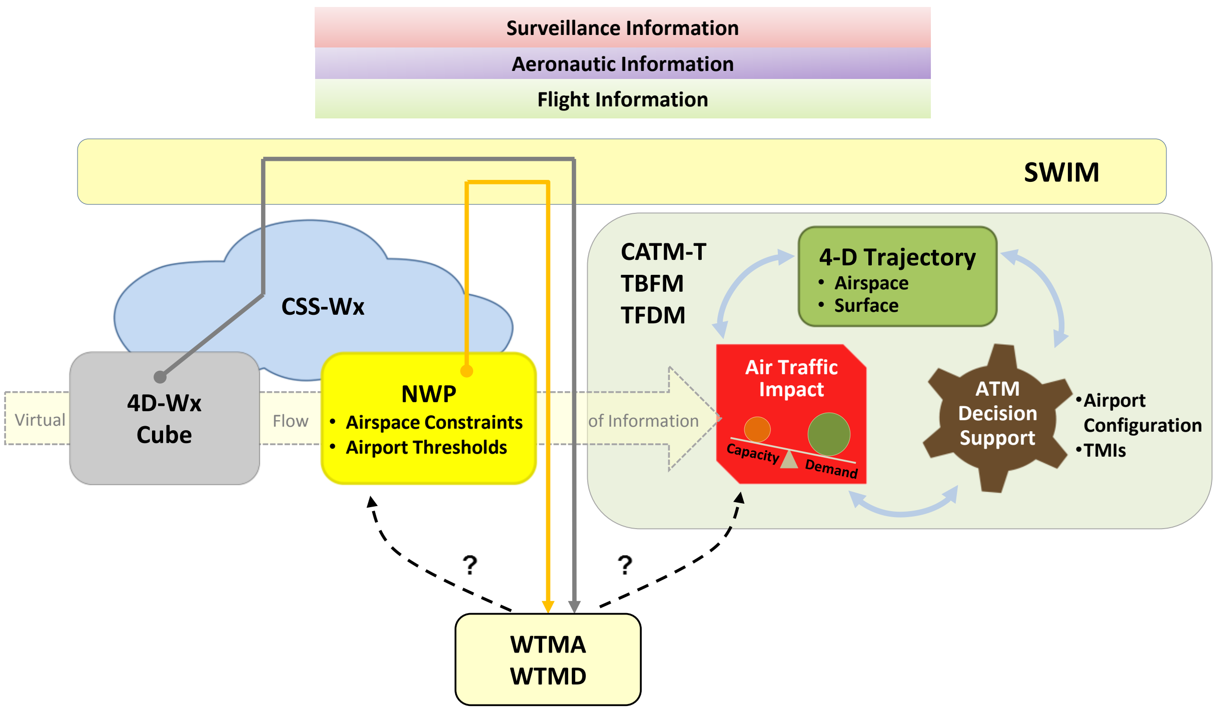

Figure 3-4. Functional Allocation Alternatives for Wake Turbulence Mitigation.

these will be published by CSS-Wx. The ATM systems with existing trajectory computation capabilities will be switching from the current point-to-point interface to accessing the needed information published by CSS-Wx through SWIM. The needed information is selected from the 4-D Wx Cube with specific filtering criteria such as weather parameters (i.e., wind, pressure, and temperature), location, altitude, and time of interest.

Depending on the allocation of functions, there could be other direct information dependencies between ATM systems and the CSS-Wx/4-D Wx Cube. These functions include modeling wind-based, wake-based spacing and their subsequent impacts on airport capacity, estimating AAR and ADR, or airport configuration management.

WTM increases airport capacity by applying dynamic wind-based wake procedures that, during suitable atmospheric conditions, reduce the default, conservative aircraft separation requirements. They are “dynamic” in the sense that they adapt to changing wind field characterizations.

WTM for Departure (WTMD) and WTM for Arrival (WTMA) permit aircraft to fly more closely together and expand the scope of “wake independent” operations of closely spaced parallel departures or arrivals under Instrument Meteorological Conditions (IMC). The WTMD automation support for dynamic separation management will need to (1) perform the function of identifying favorable wind conditions, (2) reduce wake separation requirements, and (3) protect operations from changing condition by alerting local controllers to terminate WTMD well prior to the onset of unfavorable winds. Analogous functions will be performed for the WTMA automation support. It is not yet clear, however, how or where these functions should be allocated. Candidate systems include the Translation component of NWP, TFDM, TBFM, TFMS/CATM or a new wake mitigation system yet to be specified.

Another open question that could be addressed in the context of the ATM-Weather Integration Development Framework is "What is the best way to allocate the functions for estimating airport arrival and departure capacity?" Unlike en route airspace, there are far fewer options to mitigate congestion in the airport environment. Airport capacity, expressed in terms of AAR and ADR, is critical to a variety of ATM decisions such as imposing arrival TMIs (e.g., ground delay program or ground stop) to avoid airborne holding or diversions. Improved airport capacity estimates will enhance the efficiency and effectiveness of NAS operation nationwide.

However, there is wide range of primary and secondary weather effects that influence AAR and ADR, and finding the right "home" for these functions needs to be considered in light of these weather effects. For example, airport wind conditions affect the airport runway configuration, ceiling and visibility affect flight operating rules (e.g., Instrument Flight Rules [IFR], Visual Flight Rules [VFR]), surface contamination affects runway occupancy time and "compression on final" introduces constraints that are not obvious at the runway threshold. In addition, WTM might be able to recapture capacity that would have been lost in Closely Spaced Parallel Operations (CSPO) during IMC or marginal Visual Meteorological Conditions (VMC). And finally, closed departure fixes or metroplex airspace interactions introduce other influences on AAR and ADR that may have little to do with the weather at the airport itself. As a result of the wide variety of influences on AAR and ADR, the home for these functions needs to be examined in the context of the ATM-Weather Integration Development Framework, as shown in Figure 3-5.

While it is expected that NWP will be the single source for translating weather into NAS constraints and threshold events, it is not yet clear whether the NWP translation should include modeling secondary effects that are not determined solely by weather (such as WTM effectiveness or metroplex airspace interactions). If it is found that these calculations for AAR and ADR are to be performed by ATM tools, then the allocation of these functions need to be clarified among the candidate systems such as TFDM, TBFM, and CATM-T.

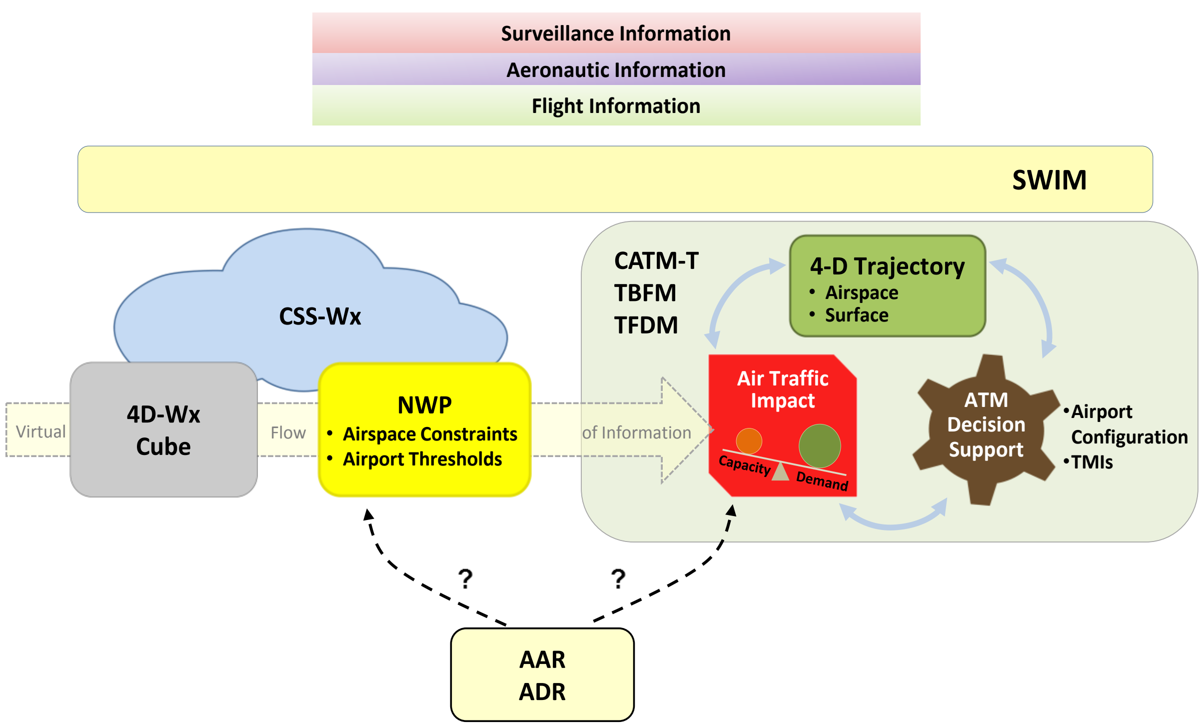

Figure 3-5. Functional Allocation Alternatives for Estimating AAR and ADR.

4 AN OPERATIONAL VIEW OF THE ATM-WEATHER INTEGRATION DEVELOPMENT FRAMEWORK

Operational decisions are what drive the need for ATM-Weather Integration. Understanding the nature of the decisions being made across a wide variety of locations, by a wide range of users, and with a broad assortment of desired outcomes, dictates the required inputs and outputs to the weather integration process. Getting the right information to the right people, at the right time and in the most efficient manner, is the key to making informed, collaborative traffic management decisions that will positively impact operations NAS-wide.

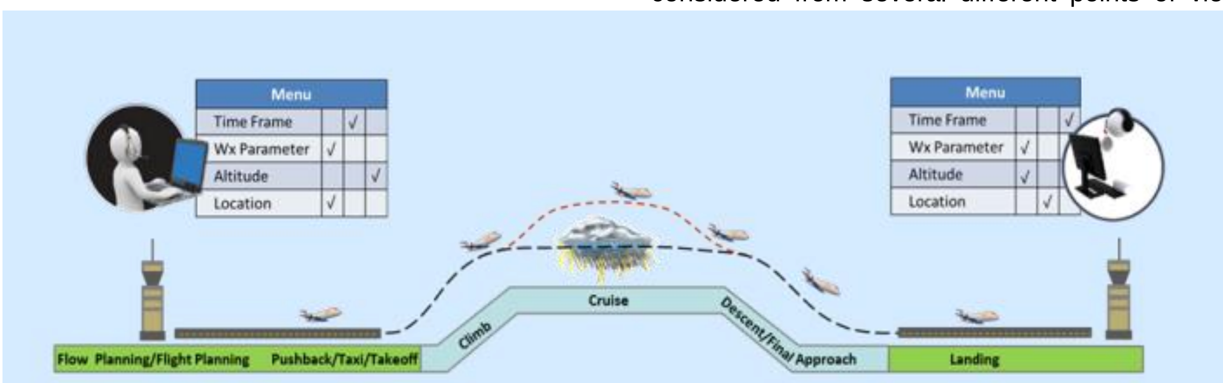

Figure 4-1. Framework for Operational Decisions.

4.1 Diagram and Description

The lower third of the enhanced ATM-Weather Integration Development Framework, shown as Figure 4-1, depicts operational users and the flow of data received either by individuals viewing selectable information on displays, or by automation systems directly ingesting translated weather data. By focusing on the specific decisions being made, only the weather data applicable to those decisions need be delivered, thus saving valuable bandwidth in a data intensive environment. Users (both human and automation) will select or subscribe to particular slices of information such as specific weather parameters, altitudes, timeframes, and locations. This menu of weather data will allow a focused evaluation of the area of concern (with the optimal fidelity and refresh rate for that condition) and will ultimately yield the most objective and proactive ATM decisions. For example, if a dispatcher at the airline operations center (AOC) is planning a flight that is two hours from departure, he or she would select a different set of menu options than an ARTCC sector controller whose adjacent sector was just significantly impacted due to a passing frontal system. Although these menu items are currently notional, Figure 4-2 depicts a possible breakdown of information.

4.2 Scenarios

Two scenarios were selected from the NextGen OV-6c Scenarios [The MITRE Corporation, 2010] to demonstrate the functionality of ATM-Weather Integration as it applies to operational decisions made in both the en route and terminal environments.

In each case, the actors involved, the timing of the decisions, locations (including altitude) in question, and the applicable weather conditions were considered from several different points of view. These scenarios take place in a future state where ATM-Weather Integration has been implemented at Level 2 or above. There is a short description of shortfalls in the current way of doing business in each scenario area to highlight the contrast with the anticipated advantages of the improved future state.

- **Actors:**
  - ATCSCC Planner
  - ARTCC
    - STMC
    - Sector Controller
  - TRACON STMC
  - ATCT
  - AOC
    - ATC Coordinator
    - Dispatcher
  - Pilots

- **Time Frame:**
  - 8+ Hours
  - 4-8 Hours
  - 2-4 Hours
  - 1-2 Hours
  - 30-60 Minutes
  - < 30 Minutes
- **Location:**
  - Sector X
  - Airport Y
  - Route Z

- **Altitude:**
  - 0-6k Feet
  - 6-18k Feet
  - 18-24k Feet
  - 24-30k Feet
  - >30k Feet
- **Wx Parameter:**
  - Convection
  - Icing
  - Turbulence
  - Winds
  - Lightning

Figure 4-2. Actors and Notional Weather Translation Product "Menu" Items.

4.3 OV-6C Turbulence Avoidance Scenario

Operational Objective: Proactively address a series of flight plan trajectory changes to maintain the overall flow, while granting each flight the best option which meets its needs in circumventing turbulence. See Figure 4-3 for a visual depiction of the scenario.

- Established EDR values and limits that correspond to criteria such as aircraft GWT, cargo load, regulations, and company policy.
- Altitude-specific turbulence forecasts with associated EDR values, a higher fidelity (e.g., 3 kilometer [km] grid) and with a probability of occurrence, possibly depicted as an area of

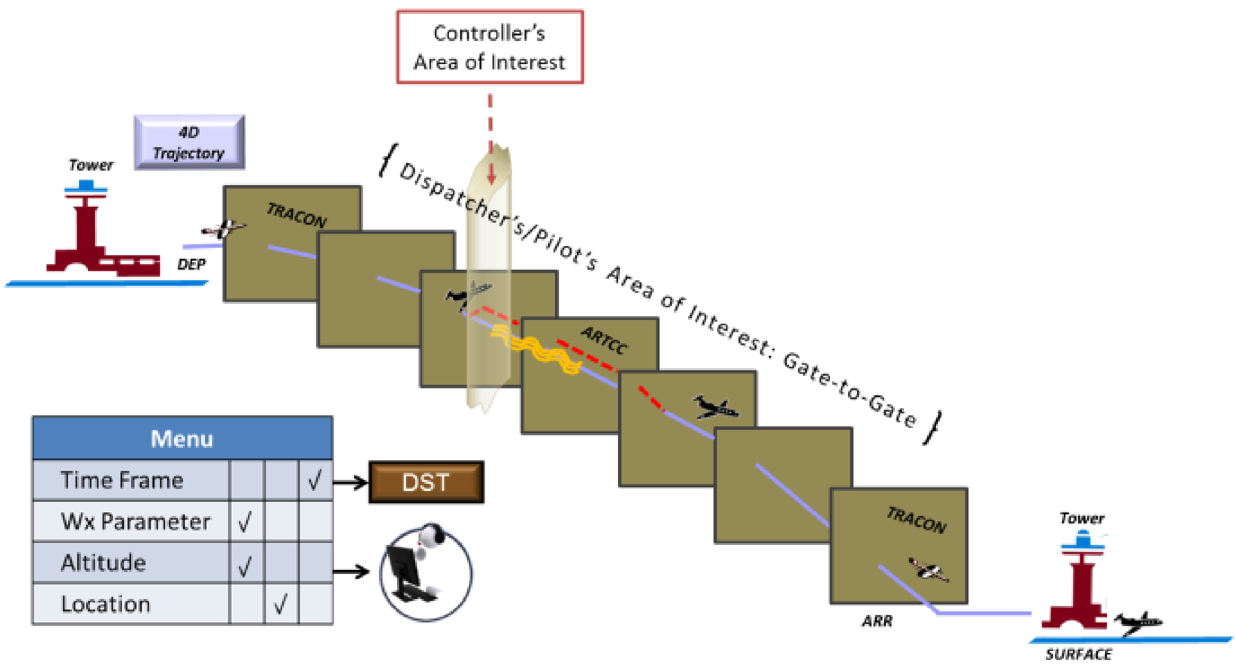

Figure 4-3. Visual Depiction of Turbulence Avoidance Scenario.

Current Process: Turbulence forecasting and reporting is somewhat subjective as there are no objective, quantitative values that are directly applicable to various airframe types and associated operating configurations, such as aircraft gross weight (GWT) and cargo versus passenger payloads. When faced with an emerging weather constraint (e.g., turbulence), users have the ability to request changes to the trajectories of affected flights, both before and after they are airborne. Depending on the immediate impact (spatial extent, severity) of the weather constraint, some percentage of flights may need to maneuver around the weather, creating a cascade of requests and unanticipated congested areas.

Improved Capabilities:

- Real-time Eddy Dissipation Rate (EDR) values sent directly (air-to-air for properly equipped aircraft, otherwise air-to-ground-to-air) to aircraft in the vicinity, as well as to local en route facilities and weather forecast models.

Weather Induced Capacity Reduction (WICR).

4.3.1 ATCSCC Planner/ARTCC TM Point of View

<u>Traffic Flow Management</u>

- FAA personnel responsible for assessing the potential NAS impact of turbulence-constrained airspace and for establishing TMIs, if needed, to deal with the anticipated congestion.

<u>Example Decision</u>

- Will turbulence be a factor for flights east of the Rockies today?
- If possible, should plans be made on how to best deal with the turbulence if it materializes?
- If probable, what class(es) of aircraft are likely to be planned on unusual trajectories, or to tactically request trajectory changes to a different altitude?

- Do the affected aircraft make up a significant portion of the total population of aircraft that normally fly through the impacted area?
- If probable, should plans be made in anticipation of a compression of traffic on fewer or different altitudes than normal through the affected area?

Required Information (ATM-Weather Integration Level)

- 4-8 hour Turbulence Weather Induced Capacity Reduction (T-WICR) forecast for FL240 through FL420 with anticipated EDR values and probability of occurrence (Level 2).
- Flight-by-flight impact calculations for the aircraft scheduled to fly through the affected area (Level 3).
- TFM plans based on the probable level of impact of the turbulence (Level 4).

4.3.2 AOC Operational Control Point of View

Assigned Aircraft Dispatcher

- Responsible for strategic planning regarding which flights to operate, and how, when, and where they will operate.
- Provides tactical support and guidance to airborne flights.
- May have geographic areas of responsibility or designated routes.

Example Decisions

- Will turbulence be a factor for the flights I am currently planning?
- If possible, should I suggest and plan for alternative trajectories in case the turbulence does materialize as forecast?
- If probable, should I plan the flights on trajectories that avoid the worst of the turbulence, or can the flight be expected to ride out the rough air?
- For flights already in the air, should I suggest alternate turbulence avoidance routings or altitudes when they approach the turbulent area?

Required Information (ATM-Weather Integration Level)

- 2-4 hour turbulence forecast (T-WICR) for FL240 through FL420 with anticipated EDR values and probability of occurrence (Level 2).
- Turbulence impact calculations based on the forecast EDR values and planned aircraft configuration (Level 3).

4.3.3 Pilot Point of View

Pilot-in-Command (PIC)

- The individual responsible for the control of an aircraft while it is moving on the surface or while airborne.
- Receives, evaluates, acknowledges, and executes trajectory changes (ATC clearances) that are given by the ANSP

Example Decisions

B737 passenger flight PIC

- Will I run into turbulence values greater than “Y” on my route between Los Angeles (LAX) and Washington Dulles (IAD) today?
- If probable, what are my options to mitigate the turbulent conditions, and do I have enough fuel to accomplish the mitigation strategy?

Regional Jet (RJ) passenger flight PIC

- Will I run into turbulence values greater than “X” on my route between Sacramento (SMF) and Memphis (MEM) today?
- If probable, what are my options to mitigate the turbulent conditions?
- Because this flight is right at the range limits of my aircraft, are my turbulence mitigation options within its capabilities?

Required Information (ATM-Weather Integration Level)

B737 passenger flight PIC

- 2-4 hour turbulence forecast (T-WICR) for FL320 through FL380 between LAX and IAD with anticipated EDR values and probability of occurrence (Level 2).
- Turbulence impact calculations based on the forecast EDR values and planned aircraft configuration (Level 3).
- Updated EDR values from onboard system and nearby aircraft between FL240-FL400 (Level 2).

- Turbulence impact calculations based on the observed EDR values and actual aircraft configuration (Level 3).

RJ passenger flight PIC

- 2-4 hour turbulence forecast (T-WICR) for FL240 through FL320 between SMF and MEM with anticipated EDR values and probability of occurrence (Level 2).
- Turbulence impact calculations based on the forecast EDR values and planned aircraft configuration (Level 3).
- Updated EDR values from onboard system and nearby aircraft between FL180-FL320 (Level 2)
- Turbulence impact calculations based on the observed EDR values and actual aircraft configuration (Level 3).

4.3.4 ARTCC Sector Controller Point of View

<u>Sector Controller Position</u>

- Radar Controller (with support from a Radar Associate Controller when necessary) who ensures aircraft separation.

<u>Example Decision</u>

- Will turbulence in my sector cause multiple aircraft to request a change in altitude?
- If probable, will those altitude change requests result in an unacceptable level of complexity in the sector?
- If probable, should I consider blocking the turbulent altitudes from use until further advised?
- If probable, how do I know when the condition of the affected airspace is acceptable for use by a majority of the aircraft desiring to use it?

<u>Required Information (ATM-Weather Integration Level)</u>

- Current aircraft EDR readings from within sector boundaries (Level 2).
- 30-60 minute turbulence forecast (T-WICR) for sector altitudes of responsibility with anticipated EDR values and probability of occurrence (Level 2).
- Turbulence impact calculations based on the observed and forecast EDR values and actual aircraft configurations (Level 3).

4.3.5 Automation Point of View

Assumption: Turbulence impact calculations based on the forecast EDR values and aircraft scheduled to pass through the sector (Level 3).

<u>Weather Information Management and Dissemination</u>

The NextGen automation system likely to be most affected by the forecast of turbulence is the trajectory modeler/calculator used by the ATC system in question.

- The 4-D Wx Cube provides the current CWAD forecast and observation information for time periods up to eight hours, at all altitudes, and NAS-wide geographic locations.
- The weather information is fed to NWP, where volumetric characterizations of airspace impacted by (in this case) turbulence are developed.
- These characterizations are continuously updated as new model data and airborne EDR values are received.
- A CTAD, called a T-WICR, is calculated for various altitude bands and for different geographic locations.
- This information is then pushed to ATC systems or DSTs that have a subscription or manually send a request.

<u>Example Decision</u>

Assumption: Trajectory calculator/modeler used to support ERAM.

- Will aircraft transitioning the center boundary encounter turbulence greater than their desired or safety-limited EDR level?
- What are the recommended actions to counteract the EDR level X turbulence forecast for 1500Z in sectors x, y, and z?

<u>Required Information (ATM-Weather Integration Level)</u>

- T-WICR within the ARTCC boundaries, at FL 240 to FL300+, 30 minutes to 2 hours (Level 2).
- Turbulence impact calculations based on the forecast EDR values and aircraft scheduled to pass through the sector up to one hour out (continuously updated) (Level 3).

- TFM plans based on the probable level of impact of the turbulence in the ARTCC (Level 4).

4.3.6 Shortfalls in Information and Research in the Context of ATM-Weather Integration

Weather Information - The objective turbulence observation data central to this scenario has only limited availability. Airborne EDR values are currently measured by only a subset of all commercial aircraft. The data is not able to be transmitted to adjacent aircraft using automated air-to-air or air-to-ground-to-air capabilities. EDR readings are transmitted to ground-based receiving stations for use by the affected AOC, and they are also passed along to NWS for use in turbulence forecasting. The information is not available to non-participating operators.

Weather Translation - At this time there is no equivalent to the existing convective WAF for turbulence, identified in the previous sections as a T-WICR. It is unclear whether WAF methodology in general is the most appropriate translation tool for turbulence. If it is, it is possible that different types or flavors of WAF will be needed depending on phase of flight.

Air Traffic Impact – At least two sets of capabilities will be needed to provide Air Traffic Impact information, and none of them exist today.

- In order to convert the T-WICR information to impact, some kind of Weather Conflict Detection service will first need to be utilized to determine when an aircraft and a turbulence weather constraint are likely to be geographically and temporally collocated.
- When an aircraft is projected to be in the same location at the same time as a turbulence weather constraint, a Weather Impact service would then be used to determine the impact associated with the anticipated thunderstorms on a flight-by-flight basis. This service requires research to be performed to associate the projected EDR level with the expected behavior of the aircraft (e.g., will a given level of EDR be unsafe or unacceptably uncomfortable for a given aircraft/configuration).

ATM Decision Support – Several different types of decision support are required to provide the ATM decision maker with a robust set of recommendations in this scenario, and none of them exist today.

- A Weather Conflict Resolution service is likely to be needed to project, on a flight-by-flight basis, how aircraft are likely to respond to a projected weather conflict.
- An Airspace Configuration service will likely be used to provide recommended alternative airspace configurations to the project turbulence impact.
- An Airspace Capacity Calculation service will be leveraged to determine the most likely changes to the capacity of the airspace with the forecast turbulence.
- An Impact Mitigation service will provide users with TMI suggestions that are appropriately hierarchical, incremental and adaptive.

4.4 OV-6C Terminal Airspace Reconfiguration

Operational Objective: Use alternative predefined airspace configurations and RNAV/RNP routings within a busy metropolitan airport environment in order to maintain throughput at the airport, despite the dynamic nature of the weather and airspace availability. See Figure 4-4 for a visual depiction of the scenario.

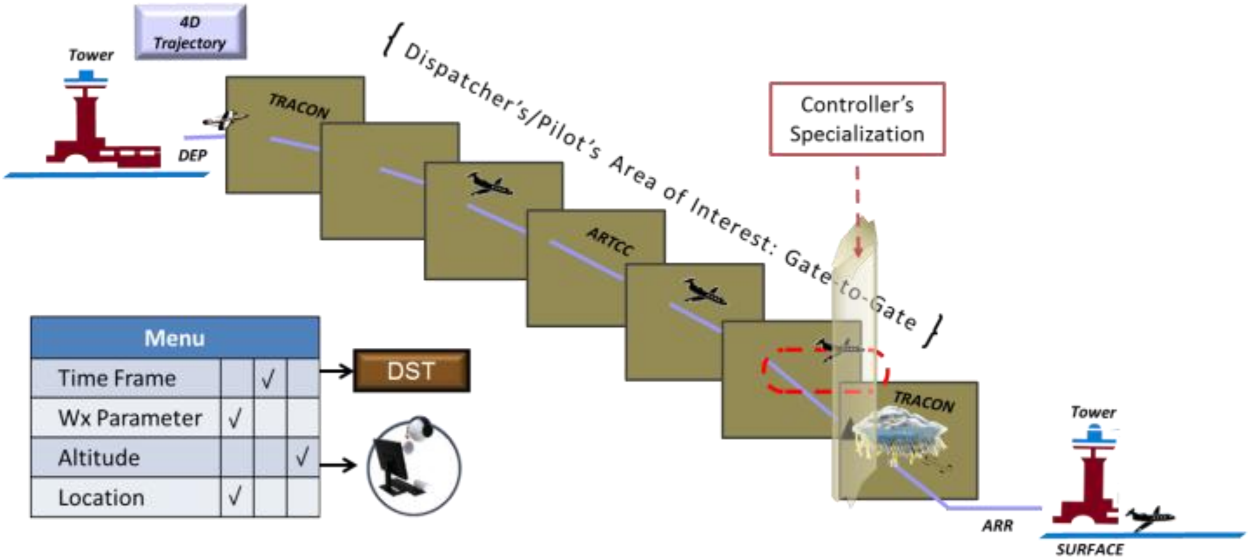

Figure 4-4. Visual Depiction of Terminal Airspace Reconfiguration Scenario.

Current Process: Pre-defined terminal airspace configurations are in place to allow for changes in traffic demand, airway and runway availability. Weather forecast products such as CCFP and CIWS are utilized by traffic management personnel to calculate potential constraints and impact on active and alternative terminal airspace configurations. When it is determined that a change in configuration is necessary (often not until aircraft start deviating from their planned trajectories), the change is coordinated between the local ANSPs (ATCT, TRACON, and ARTCC). Due to the delayed nature of the decisions, holding, diversions, and other avoidable delays often occur. The time frame for this scenario is for flights within 90 minutes of landing.

Improved Capabilities:

- Convective-Weather Induced Capacity Reduction (C-WICR) areas for specific altitudes, geographic locations (including specific air routes), and time frames, along with associated probabilities, are provided to assist in planning airport and terminal area configurations.
- As changes occur in the weather situation, updates are automatically pushed to both ANSPs and users (including automation), to increase available lead time for responding to changes via selection of an alternative terminal airspace configuration and RNAV/RNP routings.
- Other traffic flow initiatives are proactively implemented and user collaboration is conducted as necessary to adjust flows to align with the new configuration.

4.4.1 ATCSCC Traffic Management Specialist Point of View

<u>Traffic Management Specialist</u>

- Individual who performs TFM tasks in collaboration with Traffic Management Coordinators (TMCs) at the Towers, TRACONs and ARTCCs, and with NAS Customers.

<u>Example Decision</u>

- Will convective activity be a factor in the terminal airspace around Airport X or Metroplex Y today?
- If probable, how is capacity likely to be affected, and will TMIs likely be required to balance capacity and demand?

<u>Required Information (ATM-Weather Integration Level)</u>

- 4-8 hour C-WICR forecast for the terminal area with probability of occurrence (Level 2).
- Flight-by-flight impact calculations for the aircraft scheduled to operate into and out of the affected airport during the weather-impacted hours (Level 3).
- Alternative airspace configurations and RNAV/RNP routings associated with the forecast convective weather, the airport capacities associated with each and recommendations of TMIs if demand and capacity are imbalanced (Level 4).

4.4.2 AOC Operational Control Point of View

Assigned Aircraft Dispatcher

- Responsible for strategic planning regarding which flights to operate, and how, when, and where they will operate.
- Provides tactical support and guidance to airborne flights.
- May have geographic areas of responsibility or designated routes.

Example Decisions

- Will convective activity be a factor at Airport X or Metroplex Y today?
- If probable, will that activity impact flights that I am currently planning?
- If probable, what will the impact be, and should I plan to carry extra contingency fuel for holding in the terminal area?

Required Information (ATM-Weather Integration Level)

- 2-8 hour C-WICR forecast for the terminal area with probability of occurrence (Level 2).
- Impact calculations for the dispatcher's flights scheduled to operate into and out of the affected airport during the weather-impacted hours (Level 3).
- Alternative airspace configurations and RNAV/RNP routings associated with the forecast convective weather, the airport capacities associated with each, recommendations of TMIs if demand and capacity are imbalanced and the likely impact of those TMIs on the dispatcher's flights (Level 4).

4.4.3 Pilot Point of View

PIC

- The individual responsible for the control of an individual aircraft while it is moving on the surface or while airborne.
- Receives, evaluates, acknowledges, and executes trajectory changes (ATC clearances) that are given by the ANSP.

Example Decision

- Will convective activity cause me to deviate from my currently assigned flight plan route?
- If probable, how will it impact my fuel state?
- Will I be required to hold due to weather constraints in the terminal area?
- If probable, for how long and will fuel reserves become a concern?

Required Information (ATM-Weather Integration Level)

- 0-4 hour C-WICR forecast for the terminal area with probability of occurrence (Level 2).
- Impact calculation for the pilot's flight (Level 3).
- Alternative airspace configurations and RNAV/RNP routings associated with the forecast convective weather, the airport capacities associated with each, recommendations of TMIs if demand and capacity are imbalanced and the likely impact of those TMIs on the pilot's flight (Level 4).

4.4.4 ATCT Front Line Manager Point of View

Front Line Manager

- Responsible for managing staffing and duties within the ATCT to ensure that controller workload remains within acceptable limits.
- Informs TRACON TMCs of any condition in the airport area that could negatively impact the facility's ability to implement TFM initiatives.
- Works with TRACON and ARTCC TMCs to determine airport configuration.

Example Decision

- Will convective activity be a factor in the terminal airspace around my airport and terminal airspace today? If so, when and to what degree?

Required Information (ATM-Weather Integration Level)

- 0-8 hour C-WICR forecast for the terminal area with probability of occurrence (Level 2).
- Flight-by-flight impact calculations for the aircraft scheduled to operate into and out of the airport during the weather-impacted hours (Level 3).

- Alternative airspace configurations and RNAV/RNP routings associated with the forecast convective weather, the airport capacities associated with each (Level 4).

4.4.5 Automation Point of View

The NextGen automation system likely to be most affected by the forecast of convective activity in the terminal area is the trajectory modeler/calculator used by the ATC system(s) in question.

Weather Information Management and Dissemination

- The 4-D Wx Cube provides the current CWAD forecast and observation information for time periods up to eight hours, at all altitudes, and NAS-wide geographic locations.
- The weather information is fed to NWP, where volumetric characterizations of airspace and/or terminals impacted by (in this case) convective activity are developed.
- These characterizations are continuously updated as new model data and weather observations are received.
- A CTAD, called a C-WICR, is calculated from the ground up through all impacted altitudes at all affected geographic locations.
- This information is then pushed to ATC systems or DSTs that have a subscription or manually send a request.

Example Decision

(Trajectory modeling tool used to support TBFM)

- Will aircraft entering the TRACON boundary encounter convective activity that will cause them to deviate from their assigned course?
- What are the recommended actions to counteract the convective forecast for 1600Z within the TRACON boundary, in sectors x and y, and at airport X?

Required Information (ATM-Weather Integration Level)

- 0-2 hour C-WICR within TRACON boundaries, from the surface through FL240 (Level 2).
- Convective impact calculations based on probability and severity of forecast thunderstorm activity and expected reaction of individual aircraft to those thunderstorms (Level 3).
- Recommended actions (e.g., use of alternative airspace configurations with RNAV/RNP routes, use of TMIs to balance capacity and demand) in response to projected impact from convective activity (Level 4).

4.5 Shortfalls in Information and Research in the Context of ATM-Weather Integration

Weather Information – The required convective forecast information does exist. However, it is unclear whether the accuracy of today's convective weather forecasts meets the requirements of the system and process as described above.

Weather Translation – Today's convective WAFs have most or all of the characteristics expected of a C-WICR. However, it is unclear whether WAF methodology in general is the most appropriate translation tool. If so, it seems likely that different types or flavors of WAF will be needed depending on phase of flight.

Air Traffic Impact – At least two sets of capabilities will be needed to provide Air Traffic Impact information, and none of them exist today.

- In order to convert the C-WICR information to impact, some kind of Weather Conflict Detection service will need to be utilized to determine when an aircraft and a convective weather constraint are likely to be geographically and temporally collocated.
- When an aircraft is projected to be in the same location at the same time as a convective weather constraint, a Weather Impact Calculation service would then be used to determine the impact associated with the anticipated thunderstorms on a flight-by-flight basis.

ATM Decision Support – Several different types of ATM decision support are required to provide the ATM decision maker with a robust set of recommendations in this scenario, and none of them exist today.

- A Weather Conflict Resolution service is likely to be needed to project, on a flight-by-flight basis, how aircraft are likely to respond to a projected weather conflict.

- An Airspace Configuration service will likely be used to provide recommended alternative airspace configurations to the project convective impact.
- An Airport Configuration service will suggest alternative airport runway configurations based on projected weather changes at the airport surface and airspace changes in the TRACON, both related to the forecast convective activity.
- Both Airspace and Airport Capacity Calculation services will be leveraged to determine the most likely changes to capacity related to the forecast thunderstorms.
- An Impact Mitigation service will provide users with TMI suggestions that are appropriately hierarchical, incremental and adaptive.

5 Next Steps

The ATM-Weather Integration Development Framework is newly proposed. It has yet to be vetted with key stakeholders or used in the resolution of open weather integration questions. The following sequence of activities could be used to gain acceptance for this concept:

- Coordinate the proposed ATM-Weather Integration Development Framework with all affected stakeholders. These include key FAA operational, systems engineering and NextGen personnel, as well as relevant industry participants. Given the need for joint participation by members of both the weather and ATM communities in this effort, the use of an appropriately constituted COI may a way to accomplish this.
- Following the introduction and coordination of the framework with relevant stakeholders, gain approval from FAA to use the proposed ATM-Weather Integration Development Framework as a means of facilitating the effective and efficient development of the concept of weather integration.
- When approved, take steps to enable key personnel (possibly some or all members of the COI) to sufficiently understand ATM-Weather Integration, the new Development Framework and how to effectively leverage it.
- Once an effective level of understanding is reached, begin to identify and gather open weather integration issues. These include missing technical and operational requirements, process misconceptions and overall knowledge gaps.
- Following the creation of the list of open weather integration issues, create a plan to address those issues. Tasks associated with that plan will need to be identified and assigned to relevant personnel for resolution.

It is expected that a number of follow-on activities will take place once the above steps have been accomplished. These include tracking the resolution of the open issues, and observing changes in both global knowledge of, and specific efforts centered on, ATM-Weather Integration.

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Appendix A **ACRONYMS**

3-D	Three dimensional (x, y and z or x, y and t)
4-D	Four dimensional (x, y, z and t)
4-D Wx Cube	NextGen 4-D Weather Data Cube
AAR	Airport Acceptance Rate
ADR	Airport Departure Rate
AFP	Airspace Flow Program
AMS	American Meteorological Society
ANSP	Air Navigation Service Provider
AOC	Airline Operations Center
ARAM	Aviation, Range and Aerospace Meteorology
ARTCC	Air Route Traffic Control Center
ATC	Air Traffic Control/Controller
ATCSCC	Air Traffic Control System Command Center
ATCT	Air Traffic Control Tower
ATL	Atlanta Hartsfield-Jackson International Airport
ATM	Air Traffic Management/Manager
CAASD	Center for Advanced Aviation System Development
CAT	Category
CATM	Collaborative Air Traffic Management
CATM-T	Collaborative Air Traffic Management Technologies
CCFP	Collaborative Convective Forecast Product
CIWS	Corridor Integrated Weather System
COI	Community of Interest
CONINT	Concept of Integration
CONOPS	Concept of Operations
CSPO	Closely Spaced Parallel Operations
CSS-Wx	Common Support Services-Weather
CTAD	Common Translation for ATM Decisions
CWAD	Common Weather for ATM Decisions
CWAM	Convective Weather Avoidance Model
C-WICR	Convective-Weather Induced Capacity Reduction
DOD	Department of Defense
DOT	Department of Transportation
DST	Decision Support Tool
EA	Enterprise Architecture
ECFP	Extended Convective Forecast Product
EDR	Eddy Dissipation Rate
ERAM	En Route Automation Modernization
ETA	Estimated Time of Arrival
FAA	Federal Aviation Administration
FAR	Federal Aviation Regulation
FL	Flight Level
Flex	Flexible Terminal and Airports
FPAW	Friends and Partners of Aviation Weather
FTI	FAA Telecommunications Infrastructure
GDP	Ground Delay Program
GPSM	GDP Parameters Selection Model
GWT	(Aircraft) Gross Weight
HD	High Density Airports
HITL	Human-in-the-loop
IAD	Washington Dulles International Airport
IDRP	Integrated Departure Route Planning
IFR	Instrument Flight Rules
IMC	Instrument Meteorological Conditions
ITWS	Integrated Terminal Weather System
JPDO	Joint Planning and Development Office
k	Thousand

km	Kilometer
KM	Ketchup-Mustard (Chart)
LAX	Los Angeles International Airport
MEM	Memphis International Airport
METAR	Aviation Routine Weather Report
NAS	National Airspace System
NCI	Net-Centric Infrastructure
NextGen	Next Generation Air Transportation System
NFDC	National Flight Data Center
NLDN	National Lightning Detection Network
NNEW	NextGen Network-Enabled Weather
NWP	NextGen Weather Processor
NWS	National Weather Service
NY	New York
OGC	Open Geospatial Consortium
PIC	Pilot in Command
RAMP	Radar and Mosaic Processor
RAPT	Route Availability Planning Tool
REDAC	Research, Engineering and Development Advisory Committee
RJ	Regional Jet
RNAV/RNP	Area Navigation/Required Navigation Performance
RWI	Reduced Weather Impact
SAA	Special Activity Airspace
SAS	Single Authoritative Source
SMF	Sacramento International Airport
SOA	Service Oriented Architecture
SOP	Standard Operating Procedure
SoS	System of Systems
SPC	Storm Prediction Center
SS	Solution Set
STA	Scheduled Time of Arrival
STMC	Supervisory Traffic Management Coordinator

SWIM	System-Wide Information Management
TAF	Terminal Aerodrome Forecast
TBFM	Time-Based Flow Management
TBO	Trajectory Based Operations
TFDM	Terminal Flight Data Management
TFM	Traffic Flow Management
TFMS	Traffic Flow Management System
TFP	TBFM Flow Program
TM	Traffic Manager
TMI	Traffic Management Initiative
TRACON	Terminal Radar Approach Control
T-WICR	Turbulence-Weather Induced Capacity Reduction
VFR	Visual Flight Rules
VMC	Visual Meteorological Conditions
WAF	Weather Avoidance Field
WAIWG	Weather ATM Integration Work Group
WARP	Weather and Radar Processor
WCS	Web Coverage Service
WFS	Web Feature Service
WICR	Weather Induced Capacity Reduction
WMO	World Meteorological Organization
WTM	Wake Turbulence Mitigation
WTMA	Wake Turbulence Mitigation for Arrival
WTMD	Wake Turbulence Mitigation for Departure
Wx	Weather
WXXM	Weather Information Exchange Model