Findings and Recommendations from the NextGen Conference on Integrating Weather, Airports, and Air Navigation Services

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Next Generation Air Transportation System
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EXECUTIVE SUMMARY

The Next Generation Air Transportation System (NextGen) is focusing on a new direction in aviation weather information capabilities to help stakeholders at all levels make better decisions during weather situations. Safe and efficient NextGen operations will be dependent upon enhanced weather capabilities based on three major tenets:

- A common picture of the weather for all transportation decision makers and aviations system users.
- Weather integrated directly into sophisticated decision support capabilities to assist decision makers.
- Utilization of Internet-like information dissemination to realize flexible and cost-efficient access to all necessary weather information.

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

A common theme that prevailed across the working groups was that while the language in the NextGen Concept of Operations (ConOps) has been embraced by all National Airspace System (NAS) stakeholders, there are several considerations towards the reduction of weather impact that must be taken into account before many of the envisioned operational (non-weather) benefits are realized. These involve operational constructs and nuances as perceived by the intended user of the information. Such considerations (i.e., where the rubber meets the road) go beyond any specific scientific improvements in weather understanding and behavior, airborne or ground-based weather sensor density, weather forecast skill or modeling and ultimate weather integration. These considerations include how and when the information is presented, the consistency of the information among differing operators, common interpretation of the information in terms that are relevant to the operation, and the risks or consequences (real or perceived) of the use of the information. There was general agreement that the most important considerations of all will be the policies that facilitate change, the regulations that dictate change, and the transitional stages in operations that will enable operational evolution (e.g., continuity of services/conservation of functionality) while providing perceived benefits and safety.

The general consensus of the participants in the NextGen Weather work group determined that while network enabled digital data is a key to success, there was a lack of clarity and messaging (outside the Joint Planning and Development Office (JPDO)) regarding government and industry roles for populating and operating the weather 4-D Weather Cube. Weather dissemination to, and access by, aircraft is also vital to satisfying the ‘aircraft as nodes on the net’ concept. Industry is prepared to join the government in identifying options to make NextGen Weather a reality.

Weather integration into surface airport operations is also critical for NextGen. The workgroup defined what the scope of airport operations should be and determined that there are data sharing agreements that need to be put in place. To achieve success, a totally integrated approach to weather impacts across all airport stakeholders is needed. In the transitional stages, the valuation and migration of legacy systems must be taken into account.

The Trajectory Based Operations (TBO) group was by far the largest and necessitated 5 separate working groups. The results of each working group were examined for 'common threads' – issues of importance arrived via consensus by differing mixes of stakeholders within each group. Common themes emerged such as the need for better detail and understanding of the TBO 'boundaries' – between Capacity, Flow, Trajectory, and Separation Management. The operational use and integration of weather will be driven by the conduct of business and associated operational complexities within each of these TBO 'environments'. It is essential that the translation and integration of weather information and requirements for weather data for more effective four-dimensional trajectories must be developed around and within these boundaries. Stakeholders must be confident in the improvement in decision guidance with integrated weather – especially under disruptive weather events. Human factors challenges towards the use of TBO information with integrated weather and human-machine data interactions were also identified.

A major conclusion identified by the Super Density Operations (SDO) group was that weather integrated into various SDO (automated) solutions may be different by location – due to varying operational nuances in major terminal areas. Weather research initiatives for SDO must be an early NextGen priority to identify specific airport impacts (both today and in NextGen). This will address and migrate the highly deterministic non-weather integrated decision making of today into the more proactive decision making (weather integrated) paradigms of NextGen.

1 INTRODUCTION

A key capability of the Next Generation Air Transportation System (NextGen) is the assimilation or integration of weather information into operational decision making. When successful, this will dramatically change the way National Airspace System (NAS) decision makers use weather information by incorporating weather uncertainty into decision support tools. This concept is well documented into various JPDO documents: the NextGen Concept of Operations (ConOps) v2.0, the initial Integrated Work Plan, the Enterprise Architecture (EA) v2.0, and the Weather ConOps v1.0.

According to the ConOps for NextGen v2, Trajectory Based Operations, Super Density Operations and airport surface operations will be much more robust if weather impacts are reduced. Reducing weather impacts means an increase in the predictability, in space and time, of weather constraints that trigger operational changes (e.g., pilot deviation, flow restriction, flow configuration, arrival/departure/merging operations, ramp availability, etc.). The ConOps envisions that improved sensors and weather forecasting as well as the integration of weather into automated decision support tools (DST) will reduce the impact of weather constraints on NAS operations.

The foundation upon which successful weather integration can occur relies upon another critical component of the NextGen's goal: the need for stakeholder common situational awareness – of which weather is a part. Such a foundation must address the challenges of making network-enabled weather available to all users, how weather information will be accessed, and where industry can be involved in operating and populating the weather information. A key to common situational awareness and integrated weather is:

An operational focus towards the availability, integration, understanding, use, and consequences of weather.

It is important to first clarify the terminology of the previous statement. Specifically, *availability* means the right kinds of weather information (e.g., phenomena, detail, skill) in the right context and format (e.g., appropriate to the operation and intended user), in the right time frame (e.g., the end user or application has access to the information that allows for timely incorporation or assimilation in support of an operational decision). The term *integration* means that appropriate weather information is aligned in time, space, resolution (performance), and sensitivity to the construct with which it is integrated. The term *understanding* means that the end user can interpret or the application can realize what the weather information means in an operational context - either as a stand-alone decision point or as combined with other decision factors. The term *use* is different than understanding and means what an end user or application actually does or implements with the information that is perceived to add value to an operational decision. The term *consequence* means that there is a perceived risk to not using the information (an operational decision) that will lead to an inefficient or unsafe result (e.g., use of more fuel, increased time in the air, decrease in use/throughput of an airspace or route, increased risk of a potential safety hazard, etc.).

Precise understanding of these terms is crucial to laying the foundational groundwork that will bring NextGen concepts to fruition. By foundational groundwork we mean the policies that enable transition and change to achieve end state goals, research to push technology, simulations and demonstrations to prove operational concepts, planning and programming to expedite change through legacy agency cultures, and metrics of success to prove value to end users and stakeholders.

2 PLENARY SESSION

2.1 OVERVIEW

The JPDO sponsored a conference focusing on the integration of weather into the NextGen. The conference took place on February 12 and 13 at the National Transportation Safety Board Conference Center in Washington, DC. It provided a top-level review of the NextGen ConOps with a focus on Trajectory Based and Super Density Operations, and assimilating weather information into future decision-making tools and processes.

Approximately 200 participants from government, industry, and academia attended the event. The attendees separated into small work groups and discussed operational and technical actions that must be accomplished by the aviation and weather communities to ensure synchronized integration of weather information into operational decision-support tools. The recommendations made are envisioned to inform the transformational process of NextGen with regards to policy change, organizational innovation, research, and simulations and demonstrations.

2.2 HIGHLIGHTS

Mark Andrews, JPDO Weather Working Group Government Lead, welcomed the participants, thanked the various sponsors, and provided a workshop overview. Mr. Andrews informed the group that the conference results would be used as inputs towards the development of a National Plan to implement NextGen. Specifically, this workshop would introduce and discuss how weather information is integrated into air traffic and other NAS operations with the goal of reducing delays. He further emphasized that this 2-day session should be used for brainstorming to explore inside and outside of ‘the box’. For example, the translation of weather needs/impacts into operational needs may be counterintuitive! The bottom line, he concluded, was the need for good ideas as input to the Integrated Work Plan (IWP).

Charlie Leader, JPDO Director, re-iterated the NextGen vision and made clear that this workshop was not intended to be a weather research conference – but rather a forum to discuss how weather is to be used in the operation of a more successful air transportation system. He expressed two conference goals: to hear new and perhaps even controversial ideas, and to establish better stakeholder support.

Jim May, President and Chief Executive Officer of the Air Transport Association (ATA), made special mention in his opening comments that the ATA and Aircraft Owners and Pilots Association (AOPA), normally with opposing views due to distinct and differing constituency, are in full agreement with regard to the importance of this conference. Mr. May’s key points were that we need to apply our knowledge to the practical application of NextGen – or even “NowGen.”. From Mr. May’s perspective, NowGen refers to changes that major airlines, airports and associated vendors can make in the near term to improve situational awareness, ground operations, airport operations, and meaningful weather in the cockpit. One incentive, he added, is money - $1.5B annual costs due to weather delays. The integration of weather towards reduction of these costs is a very meaningful component of NextGen.

Phil Boyer, President of AOPA, contrasted his constituency with ATA. The AOPA ‘universe’ is very wide, he said, because General Aviation (GA) includes everything from the Piper Cub to the corporate jet. Because of this, affordability is the key (Note: affordability is important to ATA as well but to a lesser degree). There must be great value for these stakeholders in the form of improved collaborative decision making (CDM), access to airspace, and/or safety to drive equipage. Mr. Boyer noted that weather capability built into the panels of new GA aircraft is a huge selling point. Ease of after market installation was also noted as important. However, pilots are not meteorologists and require weather information (e.g., especially icing and convection) with little to no need for interpretation – and this needs to be from a flight deck perspective, not a ground or radar-based perspective. He ended with the assumption that the appropriate links to acquire the weather information in a timely fashion were already implemented. An issue for many in this stakeholder group is the on-going inconsistent or absent cockpit access to timely information.

Kirk Shaffer, the Federal Aviation Administrations (FAA) Associate Administrator for Airports, also emphasized the importance of the workshop. He noted that according to the National Plan of Integrated Airport Systems (NPIAS), over 3,000 airports will be funded with a $41.2 billion investment over the next several years. However, he noted that huge capacity issues remain and a decrease in delay of just 5 minutes is huge. Additionally, he made mention that the focus of weather improvements -- as best known today – was only on the identified airports and not system wide. By some measures a 20-25% improvement was envisioned. There is a need to go beyond improvements for each identified airport. Imagine, he continued, the improvements if there were system-wide weather integration across the NAS. He concluded that there is a great need to integrate weather information with expected surface improvements and to communicate that to the public and others.

Nick Sabatini, the FAA’s Associate Administrator for Aviation Safety, emphasized the need to predict, detect and share weather information in the right format to the right people. He emphasized the need to focus on aircraft-centric operations to provide guidance to pilots and serve as nodes on the network. This is consistent with the NextGen ConOps’ position that aircraft are collectors and disseminators of information. The receipt of timely, accurate, and easily-interpreted weather graphics on the flight deck is highly desired and necessary. This could mean, he continued, the same as weather on the ground but tailored for pilot use. He added that system-wide situational awareness is missing, and concluded his remarks by stating that there is a need for solutions that are technologically feasible and operationally realistic.

Jay Merkel, Chief Architect JPDO Enterprise Architecture and Engineering Division, provided more detail regarding various NextGen transformations. Mr. Merkel expressed that a key component to these transformations is the need to know what weather information is required across all timelines for air traffic management (ATM) decisions. He acknowledged that the Single Authoritative Source (SAS)/System Wide Information Management (SWIM) weather integration is severely lagging but the infrastructure is progressing.

Elizabeth Lynn Ray, Government Co-Chair of the JPDO Air Navigation Services Working Group, emphasized that the working group scope is outside of the aircraft in NextGen – and that weather is a big part of their focus. A key outcome of their group will be the production of a

JPDO Weather Integration Roadmap which will be a part of the National Plan. Specific sections of interest will be how to handle uncertainty, new procedures, and changes in culture.

Bill Leber, Chief Dispatcher for Northwest Airlines, reviewed the key findings of the Research, Engineering, and Development Advisory Committee (REDAC) Report. He emphasized the need for a risk management approach that is adaptive, incremental and can translate into ATC impacts. Mr. Leber emphasized that the enemy is uncertainty – we need to control that!

Ken Leonard, the FAA's Director of Aviation Weather Office, noted to the audience that this meeting was triggered, in part, due to those same REDAC recommendations. Mr. Leonard emphasized that it's not about the weather – it's about the use of weather in the system. We can't get fully there without a dissemination mechanism but having said that, he added, if we can just better distribute what we have today – we would gain efficiencies.

Vicki Cox, the FAA's Vice President of Air Traffic Operations Planning, made note of the Operational Evolution Partnership (OEP) – and the use of it to integrate all the parts of NextGen. Ms. Cox stated that the key aspect to achieving NextGen is to transform technology into actionable processes. Developing the technology is just not enough! This means it must integrate with procedures, design, etc., and combine with safety, certification, human factors, etc. She concluded that NASA will be a critical player in achieving this.

Karlin Toner, the National Aeronautics and Space Administration (NASA) Director of Airspace Systems Program Office, expressed their focus is on the need to look at the off-nominal situations for weather with a leveraging of key partnerships such as universities, industry, and government. A key aspect of this is the need for JPDO and NASA to effectively communicate where outside entities can provide value.

3 NEXTGEN WEATHER

3.1 INTRODUCTION

The NextGen Weather session's findings are broken out into several categories. The facilitators started the Network Enabled Weather sub-group session by providing overview presentations describing the roles of National Weather Service and the FAA, the 4-D Weather Cube and the output of the weather policy and functional requirements teams.

3.2 FINDINGS AND RECOMMENDATIONS

3.2.1 Policy Initiatives for NextGen Weather

Finding: The architectural design of the cube is not well defined.

Finding: It is not clear what the government/industry roles should be in operating and populating the cube.

Finding: The scope and content of the Single Authoritative Source (SAS) needs further refining. What data source/product is going to be used for the SAS at any particular time? The content needs to be driven by operational needs and specific automation needs, not the NextGen Weather team. Governance and policy models need to be determined and shared with industry.

During the session, many questions were fielded regarding the architectural design of the cube and the role of the SAS as compared to the 4-D Weather Cube. It was presented that the cube will be a distributed database with information located at many locations, but with metadata tagged to allow easy data discovery and subscription services.

A large discussion occurred regarding the potential role of the government and industry (both weather providers and system developers) in populating, operating, and accessing NextGen Weather. The discussion covered sensors, forecast products, interoperability, data access, and data integrity. Questions that need to be answered are:

1. What does the government intend to provide?
2. What does the government see as the fundamental service it will provide as a matter of aviation safety?
3. What is the government looking for private industry to provide? (What is paid for by the government and what is paid for by the user)?

It was stated that we need to make sure the various cubes will be able to access information regardless of location (by users and other cubes). Some government standards already exist and are in use in operational systems (e.g., Joint Metoc Brokered Language). The FAA, National Oceanic and Atmospheric Association (NOAA), and Department of Defense (DoD) are currently working together to demonstrate that we can share information and set the standards/catalogs/etc. for data-sharing. Using commercial standards is important, but the government must be flexible with respect to standards since commercial standards change. This flexibility is the key for long-term success. Another concern is how we transition to new standards for legacy systems (or do we)?

Industry needs to be engaged and understand the policy decisions the government will make regarding operations, so they can determine business models.

The scope of the 4-D cube and the SAS was discussed as well. At initial operational capability (IOC), the cube will cover the continental United States (CONUS) areas. At the end state it will be global (especially when you consider what Eurocontrol is planning with the Single European Sky Air Traffic Management Research Program (SESAR). Resolution scales will be different for CONUS, global, enroute and terminal areas based on users needs.

Recommendation: Develop an information paper that describes the SAS and 4-D cube and their relationship.

Recommendation: We need a team to focus on the scope and content of the SAS.

3.2.2 Research and Development for NextGen Weather

Finding: Some information systems can't get on the network and some networks have interoperability issues.

Finding: Some examples of information requested by users for airports are improved lightning detection and forecasts, and de-icing forecasts.

Finding: Examples of observations we can gather are icing information from Delta aircraft engines, and adding Event Data Recorder (EDR) sensors.

The concept of using probabilistic information needs to be further understood. A question that needs to be answered is how the NextGen system and future decision support tools will handle probabilistic information? For example, humans have a difficult time handling icing polygons with probability. We need to build DSTs that help the human understand the impact of the weather on the system. Also, a fundamental NextGen concept is machine-to-machine information sharing. This will require rigorous DSTs that account for individual business models and personal preferences. We need to identify the impact automation will have on the weather information in the SAS (i.e., man-to-man, machine-to-man, and machine-to-machine data requirements are different).

Recommendation: Encourage industry to participate in NextGen Weather IOC development team efforts to identify domain authority, standards, catalogs, ontologies, etc.

Recommendation: Work with non-federal organizations to identify how to incorporate their sensor information into the 4-D cube.

3.2.3 Simulations and Demonstrations of NextGen Weather

Finding: The challenge of making weather information available in the cockpit is the diversity of the users and weather products.

The communications method for transmitting weather information to aircraft has not been fully vetted. Automatic Dependent Surveillance-Broadcast (ADS-B) will provide some capability, but there is probably not enough band-width for weather information.

Various types of weather information (and how to gather the observations) desired by users was a topic of discussion.

Recommendation: The group recommends a demonstration to see if we can collect additional weather data from on-board and ground sensors and transfer it to government system(s) in a net-centric manner.

Recommendation: Have the NEO, Aircraft, and Weather Working Groups sponsor a team to identify options of how we get information into the cockpit.

- Commercial
- FIS-B
- Other frequencies
- Existing FCC regulation and policies are constricting options

3.2.4 Planning and Coordination for NextGen Weather

Finding: The definition/relationship of the SAS to the NextGen Weather 4-D cube are not well known to people outside the Weather Working Group.

Finding: Communication standards and techniques are inconsistent and lack integration. This will make it difficult to work across agencies and industry.

A large discussion occurred regarding what data would be in the cube versus in the SAS. The Weather Working Group established a functional requirements team to develop the initial list of weather information required for inclusion in the SAS. The product is in final review and will be released to industry in the near future for comment and feedback. Unfortunately, the team did not receive a large set of user input on future needs. We need to identify how we will proceed with building performance requirements.

Industry is concerned they will lose the opportunity to provide weather information to airlines, business aviation, and general aviation if the government provides the information for free. However, it was discussed that the government already provides weather information, just not detailed information into the cockpit. A market should still exist for value-added information beyond what the government provides.

How we get weather information (and what information we provide) into the cockpit was a topic of discussion. The award of the ADS-B contract that has a sub-contractor providing weather to the cockpit over Universal Access Transceivers (UATS) seems to go against the idea of a

NextGen common weather picture unless the ADS-B contract is updated to mandate the use of the SAS. There are various conceptual models that need to be addressed to determine how government and private sector service providers can provide information to users.

Recommendation: Develop an information paper that describes the SAS, 4-D cube and their relationship.

3.2.5 Performance Metrics for NextGen Weather

Finding: How do we ensure quality of data and quality of tools?
- Real-time verification of data
- Value-added of forecast and tools

Finding: How do we ensure the quality of the product from the SAS? How do we look at the quality of the DST's and determine if the picture is right and the quality of the product is right?

The reliability and availability of information were discussed. There are two types of reliability to consider: 1) data reliability and 2) operational reliability. The Weather Working Group has formed a team of subject matter experts (SMEs) to review the functional requirements document and identify some of the missing information in the document. The SME teams could also review how the reliability of the cube can be demonstrated to operational users.

Recommendation: Have weather SMEs review how the reliability of the cube can be demonstrated to operational users.

Recommendation: Task the Airport and Air Navigation Services Working Groups to set DST quality and reliability as they identify new tools that will be developed.

3.3 SUMMARY

The general consensus of the participants was network-enabled digital data is a key to success in NextGen. There are many areas that need to be addressed from a policy, operation, and data access perspective. Industry is prepared to join the government in identifying options to make NextGen Weather a reality.

4 AIRPORT OPERATIONS

4.1 INTRODUCTION

Airport operations may or may not involve aircraft in flight. However, they are still a critical aspect of NextGen which needs to be addressed. The Airport Operations breakout group identified and discussed a number of different issues. The group defined what the scope of airport operations should be, assumptions which would be held during the discussions, policy and organizational innovations needed, recommendations addressing research efforts, and general recommendations.

The first issue which the group felt needed to be addressed was that of scope. What exactly are airport operations? The answer to this would determine the domain in which the group's discussion would fall. This issue was discussed and a statement of scope that was eventually agreed upon was, "For All Wheels on the Ground." This meant that all operations, from the point when an aircraft lands to the point when an aircraft rotates, will be considered within the scope of discussion. It was also agreed that the end goal will be to get aircraft pushed from the gate on time as this will be the initiation of their trajectory.

The group then discussed how to proceed and it was agreed that there should be three operational impact categories. These categories were Winter Weather, Convection, and All Other Weather. A matrix for each of these categories would then be generated with different issues and proposed solutions. With the limited time allotted, the group was only able to address one of these categories, Winter Weather. During the discussions, it was decided that a number of different assumptions would need to be made. The first of these was that users would be able to access weather information easily and efficiently through the use of the fully functional 4-D cube. The group assumed that this NextGen functionality had already been established and appropriate communication improvements made. The second assumption was that the primary focus of the group's debates would be upon the movement of aircraft from the ramp to wheels up on the runway. It was determined that all other actions were in support of this.

It was also assumed that the group would not be considering within the discussions runway configuration or research into automated data linking. Runway configurations were determined to be within the realm of the Super Density group. This was tentatively determined through internal conversations and then finalized by conversations with the Super Density group. It was assumed that there would be no need to research automated data linking as this would already be in place and fully operational

4.2 FINDINGS AND RECOMMENDATIONS

4.2.1 Policy Initiatives for Airport Operations and Integrated Weather

During the discussions and debates, the group came up with some key policy and organizational recommendations. These recommendations were developed while building the Winter Weather matrix. Some of these recommendations were specific to winter weather alone and some were applicable along all areas.

Finding: Data sharing agreements need to be reviewed and updated.

The group recognized that users should all be viewing the same information in order to maximize efficiency and safety. In conjunction with this, information needs to be disseminated appropriately to users based upon their needs in order to prevent information overload. In order to fully realize this recommendation, it was agreed upon that data sharing agreements (Memoranda of Agreement (MOA), Memoranda of Understanding (MOU), Operational Agreements, and Service Contracts) needed to be reviewed and revised.

The need for increased data sharing and effective communications was stressed time and time again. This was seen as critically important by almost all members of the group. One of the potential impediments to this being achieved was the competitive nature of commercial airlines. Different airlines would not necessarily want to share their information with competitors regardless of the overall benefit to the NAS. This impediment was seen as a problem which would need to be addressed.

There also needs to be increased formalization of the coordination between Air Traffic Control, aircraft operators, and flight crew in order to generate a more accurate Estimated Time of Departure (ETD). More accurate ETDs would allow the system to operate with increased efficiency.

Finding: Weather impact on operations is most important.

The group discussed and agreed that more important than the weather information itself was the impact the weather would have upon users' operations. The users of weather information are not, and should not have to be, all meteorologists. To increase efficiency and safety, users should not have to determine themselves what the impact of weather will be. It should be provided for them.

Finding: Operational users are not involved effectively in the requirements process.

The requirements process spans from initial concept to deployment. Involving operational users throughout this process would insure that the researchers and developers have an accurate understanding of how their work would actually impact day to day operations. Additionally, the potential values of current legacy systems used by users today would need to be addressed as we move into the NextGen era.

Finding: More efficient operations necessitate changes in current regulation.

Recent research shows that the use of liquid water equivalent for icing accumulation is a much more effective and accurate method than current use of visibility. This is because drier snow can significantly reduce visibility just like snow which is moister. However, the two have a significant difference in their impact on icing and de-icing.

It was also agreed upon that weather observation practices need to be adjusted. The frequency of measurements needs to be updated to a minimum of once every 5 minutes and these measurements need to be taken closer to the runways than performed currently. The capability currently exists to receive measurements every 5 minutes and the change could be made with little additional cost or effort. Both the additional reports and the change of location would serve to increase the accuracy of information available for dissemination to the users.

Lastly, it was decided that airport weather service levels should be defined and standardized as much as possible. This would serve to decrease inefficiencies due to ambiguity. It would also increase efficiency by increasing overall user awareness.

Recommendation: Effective communication and information/data sharing, across all levels, is critical.

Recommendation: Weather information need to be translated into impact information specific to user needs.

Recommendation: Operational users need to be involved in the entire requirements process.

Recommendation: Use liquid equivalent water instead of visibility to determine deicing needs and holdover times.

4.2.2 Research and Development Efforts for Airport Operations and Integrated Weather

A number of different research areas were also discussed during the 2 day period. These research subjects covered a number of different topics. However, the focus of all discussions on research was in the category of Winter Weather.

Finding: Legacy system integration is very important.

The first research area to be discussed was on how to integrate the legacy systems. It was agreed upon by the group that the usefulness of each legacy system should be evaluated to determine if they should be carried forward into the NextGen era. The group agreed that there was no reason to spend resources developing new systems if the legacy systems would continue to meet requirements. However, legacy systems which were found to be inadequate would need to be retired and replaced.

Finding: Need for improved forecasts of runway conditions.

The next area of research which was agreed upon was the need for better sensing and runway condition forecasts. With improved forecast reliability and accuracy, operators would be able to better trust in the weather information they were given. This would then allow them to more efficiently plan around anticipated hazardous weather events.

Finding: Need to take into account an integrated approach to weather impacts on airport parking, terminal and ramp areas, surface maneuvering of all vehicles, as well as aircraft.

The third area of research to be discussed was that of the need for development of three weather matrices—one for each of the weather categories. A rough version of the first of these matrices, Winter Weather, was developed by the group over the 2 days. This document needs to be further refined and the other documents generated. Each matrix would list concerns of the airport separated into the following areas: Parking lot, Terminal, Ramp, Maneuvering, Aircraft, and All other ground vehicles. For each area, potential impacts/challenges would be listed and their solutions given.

Finding: De-icing activities need reduced costs and increased flexibility.

Continued research toward more efficient and environmentally-friendly anti/deicing methods/technologies was seen as highly beneficial by the group. An improvement toward more environmentally-friendly methods/technologies was seen as having the dual benefits of decreased costs and increased flexibility in usage. Increased efficiency of anti/deicing methods would also increase the efficiency of overall operations. Additionally, alternative delivery methods of both runway and aircraft deicing fluids were determined to be necessary avenues of research for the same reasons.

The group concluded that deicing by aircraft type would be advantageous in two primary ways. First, this would help to increase the safety of operations by maximizing the benefits gained. Second, this would help to reduce cost and economic impact by minimizing potential inefficient use of deicing fluids.

Finding: Advances in modeling is needed.

The final area of research which was discussed by the group was in the area of modeling. The group determined that research to develop a model which would provide a systematic way to coordinate planes to their release points would greatly increase efficiency and decrease workload on users. Additionally, the addition of probabilistic weather forecasts was seen as advantageous. This was because it allowed users to evaluate the elements of uncertainty as they incorporated the weather impact into their decisions.

Recommendation: Prioritize legacy system value according to NextGen requirements.

Recommendation: Address runway sensors that are non-representative of actual conditions. Improve runway forecasts' accuracy and reliability.

Recommendation: Develop and validate a requirements matrix to address user needs for weather as integrated with various surface movement operations.

Recommendation: Deicing should be standardized by aircraft type.

4.2.3 Simulations, Demonstrations, and Metrics for Airport Operations and Integrated Weather

Finding: Run simulations before demonstrations.

How simulations, demos, and metrics should be used was discussed as the group began to build a more fully defined idea of what was needed. It was decided that a simulation should be run before a demonstration was fully developed. This would help to point out initial flaws and save in overall costs. One of the members suggested that the Theory of Serious Games Initiative be utilized in developing the simulation. This would work to create a collaborative platform which would simulate decisions made in the real world and provide more meaningful results.

Finding: Demonstrate integrated weather at an Operational Evolution Plan (OEP) airport

For the demonstration, the group decided that it should take place at a major OEP airport. Chicago O'Hare Airport (ORD) was determined to be the best airport with which to test the Winter Weather categories due to its climatology. Demonstrations in part 91, part 135, and part 121 would then take place after ORD.

Finding: Derive and validate metrics from operational users

The metrics to use would be the ability to predict delta from scheduled departure time from the gate and off runway during weather impacted operations. It is important that additional metrics be both derived and validated from operational users to insure their accuracy and applicability.

Recommendation: Investigate use of the "Theory of Serious Games" for simulation development.

Recommendation: Demonstrate integrated weather for winter operations at ORD.

Recommendation: Determine metrics of value from operational personnel.

4.3 SUMMARY

In summary, airport operations are a critical aspect of NextGen which need to be addressed. The Airport Operations breakout group identified and discussed a number of different issues. The group defined what the scope of airport operations should be, assumptions which would be held during the discussions, policy and organizational innovations needed, recommendations addressing research efforts, and general recommendations.

5 TRAJECTORY BASED OPERATIONS

5.1 INTRODUCTION

Trajectory Based Operations (TBO) is a major change in the way air traffic is managed in the NextGen airspace. Based on the availability of digital data communications as well as ground to ground trajectory negotiations and cockpit automation, the uncertainty of aircraft position in time and space and their trajectory predictions can be reduced. Reductions in position uncertainty enable NAS users to more effectively maximize the capacity of increasingly congested airspace and/or conduct diverse operations, while maintaining safety.

Separation management (SM) is an element of TBO that is facilitated by the use of automation and shared trajectory information. SM allows NAS users and providers to manage separation between individual aircraft, manage separation between unique flows within airspace, manage separation from potentially hazardous weather, and manage separation from terrain.

Interestingly, the participants of the TBO breakout sessions did not focus on specific weather phenomena that can affect TBO (e.g., convection, icing, turbulence, etc.). The majority of the sub-group constituents were not meteorologists but rather government, airline and industry representatives. Thus, the focus was more operational in flavor and the issues raised were more relegated to use of weather information in an operational setting if it were made available and integrated with decision support tools. The consequences of its use also need to be understood.

5.2 FINDINGS AND RECOMMENDATIONS

5.2.1 Policy initiatives for Trajectory Based Operations

As indicated in the NextGen ConOps, the vision of enabling TBO depends heavily on reducing the impact of weather in 4-D Trajectory (4DT) calculations. The conferees were asked to consider policy changes that may affect TBO.

5.2.1.1 Global connectivity and collaboration

Finding: There is a need to synchronize with the international aviation community in establishing a weather data standard.

Since the International Civil Aviation Organization (ICAO) sets international aviation standards and practices, policy changes with respect to global connectivity and collaboration will necessarily involve ICAO standards. In order to enable seamless operations, ICAO weather data standards must be considered and appropriate steps toward establishing a compliant NextGen data framework. As the single authoritative source for weather is developed, interaction with ICAO must occur to set policy related to its content and use for domestic and foreign-based NextGen users. There must be a coordinated effort to synchronize with the international community with respect to standards and establish US policies and standards that are compliant.

Recommendation: Establish a weather data standard that is compliant with ICAO standards and use this standard in TBO.

5.2.1.2 Define phases of TBO and weather integration

Finding: Incremental transition to TBO should be well defined and include weather data integration at the outset to provide optimum benefit to NextGen users.

A clear roadmap of the incremental development and implementation of TBO and weather integration must occur. It must involve all stakeholders and clearly define their roles. The roadmap should essentially be a long-term commitment to fully integrate weather information into TBO. Incremental policy changes, or stages, must be incorporated into the roadmap as well as the associated regulations. Therefore, early in the development of TBO, a standard for weather information data must be decided. Focus innovation on the first couple stages of development. Another initial step is that we need to start integrating weather data into ATM decision support tools and any system that will be computing. This would assume everyone gets the tools they need and are trained in their use. Policies and procedures must be changed to direct personnel to use weather information in a standard way; this should be done prototypically first, and then expanded. Additionally, individual flight-based trajectories could help define 4DT and weather relations – pick specific aircraft in a certain sector(s) that can participate in a TBO program.

As TBO stages are planned, the concept of today's sectors will gradually disappear. Ensure there is a clear transition plan to enable this. Also, the pilot views today's flight as a series of negotiations. As TBO is better defined, opportunities for negotiation may diminish. However, weather re-negotiations will still change 4DT more frequently than, for example, deviation for special use airspace. Policy should follow the needs for re-negotiation. Operators, pilots and ATM providers need to be able to manage both traffic volumes and weather and they will need to overcome the biased view that they will be re-routed based on more complete weather information than they currently have available. System requirements for TBO that are weather integrated must allow for rapid updates, be flexible and able to re-negotiate. A related issue regarding TBO development is that choosing one 4DT model would enable researchers in all communities to proceed without delay toward TBO implementation. Consistent results from 4DT are required for TBO to work.

Recommendation: Bring stakeholders together early in the development of TBO implementation roadmap to ensure weather integration at the inception. Do not follow the path of treating weather as an "add-on" in later phases of TBO development, as this will delay or negate the value of a fully-integrated solution that assimilates weather information.

Recommendation: Establish policy that allows flexible trajectory re-negotiation as weather information is updated throughout the NAS.

5.2.1.3 Performance/Capability Based Policy

Finding: There is a need to establish policies that encourage NextGen users to incorporate capabilities that meet or exceed new performance-based standards.

Under the NextGen concept, the system is performance-based. TBO and weather only work together if there is a consistent, defined system performance goal and objective for all parties involved. This will involve policy changes that define performance capabilities for participants, including weather performance. Policy should be developed to encourage high performance equipage but be mindful of fiscal constraints of NextGen users. For example, an aircraft configured with high end weather capability could mitigate a gate hold. However, be considerate of user needs when developing performance/capabilities requirements. Aircraft owners will be reluctant to purchase any avionics to participate in NextGen unless there is a clear benefit and the equipage is affordable. Policy and procedures will need to be developed for mixed equipage and capabilities. Keep in mind that on board flight deck weather equipage and performance is closely related to safety.

There is a need for open system architecture for expansion. Allow for evolution of sensors aboard aircraft as a potential capability wedge into the NAS. Policy should be adaptive to system performance not known today yet account for users with mixed equipage. Governance will necessarily need to be designed to arbitrate conflicting requests. All users must be involved in governance discussions and policy formation. These discussions are crucial in establishing a common understanding among government and non-government stakeholders. Issues such as how users are able to collaborate with the system and other users to negotiate 4DT will form the underpinnings of new policy. There must be clear policy with respect to business-related decisions and safety-related decisions in the performance-based environment.

Recommendation: Develop an agency policy for user performance capabilities in parallel with policy that supports incentives across all stakeholders to meet or exceed performance standards.

Recommendation: Develop agency policy that is adaptive to system performance increases as equipage evolves.

5.2.1.4 Decision making capability using the SAS

Finding: <u>Critical to the success of NextGen is early adoption of policy that supports governance, funding and usage of the weather single authoritative source particularly in the development of TBO.</u>

There are numerous policy issues surrounding use of the SAS for decision making capability for TBO and the NextGen system in general. Policy needs to address how the SAS will be used, its precedence, and how other sources of weather information can or may be used in TBO. Will there be bias in the system favoring those who use the SAS and against those who do not? Will the airlines and other users be able to use some of their own forecasting tools? They will need to accede to accepting the single source where things involve other airspace users but may use their own tools for internal decisions concerning safety, risk assessment and performance goals Analogies exist with today's strategic planning process. Airlines may use in-house tools in some cases but could pay a penalty (delays, excess distance, non-optimal flight level) to meet internal goals within the context of an overall systemic approach to traffic management. SAS data accuracy, integrity, reliability, confidence, etc. must be addressed in policy and promulgated to all users. Data consistency will facilitate collaborative decision making. Users should also be a part of the discussions concerning any policy developed for the use of the SAS in NextGen since weather is an integral part of TBO. Also, who will fund the SAS? Ensure clear policy on contents, authority and funding. Funding is a potential two-way street; for instance, who pays for weather information going into the cockpit and who pays for the information emanating from the cockpit?

What are the components of the SAS? Where do they originate? Who can change them (who is the domain authority)? Will there be a centralized facility to hold this mass of data? Who will be the holder -- the FAA? NWS? Other? Or perhaps an inter-agency office? Currently there is no cohesive ownership of multiple weather systems. There should be redundancy with sources of the SAS. What are the authorized redundant sources and how are they prioritized? How do we handle weather information from individual aircraft (such as radar, inertial systems or vapor sensors) that are nodes in the system? How is the data from individual aircraft validated, initially and long-term? NextGen needs policy and guidelines as to how to construct a common picture from different platforms and in-situ reports. Consider data validation and sensor calibration, though it is important to consider system certification vice component by component. NWS has a similar problem today and could assist in calibration process development. Policy should support collection and dissemination from all users in the system. Does the SAS throw out some information that could be utilized by some users but not all? How are the components, such as Next Generation Radar (NEXRAD) for example, incorporated into the SAS? Is there a certification process associated with the SAS? Any decision support tools that use the SAS must be designed with a fundamental understanding of underlying policies. In determining 4DT, one portion of the SAS should be used for computations. How much information will be available to users in the SAS? How is training and human factors accounted for with users of the SAS? How does risk management play into the use of the SAS?

Concerning phases of SAS implementation, are there procedural changes that could be made to current information sources that would ease transition to SAS? How does dissemination of the SAS occur over time? Ensure that legacy systems (communications, such as Very High Frequency (VHF), Aircraft Communications Addressing and Reporting System (ACARS), etc.) capabilities are factored into any SAS dissemination roadmap. The SAS must be usable by all NextGen users who will be affected by performance-based capabilities. There could be SAS data classification, such as primary for convective weather information and secondary for moisture content. All users could receive primary information but secondary information could be made available at a premium. What would define primary and secondary information? In any case, timeliness of information is critical and will help system efficiency and responsiveness. Finally, related to research in the area of weather populating the SAS, research new technologies and methods of detection for translated weather hazards and impacts (hail, wind shear, severe turbulence) **–** not just surrogates like reflectivity.

By enabling the SAS for NextGen, the aviation community will be “singing off the same sheet of music” which will provide greater predictability, precision, and a common picture for TBO.

Recommendation: Support efforts (including funding) devoted to the development of the single authoritative source concept, implementation, human factors and governance to enable NextGen TBO.

5.2.1.5 Other/Policy changes

Finding: Existing policies are inadequate to support TBO, including a number of factors such as the use of probabilistic weather forecasts, conflict resolution and data sharing.

A number of other policy changes for integrating weather into TBO that likely have a research element associated with them must be considered. What rules need to change to use probabilistic weather? Also needed is the concept of operations and training to direct and guide users in how to use probabilistic weather. Is the machine better than human at probabilistic decision making? If so, or not, when is the machine used? Should research be aimed at providing ATM impacts directly to decision makers, minimizing the disparities in individual interpretations of weather products?

What takes precedence in what situations when the SAS and on-board sensors (or other sources) don't agree? Ground-based and airborne systems will most likely work together (but the final decision is likely to remain with the pilot in-charge). Ground provides longer-range strategic view; on-board systems – and visual observations – provide short-range tactical view. The two will be integrated into one decision regarding 4DT. Example: A pilot is considering deviation left of course based on what he sees on airborne radar. But Airline Operations Center (AOC) and ATC suggests right of course (more build-ups further ahead if deviating left of course; or traffic situation is worse). Details regarding trajectory management responsibilities of the flight crew, AOC and ATC must be delineated and adapted to phase of the trajectory. How can the pilot make a trajectory choice for the next leg of his trip while he is busy flying the present leg, or rolling down the runway for takeoff?

It was noted that the FAA has not retained its ATM data for research purposes (whereas NWS saves their data). We need to save and make available to Research and Development (R&D) community. Runway Visual Range data is being archived and can be used for work in TBO development.

Recommendation: Develop policy for the use of probabilistic weather as it pertains to decision support tools and NextGen system users.

Recommendation: Develop appropriate precedence and procedures to determine proper course of action an operator must make when conflicting weather information is presented.

Recommendation: Make ATM data available to the research community at large to facilitate research and development efforts supporting NextGen.

Recommendation: Find ways to test and implement new science and innovation into the NAS in an expedient manner to incorporate the latest technology.

5.2.1.6 Other/Organization changes

Finding: Traditional organizational structures must evolve to embrace new roles and responsibilities to implement NextGen concepts and realize benefits.

Some organizational changes are apparent that will need addressing as transition to NextGen occurs. An obvious strategic issue involves moving from sectors to “tubes”, SDO and TBO. Do controllers now follow flows or platoons of flight like dispatchers? What organization needs to change if we move to a “tube-based” control paradigm from sector control? Do sector boundaries change and become more dynamic under NextGen or are they eliminated? Under NextGen do sizes and shapes of sectors matter? It was noted that sector boundaries cause complexity. Does that mean doing away with all the limitations sectors host? What is the ideal state for airspace organization? Different business units (Terminal, En Route and Traffic Flow Management controllers) use the same information in different ways because of parochial needs and objectives. Goals and risks are different for each organization so approaches are different. Should there be a wholesale redesign of not only airspace but the business units themselves?

As weather moves from the “meteorologist to the machine”, where in the organization do we put the forecaster? At what point is the forecaster over the loop and where is that? How are forecaster’s interactions with the system accomplished and where are they made?

Recommendation: Carefully consider the affects of implementing NextGen concepts in terms of organizational changes. Identify “cross boundary” issues that affect more than one organization, and determine whether a new division of responsibilities is necessary prior to implementing NextGen concepts and systems.

Recommendation: Define a transition strategy, but do not perpetuate traditional organizational responsibilities and relationships unless they clearly benefit the governance and operation of NextGen.

5.2.1.7 Define the Safety Assessment for Certifying Weather Products to be Used in TBO

Finding: <u>There is a need to establish a certification or validation process for weather information that will be used in TBO.</u>

A major element of TBO is separation management that uses automation and shared trajectory information to better manage separation among aircraft, airspace, hazards such as weather, and terrain. Weather information used in TBO is likely to cause significant perturbations in the calculation of optimum 4DT solutions simply due to the ever changing nature of weather. Because of its effect on 4DT, weather information should be subject to a certification or validation process that includes a safety assessment to ensure reliable data is used and safety risk is mitigated to acceptable levels. Today, weather products are not the subject of such a process. However, there is recognition that weather information provided to the NextGen system and its users must conform to standards that are yet to be developed. The weather information used for TBO will originate from the common weather picture built from the SAS. This is a key priority in the weather community and an essential step in the initial development of 4DT inputs that are used for TBO. As a side note, in adverse weather management, pilots will likely retain the ability to tactically self-separate and deviate, an issue that is not fully addressed in the ConOps.

Recommendation: Develop a certification or validation process for weather information and forecasts used in the SAS that tests for reliability and recognized safety and traffic flow management conventions.

5.2.2 Research and Development Initiatives for Trajectory Based Operations

Within the context of an operational NextGen world in general and TBO in particular, several weather research issues were identified. These were perceived as essential towards the success of weather integration into TBO.

5.2.2.1 Human Factors

Finding: Human reaction, response and risk of product use that contain integrated weather must be examined.

Human factors analysis with regard to trust and use of weather integrated uncertainty information is important for all stakeholders to determine risk of accepting probabilistic weather forecasts for operational decision making. This can include just the display of weather alone. For example, as related to weather integration, there is an abundant supply of experimental graphical products that could be combined with flight deck or ground-based automation tools to determine the visual response to 3-D and 4-D representations.

However, operational use in general can be much broader and implies an integrated view of all operational elements. Risk of use extends to quantifying stakeholder confidence of automated guidance and/or risk management systems with integrated weather. Human factors research needs to take into account how to combine, fuse, present, and indicate alerts, etc. Data conflict resolution, data fusion algorithms, and reconciliation of model differences are also important.

Of particular interest is the reaction to weather forecasts that will affect a particular operation as well as reaction to forecasts that do not verify and the relative reluctance to use them again. This is separate and distinct from reaction and use of forecasts with probability.

Recommendation: Human factors research is needed to quantify the effects of inherent human conservatism and caution and the effect of inconsistent forecasting skill on operational decision making.

Recommendation: Conduct human factors research to understand how controllers will handle air traffic in a TBO world – specifically their reactions to weather that affects sector loading, controller workload, transition to dynamic sectors, and delegation of separation responsibilities to the flight deck.

Recommendation: Continue research to quantify predictions of pilot/controller actions when faced with current weather impacts.

Recommendation: Understand the human/machine interface role for each stakeholder including weather information integrated into a single display. Related research should eventually embrace the transition to complex technological systems designed for use with NextGen constructs.

5.2.2.2 Probabilistic Forecast Translation

Finding: Operationally relevant, risk quantifying, applications research that translates probabilistic forecasts into deterministic-with-options user and ATM solutions (e.g., impact assessment) is needed.

It was suggested that translations could use a scenario-based focus with a prioritized set of routes or alternates that each stakeholder can use depending on how the situation develops. An approach to this could be to reconstruct a past event and compare probabilistic forecasts with “perfect” forecasts to quantify levels of risk, trigger points, etc. All translations need to be operationally relevant and in terms that the automation tools can understand.

Research is needed in density management techniques so that probabilistic weather and traffic predictions can be adjusted for strategically to tailor a fit between tactical and strategic solution spaces in the face of weather driven uncertainty. This implies rapid modeling, and analysis of the trade space between tactical and strategic uncertainties and solutions. During periods of sustained weather impacts, agile trajectory negotiations will be required to fully leverage 4DT’s into 4-D User Preferred Trajectories (UPT’s) that meet stakeholders business needs, given reduced NAS throughput.

Quantifying risk is very important. Establishing an agreed-upon set of thresholds that are operationally based could be an effective approach. It was also felt that separation of the risk could be done in terms of space (forecast phenomena and location) and time (forecast time) to develop a set of ‘business rules’. Different stakeholders will need to understand the impacts of such risks and how to interact effectively with both tactical and strategic options.

Recommendation: There is a need for research into how forecast uncertainty can be ‘partitioned’ into spatial and temporal elements as a possible way to quantify and reduce risk and impact of uncertainty and forecast errors.

Recommendation: There is a need to determine who has the authority to take the risk and what are the allowed levels of action for both systemic approaches -- Traffic Management Initiative and individual trajectory negotiations (e.g., go/no go, red/green, or shades such as red/yellow/green, etc.).

Recommendation: A weather translation model could be developed to select different convective forecast and now-cast products and assess how they help achieve a more accurate airspace capacity estimate – separately and as an ensemble forecast. Additional research would be needed to determine how to validate and to determine the granularity (e.g., ARTCC/Sector/Flow/Airway/Gate/Fix).

Recommendation: There is a need for operationally relevant research that translates and integrates weather forecast probability into language (e.g., triggers or sliding scales or time smears, etc.) that can be used by ATM tools.

5.2.2.3 Weather Performance Quantification

Finding: There is an overall need to determine weather performance requirements/characteristics for all stakeholders and decision support tools.

Weather performance requirements extend to stand-alone weather information for the 4-D Cube/SAS as well as that which is obtained from the 4-D Cube/SAS and integrated into DST's.

Performance needs or characteristics such as accuracy, latency and resolution may not be the same for all stakeholders or all DST's. Such performance needs will be driven more by air traffic constructs in general and automated systems/trajectory generation constructs in particular - and not meteorological constructs.

It was unknown if the weather information available today was good enough for TBO. For example, it should be determined if the same sensors that are available today are sufficient for the model resolution needed to support trajectory prediction. If the wind information is not consistent with TBO needs then it should be determined how much the information should improve and delta value.

Stakeholders also perceived that in determining weather performance requirements, there may be a point of diminishing returns for further improvement - even if the science and technology of weather is or can be made available.

Additionally, it was assumed that weather performance needs change as TBO constructs change (specific airspace, specific TBO operation, day/night, congestion, on-board equipage, etc.) and that weather performance characteristics would need to adjust as appropriate.

Finally, there needs to be consistency and standardization across trajectory predictions. Obtaining weather information from the 4-D Cube/SAS will enable one such aspect of weather consistency.

Recommendation: There is a need to conduct applications research to identify and then match the performance of the weather information with user functional needs for TBO.

Recommendation: There is a need to conduct research that identifies the weather performance requirements for the entire environment in which TBO-based systems act (e.g., TBO performance changing triggers, how they change and by how much).

Recommendation: There is research needed to quantify how to develop higher fidelity and standardized trajectory predictions with lower fidelity weather (i.e., what is good enough weather for a trajectory prediction and how does such fidelity change from operation to operation).

Recommendation: There needs to be research conducted to determine if there are significant benefits (consistent with 5.2.6) in obtaining more accurate weather forecasts. There is a further need to identify tools, models (e.g., Numerical Weather Prediction), techniques, etc. that validate and measure the real or perceived improvements.

5.2.2.4 Weather Impacts on Aircraft in Achieving TBO Objectives

Finding: Need to quantify the effect of weather on the ability for aircraft to meet 'wheels off time' while still on the ground, to maintain a given trajectory, and to arrive at designated waypoints at expected points in time.

The ability for an aircraft to meet 'wheels off time' initiates a TBO construct. The continued ability of an aircraft or a flow of aircraft to maintain a given trajectory and/or arrive at designated waypoints at expected times are equally critical to successful TBO. Current weather, forecasted weather and its affect on aircraft performance will disrupt all these abilities. Equipage and unique agency ConOps will need to be taken into account.

Recommendation: There is a need to conduct TBO and weather research (e.g., time-based research) that overlaps with airport surface movement and weather research to understand and categorize wheels off departure/wheel on arrival times. This could be enhanced through the combined use of ground vehicles and aircraft sensors to determine position.

Recommendation: Research is needed to establish a set of agreed-upon thresholds that are not based on operations as described earlier, but based on aircraft performance and requirements for safe operation for weather phenomena such as icing for deicing, lightning for refueling, etc. Similar issues as previously identified emerge, such as what are the risk factors, who has authority to take the risk, levels of action (go/no/go) or can there be shades (red/yellow/green).

Recommendation: In the first (departure) or final (arrival) stages of TBO, research is needed to quantify the affects of weather on aircraft performance in 4DT SDO with regard to trajectory and arrival times in space and the ability to penetrate weather when there are the fewest options available for safe flight.

Recommendation: Research is needed to understand the capabilities of the aircraft with respect to weather factors to reduce the uncertainty of meeting TBO objectives. In the worst-case weather scenarios, research is needed to define airspace which cannot be accessed based on high weather impact phenomena.

Recommendation: In the (legacy) en route portion of TBO, research is needed to quantify the effects of aircraft trajectory performance based on convective (especially) and other (e.g., icing) weather characteristics. There is a need to know what aspects (echo tops, storm tops, cloud/visibility tops, turbulence, vertical impact altitudes, etc) most significantly affect aircraft performance from meeting time and space TBO objectives. There is a need to determine how much equipage and differing agency operations (civil vs. military) will play a role in meeting this objective.

5.2.2.5 Incremental Adaptive Flow Management Strategies

Finding: It is important to partition uncertainty over the entire trajectory.

For the NAS of today, flight plans are calculated and filed as a complete end-to-end trajectory. They are treated in a deterministic manner in their entirety (e.g., go/no go). However for

NextGen, in a similar way as first noted for risk in the probability forecast translation section (3.2.3.2), stakeholders felt it would be important to partition uncertainty over the entire trajectory. Stakeholders agreed that this approach is needed because forecast uncertainty will evolve (as does the weather) from the early portion of the trajectory to the later portion. Further, depending on other operational constraints and nuances, the risk of accepting or not accepting the forecasted information will also change. Taking such an adaptive and incremental approach will allow weather-influenced 4-D trajectories to begin as more realistic envelops of uncertainty that narrow to the required deterministic trajectories with time as weather impact uncertainty recedes and separation assurance requires containment and predictability in the trajectory.

Recommendation: Research is needed to identify how weather forecast uncertainty and associated operational risks change over the entire course of the trajectory.

5.2.2.6 Measure Real Weather Hazards to TBO

Finding: There is a need to conduct fundamental as well as applications measurement of real weather hazards in the context of TBO.

It was noted that these are important research endeavors because they will enhance stakeholder understanding of weather impacts on the safe and efficient conduct of flight. This refers to more than just convection and includes en route icing and turbulence as well as the effects of weather on the transition between TBO constructs as well as within the transition space between TBO and SDO.

Recommendation: There is a need to conduct fundamental weather research regarding specific weather phenomena, over specific areas, occurring or lasting over a range of times, and achieving and/or maintaining specific levels of magnitude that can impact TBO.

Recommendation: Applications research is additionally needed to identify important weather thresholds that trigger trajectory-based operation changes.

5.2.3 Simulations of Trajectory Based Operations with Integrated Weather

5.2.3.1 Human In and Over the Loop

Finding: The need for human factors simulations cannot be overstated.

Use of TBO creates new operational paradigms/challenges because these new operational philosophies and the potential impacts of weather (and its mitigation) are largely unknown. Human factors simulations regarding the use of integrated weather combined with TBO constructs are anticipated to provide value to illustrate changes in decision-maker workload, changes in collaborative decision making (CDM), and changes in the way that business is conducted in the most safe and efficient manner.

Information overload is very important. By identifying such boundaries, the ‘real’ (minimal) informational needs will emerge for a given situation. Validation of information integrity should be included in the simulations to further define minimal information need, how good it must be for a particular situation, quantified decision maker response given varying degrees of weather information integrity, and mitigation of operational uncertainties (e.g., pilot deviations, etc.)

Recommendation: CDM between all decision makers (pilots, dispatchers, controllers) needs to be simulated under varied weather conditions and varied TBO activities to quantify relative workload on each, quantify response differences/reactions, and to quantify the relative flexibility (or not) to combined operations/impacting weather scenarios.

Recommendation: Conduct simulations to explore information overload.

5.2.3.2 TBO Sensitivity to Weather

Finding: For weather integration to provide value to DST's supporting ATM in general, or TBO in particular, the weather information integrity must be aligned to the integrity of the functionality (DST components) or operation being performed.

This means that the data, as is required by the governing structure of the tool or operation, is available in appropriate timeframes, for appropriate spatial areas, contains appropriate resolution or accuracy that can be easily converted for use or weighing, and contains degrees of uncertainty that can be quantified (either as yes/no, a sliding scale feature, or other) for use with other decision objects/components.

For example, if a DST for TBO updates or provides trends for flow availability (e.g., a capacity value or range) every 5 minutes, the availability of weather information needed for the 'calculation' every 10 minutes will not allow the integrated weather to weigh appropriately on new TBO calculations (not granular enough). Moreover, if weather information is made available every 30 seconds, the value of nine additional weather updates before a TBO calculation change can be suspect. In summary, if TBO sensitivity to weather is not aligned, the effects of weather will be disproportionately weighted.

Recommendation: Simulations are needed to quantify TBO sensitivity to weather. This should include modeling or simulating the value of DST's over a range of weather fidelity or outcomes.

Recommendation: This also includes the simulation of weather probability translation upon TBO constructs (i.e., how each probability 'level' is translated and weighted within the DST components).

Recommendation: The value of the integrated weather needs to be simulated and measured in terms of the metrics highlighted in 5.2.6 or from a cost/benefit perspective. In this regard, the value of continued 'improvement' in weather information fidelity needs to be modeled against real or perceived 'improvement' in DST outputs.

5.2.3.3 Mixed Equipage

Finding: There is a need to understand the operational impacts to users in mixed equipage scenarios.

During any extended transition period it is anticipated that equipage and display standards – especially on the flight deck – will evolve as market forces, rulemaking, and real or perceived benefits are realized. This will mean that users between, and even within, specific user groups (Part 121, 135, 91, etc.) will have varying capabilities with regard to airspace access, improved flight deck guidance (with or without integrated weather), and other evolving benefits of new or enhanced operations. Simulations could take into account varying display prototypes as well as the simulation of CDM between decision makers. It is important to understand, in a mixed equipage mode, what is required to maintain or achieve optimal trajectory and the consequences of deviation.

Recommendation: Simulations of NAS users operating in a mixed equipage mode need to be conducted to determine consequences and relative sensitivity of continued mixed equipage towards achieving TBO objectives.

Recommendation: The cost/benefit of optimal or minimal equipage needs to be simulated.

5.2.3.4 Cost/Benefit Analysis of Forecasts

Finding: In a related effort to TBO sensitivity to weather, the benefits of any additional costs must be clear to each stakeholder.

Recommendation: There needs to be simulations performed that describe the cost to benefit of further improvements in weather products and forecasts beyond those so matched in informational integrity to TBO constructs. In this regard, there may be, for example, trending routines that could be designed that allow more frequent weather updates to be time-based averaged before integrating.

5.2.3.5 Simulate Performance Measures

Finding: Simulations should be designed to show *relative value* of weather integration against performance metrics important to different stakeholders (e.g., value will not be the same across all stakeholders).

Recommendation: Simulate value of integrated weather with TBO by simulating various NAS performance measures (e.g., route timing, fuel savings, operational options, etc.) to determine sensitivity to weather.

5.2.4 Demonstrations/Trials of Trajectory Based Operations with Integrated Weather

5.2.4.1 Transition and Integration

Finding: To ensure NextGen success, NAS operations must transition incrementally but with purpose (e.g., with a well-documented roadmap that illustrates defined goals, benefits and incentives) in order to meet anticipated air traffic demands and NextGen user needs. Transition must also be designed to prove conservation of services and more specifically, conservation of functionality.

A successful initial transition could be designed to only facilitate a change in *how* the service is provided. For example, weather information can be disseminated or accessed through net-centric means vs. point-to-point arrangements. Human interpretation of weather information and potential impacts can become human-in-the-loop or human-over-the-loop or eventually, translation, integration and interpretation by an automated tool. Using new dissemination or translation/integration paradigms as a foundation, new functionality, as driven by changes in requirements needed to meet pure NextGen concepts, can be designed and demonstrated. NextGen improvements will not be imagined until transition is addressed.

One way forward is to leverage recent experience to show a transition path. For TBO specifically, this could mean demonstrating the dissemination and access of weather information in the CONUS over ADS-B or ADS-B –like functionality.

In a similar way, an application of the Center Traffic Advisory Service (CTAS) called the Traffic Management Advisor (TMA) is a current DST that uses wind information to schedule arrivals to busy hub airports during peak traffic periods. If these kinds of operational constructs will still be value for TBO and the transition to Super Density operations, then possible demonstrations integrating convection or icing information could be incorporated to improve value. The access to different wind information sources (such as an ensemble of wind models) could facilitate an initial transition-like (NEO) functionality. Finally, a TMA prototype could be made to be more ‘NAS-wide’ instead of airport-specific.

A transition path or roadmap is very important to show incremental value and benefit. If there are specific timeframes and capabilities where perceived value and benefit to one or more NAS stakeholders are anticipated, then the transition paths need to be designed to each of these – even if such paths terminate long before final NextGen implementation (e.g., mid-term).

Recommendation: An approach to initial transition in general is to capture the experience of successful recent trials (e.g., ADS-B in Alaska) and extrapolate or leverage to achieve perceived NextGen benefits.

Recommendation: Regardless of the kinds of transition, there needs to be a well-defined transition path or roadmap.

5.2.4.2 Aspects of Convective Uncertainty

Finding: The overall degradation in the performance and stability of the NAS in recent years may, in part, be evidence that probabilistic approaches to ATM/Traffic Flow Management (TFM) are of high value to NextGen.

Today’s NAS is slowly taking away probabilistic approaches to TFM which actually have been effective in the past. Efforts by operators to file trajectories which avoid higher risk areas are presently thwarted by outdated HOST automation which ignores operator requested routes and forces them into weather the operator is trying to avoid. Recent studies by Lockheed Martin and other vendors suggest large scale reductions in the overall number of weather impacted flights are possible. Probabilistic approaches have enroute application but even greater application to the pre-departure phase of flight planning and are therefore quite important to AOC/Flight Operations Center (FOC) interactions with traffic management.

It has been suggested that a building block approach be used. This is meant to say to start with areas of low traffic density and then demonstrate convective uncertainty as traffic density increases and operational airspace operations become more complex.

Both tactical and strategic assessments are important. Tactical assessments via short-term weather phenomena predictions are important for separation management. It may not be possible in more strategic time horizons to model specific conflictions between specific flight trajectories and convective impacts. However, assessment of overall risk of further route impacts for a specific trajectory, through various traffic densities and forecast weather impacts could produce valuable risk models and planning information both for individual operators and the Air Traffic Service Provider (ATSP) in approving requested trajectories. Further the ATSP must maintain the stability and predictability of the overall NAS during predicted future NAS weather impacts. This approach would enable scenario-based risk assessment of various flow strategies by the ATSP such as time-based operations with metering constraints in en route airspace using convective uncertainty weighing (e.g., for flow corridor management or other more strategic TBO constructs).

Recommendation: There is a need to demonstrate both tactical and strategic use of probabilistic convective impacts under various levels of uncertainty.

Recommendation: There is a need to demonstrate the operational effectiveness of weather integrated DST's under various levels of uncertainty.

Recommendation: There is a need to demonstrate operational value (tactical) to using predicted convection locations rather than planning based on current convection locations.

Recommendation: For more strategic assessment, there is a need to demonstrate effective risk management both for strategic TFM approaches and at the individual flight or trajectory level.

Recommendation: In the spirit of leveraging from current operations, demonstrations could be designed to use existing systems and begin rolling in new 'numeric' systems for integration of convective uncertainty forecasting.

Recommendation: On-going research efforts at NASA - Ames and the United States Air Force's Air Mobility Command could be demonstrated for flight profile data to understand 4-D Weather Cube uncertainties.

5.2.4.3 Weather Data Exchange

Finding: <u>There is a need to identify pilot weather needs</u>.

Data overload and disparate weather interpretations must be avoided. Efficient data link or data links, transparent to the users is needed to exchange data between ground facilities, between the flight deck and the ground facilities and in more advanced NextGen constructs between flight decks.

Automation of dispatcher/controller/pilot/traffic manager actions to achieve the most operationally acceptable route between two points is very important for successful TBO. Un-forecasted weather impacts will occur and will be highly destabilizing to NAS predictability. There must be efficient and effective trajectory adjustments to mitigate its unexpected presence. However, for overall NAS stability this implies evaluation of multiple trajectory alternatives prior to penetration of known areas of potential weather impacts whenever possible so that adjustments to mitigate known risk areas are made efficiently and seamlessly.

Recommendation: There is a need to demonstrate automation of dispatcher/controller/pilot/traffic manager actions – especially to demonstrate the optimization of routing around a weather obstruction. This could be demonstrated using a variety of weather information to determine the most optimal set for final integration.

Recommendation: The effects of data overload are highlighted again and require demonstration. This also includes mental adjustments for the pilot as well as mental adjustments for decision makers on the ground.

Recommendation: There is a need to separately demonstrate then integrate the value of specific weather information – not just convection – as integrated into automated tools. The demonstrations need to be separate for each stakeholder – cockpit, AOC, ATC, etc.

5.2.4.4 Range of Weather Outcomes

Finding: <u>Similar weather scenarios can have vastly different impacts based on traffic, airspace use, operational complexity, etc.. The effects of impacting weather are envisioned to have similar differences for TBO.</u>

It is important to determine the sensitivity of TBO airspace ‘envelopes’ to increasingly impacting weather to determine trigger or decision points. Strategic outcome risk as driven by tactical constraints becomes additionally important. If such strategic risk can be avoided altogether, it is preferable to mitigating the effects of impacting weather in a more tactical sense. Traffic density must be considered along with uncertain weather impacts before entering into some tactical scenario. Fall-back or alternative operations need to be demonstrated for existing weather that is poorly forecasted (e.g., sudden changes in weather) and for un-forecasted weather. This is important for users to realize when and where trigger points are being approached.

Recommendation: There is a need to demonstrate a sufficient number of off-nominal (bad weather) scenarios to test the boundaries of NextGen system adaptability.

Recommendation: There needs to be demonstrations that incorporate scenario-based research initiatives to help quantify, in a more strategic way, the potential risks prior to entering into these more tactical scenarios.

Recommendations: Related to both tactical and strategic focus, there needs to be follow-on demonstrations to illustrate what kinds of safety nets (i.e., fall-back or alternative operations) are available when weather reaches such triggers (tactically) – or in a more strategic sense, at what point is the commitment made to continue a TBO given an availability of alternate (operational) options that will exist in the future.

Recommendation: There needs to be various demonstrations that highlight the relative effects of weather forecast errors with trajectory prediction studies. This could be performed using canned wind forecasts having increasing degrees of error.

5.2.4.5 4-D Cube Viability

Finding: Stakeholders identified the lack of a complete understanding of the 4-D Weather Cube and SAS.

The underlying issue here is that in theory and on paper the concept of the 4-D Weather Cube/SAS makes sense on many levels but it is an unknown quantity of value on real or perceived improvement in operations and decision making.

One key to 4-D/SAS success/value is to populate it with the kinds of weather information that the users/stakeholders will be able to do something with. This may mean, for example, objective measures of turbulence that are calibrated to aircraft, aircraft that are equipped to detect turbulence and act like informational nodes to 'fill in informational gaps', and then to be able to identify usable airspace (vs. where it is not good). A broader application would be the identification and a common picture of all good airspace.

Recommendation: There is a need to demonstrate the viability of the 4-D Weather Cube and SAS and to show the risks (costs/safety) associated with *not* having "NextGen Weather".

5.2.4.6 4DT Defined Objectives

Finding: There is a lack of definition of central objectives for each trajectory and each of these objectives must be demonstrated.

TBO demonstrations need clearly defined goals or objectives for each flight object in the NAS. Trajectory negotiations between the ATSP and the operators will largely consist of finding common ground between these two basic objectives.

Recommendation: Trajectories in the NAS should ultimately satisfy two objectives:

1. Separation from other trajectories by the minimum separation standard of the occupied airspace. Satisfaction of this objective is generally best defined by the ATSP.
2. The user preferred trajectory provides optimum cost and satisfaction of other operator defined objectives such as safety of flight, passenger comfort and emissions. These are generally objectives best defined by the system user.

5.2.5 Planning and Programming Support for TBO with Integrated Weather

Users of the NextGen system will necessarily have to support the system that is eventually designed and implemented. To date government and industry partners have taken great strides in developing a concept of operations and an initial integrated work plan that form the basis of a road map from the current system to tomorrow's vision. The Weather Working Group developed the concept of the common weather picture that will be implemented to facilitate the NextGen system. Conference participants were asked to consider what planning and programming must occur to use the common weather picture.

5.2.5.1 Transition Planning – all tied to incentives and buy-in

Finding: There is a need to develop clear transition plans between legacy systems and NextGen systems that incorporate stakeholder incentives and government commitment.

Transition plans for today's systems to tomorrow's should contain concrete, incremental milestones that work in short steps, perhaps as short as 2-4 years or longer term, 5-6 years. New technology insertion during transition must be embraced. Need standards and performance incentives to lead to advancement in the industry. Another extremely important aspect of transition planning is government commitment via investment. This provides industry incentive to develop products and services that will enable the NextGen vision. Commitment is needed even without 100% confidence that industry will build the widgets that provide benefits. Benefits and incentives are closely coupled and tied to specific user groups. JPDO influence should be at the program level for agency programs to coordinate and synchronize government-wide investment. Must move to portfolio management of budgets (cross-agency) to synchronize programs and align budgets for 4DT development with weather incorporated. NextGen goals need to be linked directly to intermediate agency goals. This will aid in budget planning processes and produce presentable results on investment in research, system development, technology deployment, etc.

Recommendation: Establish clear transition plans from today's systems to full NextGen system implementation using short-term periods.

Recommendation: Incorporate "hard" milestones for government system decisions related to investments to foster industry incentives to enable timely system benefits.

5.2.5.2 The 'System' is not the customer – Give industry and operators confidence that NextGen is user-centric.

Finding: User needs are preeminent in any design and implementation of the NextGen concepts and all communities of interest must be involved in the process.

There is a perception that the NextGen system is the most important concept to implement. Conference attendees from industry emphasized that there is a need to change the view to "user-centric" vice "system-centric". This involves understanding the various communities of interest, their needs and the benefits of implementing NextGen to solve their needs. We should re-evaluate what different participants in the system really need (different for controllers, pilots, supervisors). Benefits and incentives must be laid out for each stakeholder – one size does not fit all. Industry, GA, airlines, controllers, etc. must have confidence that NextGen is user-centric. A roadmap of specific benefits tied to government investment may help. Also, we have to show that jobs will become easier with NextGen, not just tell them to use different tools to handle greater capacity; show personal stakeholder benefit, not just system-wide benefit. To implement common weather picture and integrate into TBO, various operational service providers and business units need to collaborate, bringing personnel together from various perspectives on the TBO process under NextGen; bring together these varying views to improve the entire process from all angles. Additionally, we need to show what new tools will look like and train users in them so that they can gain confidence.

Recommendation: Adopt User Preferred Trajectory (UPT's) as a central objective of TBO to maintain a user-centric focus**.**

Recommendation: Conduct outreach programs with each user community of interest to solicit their specific needs and requirements. Describe specific benefits for each Community of Interest (COI) and a corresponding roadmap that lays out the actions to implement NextGen-related weather programs that enable those benefits.

5.2.5.3 Meet on-going weather service needs of users as building blocks to NextGen

Finding: Planning and programming should match user needs for weather services.

An important aspect of planning and programming is to prioritize actions based on on-going weather service needs of the users. For example, airport managers express concern that, under convective weather conditions, air traffic flow and TBO become chaotic. Is this problem handled in NextGen? Today's high priority weather issues for each user community of interest must be clearly addressed in the roadmap to implementing NextGen. As high priority issues are addressed and solutions implemented, they form the building blocks to NextGen. Use previous certification and successful program experience of recent systems as the initial steps in the planning process.

Recommendation: Develop a cross-cutting NextGen Weather service implementation roadmap that addresses the needs and requirements of each user community of interest.

5.2.5.4 Data standards for SAS

Finding: Weather data standards need to be established to enable NextGen concepts and form the basis for system standardization.

There must be a data standard for the SAS. The standard must conform to ICAO standards and must be backward compatible with legacy systems. This standard should be established in the near future and made widely available to the companies who are designing the systems to support NextGen. Associated with data standards is an understanding of the minimum data set requirements for each node of the system and from all users' perspectives. For example, what set of data is required for EFB users, for on-board processing, for controllers, etc.? Additionally, what will regulators accept in the way of data standards?

Recommendations: Develop the data specifications for weather information that will be used in the SAS at the soonest opportunity. Ensure it is ICAO compliant. Widely disseminate the standards once developed.

5.2.5.5 Process and procedures

Finding: A system that incorporates rapid, intelligent dissemination should be developed that informs all users of process or procedural changes to the system.

Processes and procedures for implementing any NextGen plan is different for any given user community or stakeholder. Two-way dialog with users and stakeholders is essential for effective planning. Pilot notification is critical when implementing a common weather picture. During a new process or procedure installment, an intelligent notification system that includes a read and acknowledge function would provide an excellent means to maintain a high level of user familiarity with the system.

Recommendation: Implement an intelligent pilot notification of system or operational changes that affect a user participating in NextGen.

5.2.5.6 Other

Other comments related to the planning and programming of systems for NextGen and the implementation of the common weather picture.

- Develop a Controller Workstation of the Future
    - Should be funded and supported similar to the way User Request Evaluation Tool (URET) was done in Indianapolis
    - Release it and get some visibility so that users and other interested parties can begin to become familiar with the resulting changes in a way that’s visible and tangible
- There must be a transition plan from the current sector system to the NextGen “seamless control system”.
- The Integrated Work Plan (IWP) contains lots of R&D but is weak on system engineering.

5.2.6 Performance Metrics for Trajectory Based Operations with Integrated Weather

An important element of NextGen design and associated operations, including TBO, is metrics. Metrics are measurements that characterize various aspects of the NAS, the operations therein and the factors affecting those operations, including weather. During the design, implementation and maintenance of NextGen, there will be a need to determine if various elements have an affect on overall operations and performance within the NAS. TBO will assimilate weather into its dynamic decision-making tools which will have a direct effect on the efficiency of operations in the NAS. Currently the aviation community uses several metrics such as delays, fuel burn and throughput to measure the effects of weather either directly or indirectly. Metrics also provide important feedback that is essential in refining any weather-related system, product, etc that is used to make the system more efficient. Conference attendees were asked to visit the question of metrics with respect to weather to assist in evaluating different solutions for TBO.

5.2.6.1 ATM and other NAS user relevant verification metrics for weather (vice meteorological)

Finding: There is a need to develop a metric that measures the quality of weather information provided to a DST in terms of tool performance.

A critical set of metrics for the weather community will involve those that provide continuous feedback on weather information provided to NAS users by the weather cube and the performance of decision support tools that use weather information. TBO will optimize 4DT contracts based on many inputs including weather. However, the metrics must focus on user performance and performance of the DST's, not the meteorology that goes into the weather information.

TBO will necessarily involve the evaluation of user performance to optimize the system. With respect to the user, what is the number of cancellations due to inaccurate weather information? Metrics quantify if weather data meets performance requirements. There should be metrics for the number of weather-related incidents (possibly use existing airlines in-house safety reporting systems as the basis). When developing metrics used to measure user performance, ensure that user's sensitivity with respect to their competitive concerns are taken into account. For example, one idea was to evaluate the use of schedule pad by airlines as way to evaluate the reaction of the user on improved NAS performance. Also, performance metrics vary among stakeholders. Involve the stakeholders in any metrics development. Selecting the right system-wide metrics will also facilitate competition that will lead to improved overall system performance.

With respect to system tools such as decision support tools that use weather information, particularly the 4DT generator, metrics must be developed to provide the means to evaluate predicted performance and weather input against the actual performance and weather. Some ideas were discussed, such as ATM relevant weather forecast verification metrics or a verification loop that continually asks, is it the right weather? One comment was to base line the efficacy of using weather in today's NAS in order to proceed into developing weather metrics. This will help compare progress as an implementation plan proceeds toward the NextGen goals.

Recommendation: Establish weather information performance criteria for the decision support tools that use the information and develop associated metrics to measure support tool performance.

5.2.6.2 Route Time Performance

Finding: There is a need to develop route time performance metrics to measure user performance.

Use a schedule-based metric that compares proposed or scheduled times to actual times. This is a big picture metric for the airlines. Block time reductions for city pairs could also be used. Route deviations due to weather should be measured with respect to timing to provide feedback on tools that account for weather. A metric that measures the difference between filed flight plan and actual flight time could also provide feedback on weather information accuracy where weather is determined to contribute to the difference.

Recommendation: Establish a route timing metric that measures scheduled timing versus actual and incorporates weather inputs.

5.2.6.3 Fuel Savings/Use/Economy

Finding: Fuel consumption metrics will continue to measure system efficiency and help establish cost/benefit analyses.

A common metric used by the industry today that is directly tied to the profitability of commercial operations and minimizing costs of all aircraft operations is fuel usage. Discussions revalidated the use of financial-based metrics that included fuel economy.

Recommendation: Establish a fuel usage metric that measures predicted fuel usage with actual.

Recommendation: Measure the difference between the actual fuel consumed and the planned fuel use of the 4-D UPT.

5.2.6.4 Measurable Capability Standards

Finding: There is a need to establish metrics that measure user weather capability versus actual performance to continually refine 4DT algorithms.

Currently aircraft file flight plans that include their navigation capability. In TBO, developing and negotiating a 4DT will certainly involve more resolution of aircraft capability including weather capability to determine the contract trajectory. It may be beneficial to develop capability standards with respect to weather. In turn, metrics could be developed to measure aircraft capability in relation to weather phenomena, thus providing data to analyze how to refine and design better 4DT weather algorithms. Also, having measurable capability standards would allow any manufacturer to build to the standards and provide incentive to those who can meet or exceed the standards faster/better/cheaper.

Recommendation: Establish a metric that measures the aircraft weather capability versus its performance with respect to assigned trajectory.

5.2.6.5 Re-Maneuver Rates/Flown as Originally Filed

Finding: Establishing a metric to measure 4DT contract re-negotiations and actual weather encountered during the flight will provide valuable insight into system efficiency.

As an aircraft encounters weather that causes the pilot to deviate from the original 4DT contract (i.e. flight plan), a metric should be developed that measures the number of “re-maneuvers” or contract re-negotiations. This would provide feedback on the accuracy of weather information used in 4DT calculations or the specific algorithms used to perform the calculations. It may also provide an indication of other factors besides weather that impact TBO and could help identify areas of additional “workload” in the system that need attention. Since 4DT will change for a number of factors besides weather, a complementary metric should measure the number of re-negotiations that are based on non-weather causes.

Recommendation: Develop metric(s) that measure the number of 4DT contract re-negotiations and accounts for unforeseen weather encountered by the pilot.

5.2.6.6 Predictability (hitting flight plan points)

Finding: <u>A metric that would provide continuous feedback on user trajectory compliance would enable a more predictable system.</u>

Predictability is closely related to route timing discussed above. There may be interim steps in fully implementing 4DT that call out specific points in the flight plan that must be hit at given times. For example, “enroute” predictability may be easier to plan than gate time predictability at the terminal end. Develop metrics to measure 4DT predictability from gate to gate, such as a “trajectory compliance index”. These metrics could serve as a performance feedback mechanism to users and to the ANS algorithms developers (or the learning machine itself) to continually tweak the system based on user performance trends. In designing this metric, care must be taken to account for intervening weather, another use of the metric that would be used to develop better weather assimilation into DSTs.

The metric should be cognizant of the adaptive nature of TBO. It may not be critical to know with precision the exact time over the arrival gateway fix an hour prior to departure. However, once enroute and 30 minutes from the fix, far greater certainty will be required.

Recommendation: Incrementally phase in metrics that measure the “predictability” of users to comply with assigned trajectory, such as a trajectory compliance index.

5.2.6.7 Delay Reduction Quantification

Finding: <u>There is a benefit to establishing and maintaining quantifiable, clear factors in metrics that measure avoidable or unavoidable delays.</u>

Delays are a common metric used today to indicate systemic and other problems with the air traffic system. Delays cause more fuel costs, higher emissions, higher crew costs, “ripple effect” through the NAS, incalculable loss of productivity of business community, etc. Better definition of delay parameters are necessary to differentiate those that are “avoidable” and those that are not. An obvious example of an unavoidable delay is when a thunderstorm rolls over an airport or the final approach to a runway. However, when the same thunderstorm is observed or forecast by the weather community, the chain of events precipitated before, during and after the incident constitutes many of today’s avoidable delays and is of primary importance in TBO.

Standardizing the methods to quantify and estimate delays will refine delay metrics and help identify associated problems, such as the need to adjust weather information inputs to TBO decision making. Delay metrics must be normalized for increased traffic demand and system enhancements such as new runways. Delay parameters may include whether the pilot was equipped with EFB or not, aircraft equipage, etc. as possible measures of weather information effectiveness and in differentiating between avoidable and unavoidable delays.

Recommendation: Establish a set of delay parameters and develop corresponding delay metrics that quantify delays as either avoidable or unavoidable.

5.2.6.8 Throughput of a specific area/"Real Rates" (Airport Arrival Rate (AAR), measure of route/airspace permeability)

Finding: There is a need to establish an airspace permeability metric that measures the predicted versus actual throughput in terms of weather forecast.

The weather community observes and forecasts meteorological conditions throughout the NAS that affect airspace "permeability" which is made available to airspace users. Throughput is a measure of the number of aircraft through certain area or point over a defined time period and is used today. TBO will rely heavily on permeability as one of the factors that affect the optimum throughput of a given airspace. To increase throughput of volumes of airspace in the NAS, TBO must account for weather to better understand and predict where traffic flow may go. For example, during periods of convective activity, particularly when there is a line of thunderstorms or a point of thunderstorm activity in the vicinity of metroplex airspace, dynamic TBO that assimilates weather information will optimize aircraft routing. Throughput will continue to be an important metric particularly with weather information assimilated into 4DT algorithms.

Recommendation: Develop a metric that measures the predicted permeability of airspace and the actual permeability and throughput.

5.2.6.9 Equipage

Finding: A metric that measures aircraft equipage versus performance would be valuable in optimizing the NextGen system, particularly with weather capabilities.

Aircraft equipage and its associated capability as related to weather is an important factor in the NextGen performance-based system. Delay reduction is one possible benefit of aircraft equipage. Aircraft equipage metrics may help systems designers to better understand the relationships between equipment installed and overall system capability. Some considerations might be:

- Identification of alternative approaches to equipage in order to weigh relative costs and benefits (e.g. self-separation capabilities through equipage versus ground-based separation)
    - Percent of aircraft equipped with weather systems and the type of systems
    - Until we have 100% of the system equipped, we will be accommodating the unequipped (affecting efficiency)

- Correlate equipage to other metrics (identify specific NextGen benefits linked to equipage and show metrics that track to that benefit).

Key to any standards involving equipage is a thorough understanding of the impact to all NextGen users/stakeholders in terms of access to the NAS and various subsets thereof. Equipage has the potential to contribute to safety, such as turbulence and storm avoidance, and provide incentives to improve designs and system efficiency. Historically, it has also been demonstrated that equipage has the potential to add enormous costs to operators without proportional benefits. Also, it is important to the aviation industry that once the government is committed to an equipage standard that it remains committed. The industry can accept minor tweaks but not wholesale concept drops or redirections. Finally, equipage should be mandated in gradual increments corresponding linearly to the density of operations expected to be encountered.

Recommendation: Establish aircraft equipage metrics that help evaluate system efficiency with respect to user weather capability.

5.2.6.10 Other

A number of other metrics were discussed that do not necessarily fit the discussions above but are important to consider.

- While not specifically linked to weather, all NextGen program implementations must consider safety. Safety in the NAS is a top consideration and must not be compromised to try to gain any efficiency.
- Quantify the airlines' use of additional personnel as a metric of NAS performance.
- Metrics should be specific to NAS users and providers.
- Metrics should change to new technology. Disruptive technology can raise the "bar".
- GA metrics are NOT the same! ATM metrics are NOT the same!
- Is there a place for both national and regional metrics?
- Should there be combined NAS-wide metrics such as Operational Response Index (average cost per flight of system-wide delays, excess miles flown, cancellations and diversions)?
- Remove personalities from the CDM process and move to system performance-based metrics.

5.3 SUMMARY

Trajectory Based Operations is a cornerstone of the NextGen concept and fundamental to its success. It cannot be effectively defined outside the context of the medium through which it is conducted, that is, the atmosphere and its weather. Further, TBO cannot be effectively addressed by itself, outside of the fully integrated NextGen ConOps, across various ATM decisions points in time. It is imperative that detailed and integrated definitions of the boundaries of Capacity Management, Flow Contingency Management, Trajectory Management, and Separation Management be more fully explored.

The conference drew out input from all quarters of the aviation community and found:

- There are technical, policies, organizational and human factors challenges to achieving TBO. Technical include translation of weather information and requirements for weather data for 4DT.
- Policy issues include global harmonization, satisfaction of diverse stakeholder interests, and performance based services.
- Organizational include the support of the SAS and roles and responsibilities of various decision makers such as controllers, pilots and meteorologists.
- Human factors challenges include how to use TBO information and human-machine data interaction in the context of weather impacted operations.

Weather Integration across the entirety of TBO presents an enormous challenge but also an imperative. If NextGen is to satisfy the traveling public’s need it must vastly outperform today’s NAS even under disruptive weather impacts.

6 SUPER DENSITY OPERATIONS

6.1 INTRODUCTION

The SDO session included SMEs from the following communities: government, industry, R&D, user (airlines and pilots), service provider, academic, and international aviation. The participants discussed NextGen SDO from many perspectives including: policy, research, simulations, demonstrations, planning, and metrics. The discussion was open and energetic, and provided a number of findings and recommendations that should be of great value for integrating weather information into SDO automation.

The following sections include the SDO session's findings, recommendations, and a brief summary.

6.2 FINDINGS AND RECOMMENDATIONS

6.2.1 Policy Initiatives for Super Density Operations and Integrated Weather

Session participants briefly discussed several policy issues, all of which exist without weather, but are exacerbated by it.

Finding: Existing SDO separation standards need to be reviewed in light of NextGen Weather integration (as well as other non-weather) capabilities.

In a NextGen automated environment, where risk is managed, separation standards may need to be modified. Separation standard analysis needs to be conducted and should also include:

- NextGen Metroplex operations,
- Transfer of separation responsibility to the cockpit in IFR, and
- Optimization of runway usage on intersecting runways.

Finding: Weather information to the flight deck is critical to SDO. How can this be accomplished sooner?

The ADS-B 'IN' timeline may need to be accelerated, if we are going to more fully realize NextGen benefits, including weather integration; 80% equipage by 2035 will not get us to NextGen in 2025. Are there alternatives? For example, if airlines can provide internet to passengers in the cabin, why cannot NextGen Weather be provided to the flight deck?

Finding: Analysis is needed to support a policy decision on how safety-related aircraft observations, passed directly from aircraft to aircraft, will be quality controlled.

The National Center for Environmental Prediction (NCEP) is currently tasked with performing quality control of aircraft weather reports. NCEP performs this function using a ground-based system. In the NextGen timeframe, safety related aircraft observations will be communicated directly from aircraft to aircraft. How will these reports be quality controlled? Will the airlines take responsibility for this limited quality control function and perform it at the source (i.e., on-board the aircraft), or is there a methodology whereby NCEP will remotely quality control these reports (e.g., uplink how an aircraft's weather sensors have operated over the preceding few minutes, assuming its current measurements are directly correlated)?

Finding: Analysis is needed to determine SDO staffing requirements in the NextGen timeframe.

What are the SDO staffing requirements needed to support NextGen? Do SDO personnel require more strategic, risk-based operational training and experience? Does NextGen involve a significant cultural shift for SDO?

Recommendation: Re-examine the ADS-B 'IN' timeline; it may need to be accelerated if we are going to more fully realize NextGen benefits, including NextGen Weather integration, by 2025.

6.2.2 Research and Development Initiatives for SDO and Integrated Weather

Finding: NextGen Weather-SDO integration should give priority to convection (i.e., thunderstorms) over other types of weather.

The participants of the SDO session briefly discussed the types of weather that significantly impact SDO, indicated which of these should be given NextGen priority, and (from an SME perspective) identified weather integration functional requirements and R&D needs.

Hazardous weather, such as convection, causes the most significant impact to SDO. Unanticipated pop-up storms and forecasted events that do not materialize cause significant impact, along with storms that can be well forecasted.

Assuming the New York Metropolitan area is an SDO, seemingly minor weather impacts can have far reaching capacity and delay implications. Because of the close proximity of numerous airports, which are near or at capacity, the New York area airspace is highly structured. On a macro scale, there are over 50 arrival and departure routes serving Kennedy (JFK), LaGuardia (LGA), Newark (EWR), Teterboro (TEB), and numerous other airports. In this environment, a single pop-up thunderstorm (which could easily be avoided in most areas of the NAS) can cause significant disruption to the normal flow of traffic. Conversely, when convective weather is forecast and does not materialize capacity is underutilized and cannot be recaptured at a later time.

Finding: NextGen Weather-SDO integration research should consider strategic decision making during off-nominal operations.

At times, when severe convective weather makes standard operations impossible, it is not always clear what are the costs and benefits of alternate control schemes. For example, it is not always clear how to best route an aircraft whose preferred route is blocked by storm activity. On a larger scale, it is not always clear when and how to best increase operations in the aftermath of severe weather. In order to increase safety and efficiency, it is important to study the implications of decisions made during off-nominal conditions, particularly in SDO airspace.

Finding: NextGen Weather needs to provide wind observations along descent approaches to support SDO, and analysis needs to be conducted to determine the performance requirements of these wind observations.

Strong winds, combined with wind shear between vertical layers, lead to trajectory complexity that limits the ability of human controllers to maintain SDO. In order to address the super density compression problems resulting from these wind conditions, controllers need automation assistance. This automation will require accurate and timely wind observations along descent approaches.

Finding: Calm wind conditions can increase runway occupancy time, negatively impacting SDO.

In other weather conditions, a lack of wind velocity (calm wind conditions) can increase runway occupancy time and be considered “off-nominal” based on the lack of wind. Airport surface weather and weather conditions on approach and departure trajectories need to be considered together to maximize the efficient utilization of both airports and airspace. Proper spacing and sequencing of traffic relies on accurate detection, measurement, analysis, interpretation, and implementation of mitigation strategies that closes the gap on nominal operations.

Recommendations: Perform analysis/research to determine SDO weather and weather translation requirements for NextGen; near-term efforts should include:

- **a.** Analyze all NextGen SDO operational improvements to see how weather impacts them,
- **b.** Analyze sensitivity of NextGen SDO procedures and decision support tools to winds aloft in order to establish weather observation and forecast requirements,
- **c.** Determine how SDO differ with location (e.g., major airports, Metroplexes) in order to better understand their unique NextGen requirements.

Recommendation: Send weather integration researchers into the field to learn current deterministic SDO strategies, so that they are better able to develop more strategic SDO weather integration concepts/capabilities.

6.2.3 Simulations and Demonstrations for Super Density Operations and Integrated Weather

Finding: For SDO, there should be an appropriate balance of emphasis between information regarding delay-creating severe weather and weather information used to support capacity-increasing NextGen capabilities during standard operations.

SDO session participants also discussed requirements for weather information required by SDO during ‘fair weather’ conditions. Often the emphasis of stakeholder discussions is on delay-creating severe weather, but participants of the SDO session also stressed the importance of focusing on weather information needs associated with capacity-increasing NextGen capabilities. Session participants suggested Required Navigation Performance (RNP) as a possible method of obtaining more capacity in fair weather areas, to compensate for reduced capacity in weather-impacted areas.

Finding: Analysis needs to be conducted to determine the performance requirements for weather information supporting capacity-increasing NextGen capabilities.

During "nominal" days, weather information is needed to support SDO automated capabilities (e.g., merging and spacing, Continuous Decent Approaches (CDA), wake vortex procedures, runway configuration management). For example, metering and wake vortex avoidance are anticipated to create high temporal and spatial wind observation and reporting requirements. These and other SDO routine weather requirements need to be determined.

Finding: Analysis is needed to determine how to meet SDO weather observation requirements (e.g., ground-based observation systems, aircraft reports, combination of both).

Further, agency implementers need to determine how best to meet these requirements (e.g., ground-based observation systems, aircraft reports, a combination of both).

Finding: Explore multiple solutions for controlling/optimizing real-time weather observations in support of SDO, including but not limited to, ground-based control and sensor systems acting independently as intelligent systems.

The rate at which observations are made and reported may need to be optimized in real-time to reduce cost while meeting SDO needs. In general, the current weather observation model is to obtain an ever increasing number of observations (assuming that more is better), but what will NextGen actually need and how will the need change with changing operations and weather conditions? The current NextGen concept suggests a ground-based (via NextGen Weather) dynamic sensor control solution, an alternative may be individual sensors, acting as intelligent agents, independently assessing the need for observations and acting accordingly.

Finding: Analysis is needed to resolve questions related to the role of humans in highly automated SDO.

SDO session participants asked a number of questions related to this topic including:

- How is control switched back to human for safety-related situations?
- When is human interaction not feasible?
- How can humans train and re-optimize the automation to deal with past weather experience (i.e., lessons learned)?
- In the SDO domain, who is the decision maker for weather-related TBO changes: pilot, dispatcher, service provider, automation?

Recommendation: Establish a mechanism to solve SDO problems (through joint community involvement). This could include the use of integration laboratories (to include weather integration) and computer simulations to better understand the problems we need to address in implementing NextGen.

6.2.4 Planning and Coordination for Super Density Operations and Integrated Weather

Finding: The sharing of in-flight weather observations during SDO would be beneficial for efficiency and safety and could be enabled through performance-based requirements.

To enhance SDO efficiency, as well as flight safety, aircraft observations should be shared between neighboring/following aircraft. For example, flight safety could be increased by sharing wind shear data (e.g., microburst detection) and SDO efficiency could be enhanced by providing highly-accurate spacing and sequencing information for successive or interacting arrivals and departures. Inter-airline sharing of weather observations, for the purposes just described, could be enabled through performance-based requirements.

Finding: Any exploration of NextGen Weather requirements needs careful analysis of SDO weather requirements, because they may be more stringent than those for TFM and en route operations.

Weather information requirements for SDO concepts may be more stringent/ different than those required for NextGen traffic flow and en route operations (e.g., high grid resolution wind vectors, eddy dissipation rate). SDO may require higher resolution information from NextGen Weather (i.e., 4-D Weather Cube) for the terminal area. Solving the SDO-weather integration problem is essential to ensuring a vibrant air transportation system for the future. It is unlikely that generic weather systems will address SDO. However, all aspects of NAS operation can benefit from SDO solution sets.

Finding: SDO weather requirements need to be directly tied to decisions that need to be made (e.g., specifically where can operations take place), rather than the normal methods of presenting weather information (e.g., specifying where weather is likely to occur).

For strategic SDO-weather integration, it is important to ask the right questions. For example, rather than being provided with the probability of a line of convective weather, what is needed is the probability that the line is porous enough to allow flights to pass between cells.

Finding: When assessing how to reduce the impact of weather for SDO, one should explore many possible solutions, including but not limited to infrastructure investments

SDO session participants briefly discussed how investments in non-weather related areas such as infrastructure (intended to assure operational reliability and predictability) may also help us to better work around weather constraints (e.g., surface flexibility, so one aircraft impacted by weather does not block departures).

Recommendation: Explore whether infrastructure investment intended to assure operational reliability and predictability could also help reduce the impact of weather (e.g., surface flexibility, so one aircraft impacted by weather does not block departures).

Recommendation: Explore how to overcome the cultural shift anticipated when NextGen transitions SDO from a deterministic to probabilistic paradigm.

6.2.5 Performance Metrics for Super Density Operations and Integrated Weather

Finding: SDO automation tools need to assess weather uncertainty and proactively and agilely manage its risk.

Currently, uncertainty in SDO is not a consideration; service providers work in a strictly red light - green light mode, using automation tools like Regional Airspace Procedures Team (RAPT), and deterministic forecasts like Corridor Integrated Weather System (CIWS). Today, arrival streams work effectively until the first pilot in the stream refuses to fly through an area due to unplanned for weather (or other constraint) and causes arrival/departure disruptions. This is an example of what NextGen should avoid. NextGen automation needs to assess weather uncertainty and proactively and agilely manage its associated risk to SDO.

Finding: Training and human factors are critical elements to a successful transition from deterministic to probabilistic SDO.

Addressing weather uncertainty in SDO prompts the questions:
- How do we build confidence in the weather forecast and our ability to address its uncertainty for use in SDO?
- How are weather forecasts translated into information of use to SDO users and service providers?
- How does NextGen introduce SDO users and service providers to uncertainty and risk management operations?

Training and human factors, involving decision making in uncertain SDO weather conditions, need to be explored. This is not a simple task because stakeholders may not react operationally as one would expect. SDO session participants identified Area Navigation (RNAV) as a good example of how pilots may not perform as anticipated, resulting in less benefit than originally planned.

6.3 SUMMARY

Improving SDO performance will provide significant downstream benefits to the NAS. SDO is one of the most complex traffic management areas in the NAS and NextGen SDO solutions may differ by location (i.e., one size does not fit all, New York vs. Atlanta), so implementing NextGen SDO will be very challenging. For all the above stated reasons, SDO R&D must be an early NextGen priority.

SDO weather-related research should focus on integration, because it is thought that automation support may help manage delay better at our busiest airports and Metroplexes. However, we lack an adequate understanding of how weather impacts today's SDO. Research is needed to investigate weather impacts in the current system, and potential impacts under NextGen. Today's highly-deterministic SDO will be transitioning to a more proactive, agile paradigm, complicating our understanding even further. To make NextGen operational, we need to better understand NextGen SDO by location and determine its:

- Weather requirements for both nominal and hazardous weather,
- Policy issues (e.g., separation standards), and
- The effectiveness of potential solutions to reduce weather's impact (by location).

This breakout session was a good first step toward the integration of weather into NextGen SDO. The participants look forward to continuing to work together in support of NextGen SDO implementation.

7 CONCLUSIONS

The weather integration conference was a success due to significant participation by operational users and Industry stakeholders across all working groups. Success in this regard was measured by the development of 78 findings and 102 recommendations – many with a strong operational perspective and the need for integrated weather. A clear theme emerged from the participants: the intended user of the information must be taken into account, especially unique benefits for individual stakeholder groups, and any new use or information that contains integrated weather must consider operational nuances and constructs. For example, it was realized that the following are just as important (if not more) than just the improvement and integration of weather alone:

- How and when the integrated information is presented based on specific operational scenarios;
- Information in common terms relevant to the mission or operation;
- Information consistency among differing operators and;
- Risks, consequences and options, either real or perceived, based on information use

To be successful, the integration of weather must work within a framework of change. Of considerable importance was the conclusion that policy, regulations and transition are the main tenants that will facilitate operational evolution. This is true for almost all NextGen envisioned benefits and weather integration is no exception.

The results of this report, in the form of findings and recommendations, are comprehensive (albeit with some duplication) and are listed in Appendix 1. It is anticipated that the newly formed NextGen Integrated Weather Standing Committee will use this report as a foundational document to develop a set of processes designed to implement integrated weather information into NextGen operational processes/systems at all levels. The group will develop tasks required to integrate weather, timelines, and test plans. The tasks will have sufficient detail to allow for agency cost-benefit analysis, budgeting, and planning actions to support near fiscal year budgets. Transitional issues will be addressed in terms of a developed plan to migrate legacy weather systems, services and functionality into NextGen operational weather concepts. Critical policy issues that have the potential to impede progress are to be brought to resolution in the early transitional stages. Regulations must also be addressed and it is hoped that this integration group will coordinate with various agency entities to ensure timely regulatory changes.

APPENDIX 1 FINDINGS AND RECOMMENDATIONS SUMMARY LIST

NextGen Weather Breakout Session

Findings

1) The architectural design of the cube is not well defined.
2) It's not clear what the government/industry roles should be in operating and populating the cube.
3) The scope and content of SAS needs further refining. What data source/product is going to be used for the SAS at any particular time? The content needs to be driven by operational needs and specific automation needs not the NextGen Weather team. Governance and policy model needs to be determined and shared with industry.
4) Some information systems can't get on the network and some networks have interoperability issues.
5) Some examples of information requested by users for airports are improved lightning detection and forecasts, and de-icing forecasts.
6) Examples of observations we can gather are icing information from Delta aircraft engines and adding EDR sensors.
7) The challenge of making weather information available in the cockpit is the diversity of the users and weather products.
8) The definition/relationship of the SAS to the 4-D Weather Cube are not well known to people outside the Weather Working Group.
9) Communications standards and techniques are inconsistent and lack integration. This will make it difficult to work across agencies and industry.
10) How do we ensure quality of data and quality of tools?
  - Real-time verification of data
  - Value-added of forecast and tools

11) How do we ensure the quality of the product from the SAS? How do we look at the quality of the DST's and determine if the picture is right and the quality of the product is right?

Recommendations

1) Develop an information paper that describes the SAS/4-D cube and their relationship.
2) We need a team to focus on the scope and content of the SAS.
3) Encourage industry to participate in NextGen Weather IOC development team efforts to identify domain authority, standards, catalogs, ontologies, etc.
4) Work with non-federal organizations to identify how to incorporate their sensor information into the 4-D Weather Cube.
5) The group recommends a demonstration to see if we can collect additional weather data from on-board and ground sensors and transfer it to government system(s) in a net-centric manner.

6) Have the NEO, Aircraft, and Weather Working Groups sponsor a team to identify options on how we get information into the cockpit.
  - Commercial
  - FIS-B
  - Other frequencies
  - Existing FCC regulation and policies are constricting options

7) Develop an information paper that describes the SAS/4-D cube and their relationship.
8) Have weather SMEs review how the reliability of the cube can be demonstrated to operational users.
9) Task the Airport and ANS Working Groups to set DST quality and reliability as they identify new tools that will be developed.

<u>Airport Operations Breakout Session</u>

Findings

1) Data sharing agreements need to be reviewed and updated.
2) Weather impact on operations is most important.
3) Operational users are not involved effectively in the requirements process.
4) More efficient operations necessitate changes in current regulation.
5) Legacy system integration is very important.
6) Need for improved forecasts of runway conditions.
7) Need to take into account an integrated approach to weather impacts on airport parking, terminal and ramp areas, surface maneuvering of all vehicles, as well as aircraft.
8) De-icing activities need reduced costs and increased flexibility.
9) Advances in modeling is needed.
10) Run simulations before demonstrations.
11) Demonstrate integrated weather at an OEP airport.
12) Derive and validate metrics from operational users.

Recommendations

1) Effective communication and information/data sharing, across all levels, is critical.
2) Weather information needs to be translated into impact information specific to user needs.
3) Operational users need to be involved in the entire requirements process.
4) Use liquid equivalent water instead of visibility to determine deicing needs and holdover times.
5) Prioritize legacy system value according to NextGen requirements.
6) Address runway sensors that are non-representative of actual conditions. Improve runway forecasts accuracy and reliability.
7) Develop and validate a requirements matrix to address user needs for weather as integrated with various surface movement operations.
8) Deicing be standardized by aircraft types.
9) Investigate use of the “Theory of Serious Games” for simulation development.
10) Demonstrate integrated weather for winter operations at ORD.
11) Determine metrics of value from operational personnel.

Trajectory Based Operations Breakout Session

Findings

1) There is a need to synchronize with the international aviation community in establishing a weather data standard.

2) Incremental transition to TBO should be well defined and include weather data integration at the outset to provide optimum benefit to NextGen users.

3) There is a need to establish policies that encourage NextGen users to incorporate capabilities that meet or exceed new performance-based standards.

4) Critical to the success of NextGen is early adoption of policy that supports governance, funding and usage of the weather single authoritative source particularly in the development of TBO.

5) Existing policies are inadequate to support TBO including a number of factors such as the use of probabilistic weather forecasts, conflict resolution and data sharing.

6) Traditional organizational structures must evolve to embrace new roles and responsibilities to implement NextGen concepts and realize benefits.

7) There is a need to establish a certification or validation process for weather information that will be used in TBO.

8) Human reaction, response and risk of product use that contain integrated weather must be examined.

9) Operationally relevant, risk quantifying, applications research that translates probabilistic forecasts into deterministic-with-options user and ATM solutions (e.g., impact assessment).

10) There is an overall need to determine weather performance requirements/characteristics for all stakeholders and decision support tools.

11) Need to quantify the effect of weather on the ability for aircraft to meet ‘wheels off time’ while still on the ground, to maintain a given trajectory, and to arrive at designated waypoints at expected points in time.

12) It is important to partition uncertainty over the entire trajectory.

13) The need for human factors simulations cannot be overstated.

14) For weather integration to provide value to DST’s supporting ATM in general, or TBO in particular, the weather information integrity must be aligned to the integrity of the functionality (DST components) or operation being performed.

15) There is a need to understand the operational impacts to users in mixed equipage scenarios.

16) In a related effort to TBO sensitivity to weather, the benefits of any additional costs must be clear to each stakeholder.

17) Simulations should be designed to show *relative value* of weather integration against performance metrics important to different stakeholders (e.g., value will not be the same across all stakeholders).

18) To ensure NextGen success, NAS operations must transition incrementally but with purpose (e.g., with a well documented roadmap that illustrates defined goals, benefits and incentives) in order to meet anticipated air traffic demands and NextGen user needs. Transition must also be designed to prove conservation of services and more specifically, conservation of functionality.

19) The overall degradation in the performance and stability of the NAS in recent years may, in part, be evidence that probabilistic approaches to ATM/TFM are of high value to NextGen.

20) There is a need to identify pilot weather needs.
21) Similar weather scenarios can have vastly different impacts based on traffic, airspace use, operational complexity, etc. The effects of impacting weather are envisioned to have similar differences for TBO.
22) Stakeholders identified the lack of a complete understanding of the 4-D Cube and SAS.
23) There is a lack of definition of central objectives for each trajectory and each of these objectives must be demonstrated.
24) There is a need to develop clear transition plans between legacy systems and "NextGen" systems that incorporate stakeholder incentives and government commitment.
25) User needs are preeminent in any design and implementation of the NextGen concepts and all communities of interest must be involved in the process.
26) Planning and programming should match user needs for weather services.
27) Weather data standards need to be established to enable NextGen concepts and form the basis for system standardization.
28) A system that incorporates rapid, intelligent dissemination should be developed that informs all users of process or procedure changes to the system.
29) There is a need to develop a metric that measures the quality of weather information provided to a DST in terms of tool performance.
30) There is a need to develop route time performance metrics to measure user performance.
31) Fuel consumption metrics will continue to measure system efficiency and help establish cost benefit analyses.
32) There is a need to establish metrics that measure user weather capability versus actual performance to continually refine 4DT algorithms.
33) Establishing a metric to measure 4DT contract renegotiations and actual weather encountered during the flight will provide valuable insight into system efficiency.
34) A metric that would provide continuous feedback on user trajectory compliance would enable a more predictable system.
35) There is a benefit to establishing and maintaining quantifiable, clear factors in metrics that measure avoidable or unavoidable delays.
36) There is a need to establish an airspace permeability metric that measures the predicted versus actual throughput in terms of weather forecast.
37) A metric that measures aircraft equipage versus performance would be valuable in optimizing the NextGen system, particularly with weather capabilities.

Recommendations

1) Establish a weather data standard that is compliant with ICAO standards and use this standard in TBO.
2) Bring stakeholders together early in the development of TBO implementation roadmap to ensure weather integration at the inception. Do not follow the path of treating weather as an "add-on" in later phases of TBO development, as this will delay or negate the value of a fully-integrated solution that assimilates weather information.
3) Establish policy that allows flexible trajectory re-negotiation as weather information is updated throughout the NAS.
4) Develop an agency policy for user performance capabilities in parallel with policy that supports incentives across all stakeholders to meet or exceed performance standards.

5) Develop agency policy that is adaptive to system performance increases as equipage evolves.

6) Support efforts (including funding) devoted to the development of the single authoritative source concept, implementation, human factors and governance to enable NextGen TBO.

7) Develop policy for the use of probabilistic weather as it pertains to decision support tools and NextGen system users.

8) Develop appropriate precedence and procedures to determine proper course of action an operator must make when conflicting weather information is presented.

9) Make ATM data available to the research community at large to facilitate research and development efforts supporting NextGen.

10) Find ways to test and implement new science and innovation into the NAS in an expedient manner to incorporate the latest technology.

11) Carefully consider the affects of implementing NextGen concepts in terms of organizational changes. Identify “cross boundary” issues that affect more than one organization, and determine whether a new division of responsibilities is necessary prior to implementing NextGen concepts and systems.

12) Define a transition strategy, but do not perpetuate traditional organizational responsibilities and relationships unless they clearly benefit the governance and operation of NextGen.

13) Develop a certification or validation process for weather information and forecasts used in the SAS that test for reliability and recognized safety and traffic flow management conventions.

14) Human factors research is needed to quantify the effects of inherent human conservatism and caution and the effect of inconsistent forecast skill on operational decision making.

15) Conduct human factors research to understand how controllers will handle air traffic in a TBO world – specifically their reactions to weather that affects sector loading, controller workload, transition to dynamic sectors and delegation of separation responsibilities to the flight deck.

16) Continue research to quantify predictions of pilot/controller actions when faced with current weather impacts.

17) Understand the human-machine interface role for each stakeholder, including weather information integrated into a single display. Related research should eventually embrace the transition to complex technological systems designed for use with NextGen constructs.

18) There is a need for research into how forecast uncertainty can be ‘partitioned’ into spatial and temporal elements as a possible way to quantify and reduce risk and impact of uncertainty and forecast errors.

19) There is a need to determine who has the authority to take the risk and what are the allowed levels of action for both systemic approaches Traffic Management Initiative and individual trajectory negotiations (e.g., go/no go, red/green, or shades such as red/yellow/green, etc.).

20) A weather translation model could be developed to select different convective forecast and now-cast products and assess how they help achieve a more accurate airspace capacity estimate – separately and as an ensemble forecast. Additional research would be needed to determine how to validate and to determine the granularity (e.g., ARTCC/Sector/Flow/ Airway/Gate/Fix).

21) There is a need for operationally relevant research that translates and integrates weather forecast probability into language (e.g., triggers or sliding scales or time smears, etc.) that can be used by ATM tools.

22) There is a need to conduct applications research to identify and then match the performance of the weather information with user functional needs for TBO.

23) There is a need to conduct research that identifies the weather performance requirements for the entire environment in which TBO-based systems act (e.g., TBO performance changing triggers, how they change and by how much).

24) There is research needed to quantify how to develop higher fidelity and standardized trajectory predictions with lower fidelity weather (i.e., what is good enough weather for a trajectory prediction and how does such fidelity change from operation to operation).

25) There needs to be research conducted to determine if there are significant benefits (consistent with 5.2.6) in obtaining more accurate weather forecasts. There is a further need to identify tools, models (e.g., Numerical Weather Prediction), techniques, etc., that validate and measure the real or perceived improvements.

26) There is a need to conduct TBO and weather research (e.g., time-based research) that overlaps with airport surface movement and weather research to understand and categorize wheels off departure/wheel on arrival times. This could be enhanced through the combined use of ground vehicles and aircraft sensors to determine position.

27) Research is needed to establish a set of agreed-upon thresholds that are not based on operations as described earlier, but based on aircraft performance and requirements for safe operation for weather phenomena such as icing for deicing, lightning for refueling, etc. Similar issues as previously identified emerge, such as what are the risk factors, who have authority to take the risk, levels of action (go/no go) or can there be shades (red/yellow/green).

28) In the first (departure) or final (arrival) stages of TBO, research is needed to quantify the affects of weather on aircraft performance in 4DT SDO with regard to trajectory and arrival times in space and the ability to penetrate weather when there are the fewest options available for safe flight.

29) Research is needed to understand the capabilities of the aircraft with respect to weather factors to reduce the uncertainty of meeting TBO objectives. In the worst-case weather scenarios, research is needed to define airspace which cannot be accessed based on high weather impact phenomena.

30) In the (legacy) en route portion of TBO, research is needed to quantify the effects of aircraft trajectory performance based on convective (especially) and other (e.g., icing) weather characteristics. There is a need to know what aspects (echo tops, storm tops, cloud/visibility tops, turbulence, vertical impact altitudes, etc) most significantly affect aircraft performance from meeting time and space TBO objectives. There is a need to determine how much equipage and differing agency operations (civil vs. military) will play a role in meeting this objective.

31) Research is needed to identify how weather forecast uncertainty and associated operational risks change over the entire course of the trajectory.

32) There is a need to conduct fundamental weather research regarding specific weather phenomena, over specific areas, occurring or lasting over a range of times, and achieving and/or maintaining specific levels of magnitude that can impact TBO.

33) Applications research is additionally needed to identify important weather thresholds that trigger trajectory-based operation changes.

34) CDM between all decision makers (pilots, dispatchers, controllers) needs to be simulated under varied weather conditions and varied TBO activities to quantify relative workload on each, quantify response differences/reactions, and to quantify the relative flexibility (or not) to combined operations/impacting weather scenarios.

35) Conduct simulations to explore information overload.

36) Simulations are needed to quantify TBO sensitivity to weather. This should include modeling or simulating the value of DST's over a range of weather fidelity or outcomes.

37) This also includes the simulation of weather probability translation upon TBO constructs (i.e., how each probability 'level' is translated and weighted within the DST components).

38) The value of the integrated weather needs to be simulated and measured in terms of the metrics highlighted in question 6 or from a cost/benefit perspective. In this regard, the value of continued 'improvement' in weather information fidelity needs to be modeled against real or perceived 'improvement' in DST outputs.

39) Simulations of NAS users operating in a mixed equipage mode need to be conducted to determine consequences and relative sensitivity of continued mixed equipage towards achieving TBO objectives.

40) The cost/benefit of optimal or minimal equipage needs to be simulated.

41) There needs to be simulations performed that describe the cost to benefit of further improvements in weather products and forecasts beyond those so matched in informational integrity to TBO constructs. In this regard, there may be, for example trending routines that could be designed that allow more frequent weather updates to be time-based averaged before integrating.

42) Simulate value of integrated weather with TBO by simulating various NAS performance measures (e.g., route timing, fuel savings, operational options, etc.) to determine sensitivity to weather.

43) An approach to initial transition in general is to capture the experience of successful recent trials (e.g., ADS-B in Alaska) and extrapolate or leverage to achieve perceived NextGen benefits.

44) Regardless of the kinds of transition, there needs to be a well-defined transition path or roadmap.

45) There is a need to demonstrate both tactical and strategic use of probabilistic convective impacts under various levels of uncertainty.

46) There is a need to demonstrate the operational effectiveness of weather integrated DST's under various levels of uncertainty.

47) There is a need to demonstrate operational value (tactical) to using predicted convection locations rather than planning based on current convection locations.

48) For more strategic assessment, there is a need to demonstrate effective risk management both for strategic TFM approaches and at the individual flight or trajectory level.

49) In the spirit of leveraging from current operations, demonstrations could be designed to use existing systems and begin rolling in new 'numeric' systems for integration of convective uncertainty forecasting.

50) On-going research efforts at NASA - Ames and the United States Air Force's Air Mobility Command could be demonstrated for flight profile data to understand 4-D uncertainties.

51) There is a need to demonstrate automation of dispatcher/controller/pilot/traffic manager actions – especially to demonstrate the optimization of routing around a weather obstruction. This could be demonstrated using a variety of weather information to determine the most optimal set for final integration.

52) The effects of data overload are highlighted again and require demonstration. This also includes mental adjustments for the pilot as well as mental adjustments for decision makers on the ground.

53) There is a need to separately demonstrate then integrate the value of specific weather information – not just convection – as integrated into automated tools. The demonstrations needs to be separate for each stakeholder – cockpit, AOC, ATC, etc

54) There is a need to demonstrate a sufficient number of off-nominal (bad weather) scenarios to test the boundaries of NextGen system adaptability.

55) There needs to be demonstrations that incorporate scenario-based research initiatives to help quantify, in a more strategic way, the potential risks prior to entering into these more tactical scenarios.

56) Related to both tactical and strategic focus, there needs to be follow-on demonstrations to illustrate what kinds of safety nets (i.e., fall back or alternative operations) are available when weather reaches such triggers (tactically) – or in a more strategic sense, at what point is the commitment made to continue a TBO given an availability of alternate (operational) options that will exist in the future.

57) There needs to be various demonstrations that highlight the relative effects of weather forecast errors with trajectory prediction studies. This could be performed using canned wind forecasts having increasing degrees of error.

58) There is a need to demonstrate the viability of the 4-D Cube and SAS and to show the risks (costs/safety) associated with *not* having "NextGen Weather".

59) Trajectories in the NAS should ultimately satisfy two objectives:

- Separation from other trajectories by the minimum separation standard of the occupied airspace. Satisfaction of this objective is generally best defined by the ATSP.
- The user-preferred trajectory provides optimum cost and satisfaction of other operator defined objectives such as safety of flight, passenger comfort and emissions. These are generally objectives best defined by the system user.

60) Establish clear transition plans from today's systems to full NextGen system implementation using short-term periods.

61) Incorporate "hard" milestones for government system decisions related to investments to foster industry incentives to enable timely system benefits.

62) Adopt User-Preferred Trajectory (UPT's) as a central objective of TBO to maintain a user-centric focus**.**

63) Conduct outreach programs with each user community of interest (COI) to solicit their specific needs and requirements. Describe specific benefits for each COI and a corresponding roadmap that lays out the actions to implement NextGen-related weather programs that enable those benefits.

64) Develop a cross-cutting NextGen Weather service implementation roadmap that addresses the needs and requirements of each user COI.

65) Develop the data specifications for weather information that will be used in the SAS at the soonest opportunity. Ensure it is ICAO compliant. Widely disseminate the standards once developed.

66) Implement an intelligent pilot notification of system or operational changes that affect a user participating in NextGen.

67) Establish weather information performance criteria for the decision support tools that use the information and develop associated metrics to measure support tool performance.

68) Establish a route timing metric that measures scheduled timing versus actual and incorporates weather inputs.
69) Establish a fuel usage metric that measures predicted fuel usage with actual.
70) Measure the difference between the actual fuel consumed and the planned fuel use of the 4-D UPT.
71) Establish a metric that measures the aircraft weather capability versus its performance with respect to assigned trajectory.
72) Develop metric(s) that measure the number of 4DT contract re-negotiations and accounts for unforeseen weather encountered by the pilot.
73) Incrementally phase in metrics that measure the "predictability" of users to comply with assigned trajectory, such as a trajectory compliance index.
74) Establish a set of delay parameters and develop corresponding delay metrics that quantifies delays as either avoidable or unavoidable.
75) Develop a metric that measures the predicted permeability of airspace and the actual permeability and throughput.
76) Establish aircraft equipage metrics that help evaluate system efficiency with respect to user weather capability.

<u>Super Density Operations Breakout Session</u>

Findings

1) Existing SDO separation standards need to be reviewed in light of NextGen Weather integration (as well as other non-weather) capabilities.
2) Weather information to the flight deck is critical to SDO. How can this be accomplished sooner?
3) Analysis is needed to determine SDO staffing requirements in the NextGen timeframe.
4) NextGen Weather-SDO integration should give priority to convection (i.e., thunderstorms) over other types of weather.
5) NextGen Weather-SDO integration research should consider strategic decision making during off-nominal operations.
6) NextGen Weather needs to provide wind observations along descent approaches to support SDO, and analysis needs to be conducted to determine the performance requirements of these wind observations.
7) Calm wind conditions can increase runway occupancy time, negatively impacting SDO.
8) For SDO, there should be an appropriate balance of emphasis between information regarding delay-creating severe weather and weather information used to support capacity-increasing NextGen capabilities during standard operations.
9) Analysis needs to be conducted to determine the performance requirements for weather information supporting capacity-increasing NextGen capabilities.
10) Analysis is needed to determine how to meet SDO weather observation requirements (e.g., ground-based observation systems, aircraft reports, combination of both).
11) Explore multiple solutions for controlling/optimizing real-time weather observations in support of SDO; including but not limited to ground-based control and sensor systems acting independently as intelligent systems.

12) Analysis is needed to resolve questions related to the role of humans in highly-automated SDO.

13) The sharing of in-flight weather observations during SDO would be beneficial for efficiency and safety and could be enabled through performance-based requirements.

14) Any exploration of NextGen Weather requirements needs careful analysis of SDO weather requirements, because they may be more stringent that those for TFM and en route operations.

15) SDO weather requirements need to be directly tied to decisions that need to be made (e.g., specifically where can operations take place), rather than the normal methods of presenting weather information (e.g., specifying where weather is likely to occur).

16) When assessing how to reduce the impact of weather for SDO, one should explore many possible solutions, including, but not limited to, infrastructure investments.

17) SDO automation tools need to assess weather uncertainty and proactively and agilely manage its risk.

18) Training and human factors are critical elements to a successful transition from deterministic to probabilistic SDO.

Recommendations

1) Re-examine the ADS-B ‘IN’ timeline. It may need to be accelerated if we are going to more fully realize NextGen benefits, including NextGen Weather integration, by 2025.

2) Perform analysis/research to determine SDO weather and weather translation requirements for NextGen. Near-term efforts should include:
  - Analyze all NextGen SDO operational improvements to see how weather impacts them,
  - Analyze sensitivity of NextGen SDO procedures and decision support tools to winds aloft in order to establish weather observation and forecast requirements,
  - Determine how SDO differ with location (e.g., major airports, Metroplexes) in order to better understand their unique NextGen requirements.

3) Send weather integration researchers into the field to learn current deterministic SDO strategies, so that they are better able to develop more strategic SDO weather integration concepts/capabilities.

4) Establish a mechanism to solve SDO problems (through joint community involvement). This could include the use of integration laboratories (to include weather integration) and computer simulations to better understand the problems we need to address in implementing NextGen.

5) Explore whether infrastructure investment intended to assure operational reliability and predictability could also help reduce the impact of weather (e.g., surface flexibility, so one aircraft impacted by weather does not block departures).

6) Explore how to overcome the cultural shift anticipated when NextGen transitions SDO from a deterministic to probabilistic paradigm.