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BEYOND THE CLASSROOM: APPLYING A BUSINESS PROCESS MODEL OF WEATHER FORECASTING TO AVIATION METEOROLOGY

John M. Lanicci

Abstract

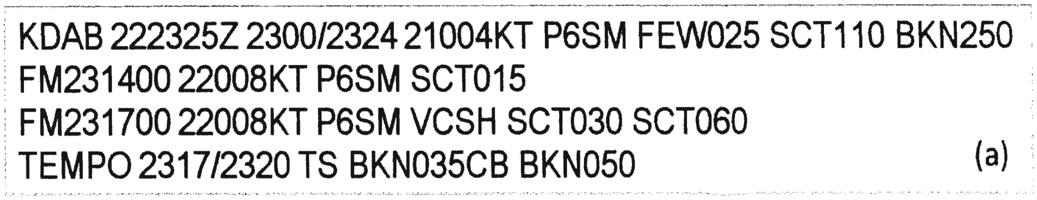
Modern weather analysis and forecasting has become a very complex enterprise, with aspects that are purely scientific, and others that are business operations-related. At Embry-Riddle Aeronautical University's Daytona Beach campus, a business process model of the weather forecasting enterprise has been used as a teaching tool in the undergraduate course *Forecasting Techniques*. The model consists of two major, interrelated components, known as the Weather Information Processing Cycle (WIPC), and the Provider-User Relationship (PUR). The WIPC describes forecasting from the traditional scientific point of view, but contains user-focused processes such as *product tailoring*, *dissemination*, and *user integration* in addition to the familiar scientific processes such as *data collection*, *analysis*, and *prediction*. The PUR examines the business relationship between the *provider* of meteorological information and the *user* of that information. While the PUR provides a bridge for students to progress from studying basic forecasting techniques in the WIPC to examining the business relationship between weather information providers and users, there are applications of this model beyond the classroom. This paper introduces the model and shows how it can be applied to investigate the relationship between aviation weather information providers and users, using examples from the interagency Next Generation Air Transportation System (NextGen) program.

Introduction

Modern weather analysis and forecasting has become a very complex enterprise, with aspects that are purely scientific, and others that are business operations-related. Traditional forecasting methodology is historically focused on the science, with some tailoring for different user communities such as shipping, agriculture, and aviation (Craft, 2001). While the vast majority of weather products have come from the public sector (i.e., National Weather Service (NWS), Department of Defense (DoD)), there is a growing number of private-sector firms now providing tailored weather information for a multitude of clients in many different industries. According to a survey conducted by the American Meteorological Society membership (Murillo, Pandya, Chu, Winkler, Czujko, and Cutrim, 2008), the proportion of members affiliated with the public sector continues to drop; approximately one in five are self-employed or part of a private-sector business (see Table 6 in their paper). While this demographic shift was taking place, an explosion of Internet-based applications and sophisticated computer graphics capabilities has occurred nearly simultaneously. The combination of the demographic shift in the meteorological profession and advances in information technology has resulted in a shift from "traditional" weather forecast products towards user-relevant weather effects and impact products.

Private and commercial aviation is a good example of an industry where the effects of the above-mentioned changes are being seen. Aviation has many diverse users of weather information, from individual pilots and aircrews, air traffic controllers and managers (ATC/M), to flight operations centers, dispatchers, and ground personnel (see for example, Stough, Shafer, Schaffner, and Martzaklis, 2000). As the National Airspace System (NAS) shifts from today's operations into the Next Generation Air Transportation System (NextGen) environment, there will be increasing requirements for tailored effects and impacts products versus traditional aviation weather forecasts (Joint Planning and

Development Office JPDO, 2010). Additionally, users will expect the information to be presented in an easy-to-understand format that can be quickly assimilated into the decision-making process—this change is already taking place. Figure 1 shows a comparison between a traditional text-based aviation weather product, the Terminal Aerodrome Forecast (TAF), and a graphical TAF representation. The text-based product covers a 24-hour period and contains more information for Daytona Beach than does the graphical product, but the graphical product, valid for the 12-hour forecast point, displays ceiling, visibility, wind, and obstruction/precipitation for the entire southeast U.S., including Daytona Beach. Many users would find the graphical TAF easier to use because the ceiling/visibility and winds for Daytona Beach can be determined by just a quick glance at the product. While the product examples in Figure 1 came from a public-sector source (NWS Aviation Weather Center), a number of private companies offer graphical products tailored for aviators, many of which can now be transmitted directly to the cockpit in real-time if the pilot subscribes to the vendor's services (for more information, see the Federal Aviation Administration's (FAA) Qualified Internet Communications Provider page, at http://www.faa.gov/about/office_org/headquarters_offices/ato/service_units/operations/qicp/).



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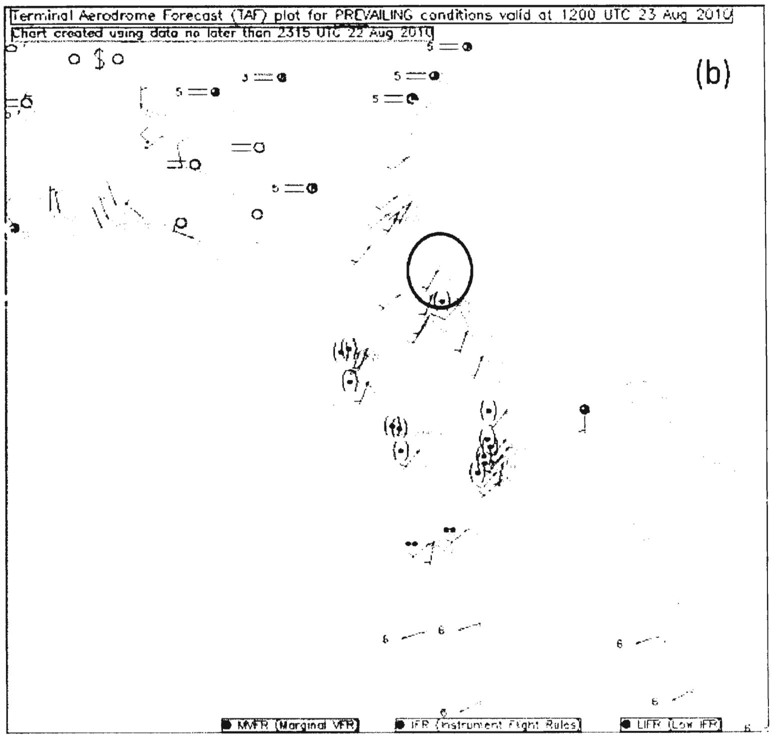

Figure 1. Panel (a): Text-based TAF for Daytona Beach International Airport (KDAB) covering period from 0000 UTC 23 August 2010 to 0000 UTC 24 August 2010. Panel (b): Graphical TAF for southeast U.S. valid for 1200 UTC 24 August 2010 (location of KDAB circled). Ceiling and visibility category is color coded (key located at bottom), and is consistent with forecast conditions from text-based product (courtesy of Aviation Digital Data Service; http://aviationweather.gov/adds/).

The previous discussion illustrates that graduates from atmospheric science programs who desire to enter the aviation weather-forecasting profession must be equipped with both scientific as well as business tools to be successful. At Embry-Riddle Aeronautical University's (ERAU) Daytona Beach campus, a business process model of the weather forecasting enterprise has been used as a teaching tool in the undergraduate *Forecasting Techniques* course since 2006. What is a business process model? According to Aguilar-Savén (2004), a business process model is a representation of a set of activities within an enterprise that describes its business logic and dependencies. Business process modeling enables a common understanding and analysis of the enterprise's key processes, and can also be used to identify deficiencies and areas for process improvement. Aguilar-Savén reviewed a dozen different methodologies for business process modeling, ranging from flowcharts to very structured techniques that can be implemented as computer software applications.

The business process model used in *Forecasting Techniques* is flowchart-based, consisting of two major, interrelated components, known as the Weather Information Processing Cycle (WIPC), and the Provider-User Relationship (PUR). The WIPC describes the forecast process using traditional scientific terms such as *data collection*, *analysis*, and *prediction*, but also contains user-focused terms such as *product tailoring*, *dissemination*, and *user integration*. The PUR examines the business relationship between the *provider* of meteorological information and the *user* of that information. The inclusion of both the WIPC and PUR in the same process model allows students to progress from studying basic forecasting techniques to examining the business relationship between weather information providers and users. The inclusion of the PUR in the *Forecasting Techniques* course introduces students to seldom-taught topics such as user requirements determination and mission analysis. Additionally, the students are shown examples of different types of user groups, some of which (e.g., air traffic controllers and flight dispatchers) can be *both providers and users of weather information*, providing significant implications when evaluating requirements for weather information, education, and training.

The purpose of this paper is to introduce the process model, provide a brief description of how it is used in *Forecasting Techniques*, and show how it can be applied outside the classroom to investigate the relationship between aviation weather information providers and users. To illustrate this application, examples are shown using the interagency Next Generation Air Transportation System (NextGen) program.

The Business Process Model as Used in the *Forecasting Techniques* Course

The *Forecasting Techniques* course (hereafter referred to as WX 427, its catalog designator), is a three-credit course that is normally taken second or third in a required four-course sequence in the junior and senior years. The sequence begins with *Synoptic Meteorology* (an introductory course to synoptic meteorology[1] and computer applications). The WX 427 course can be taken either in conjunction with or after *Advanced Weather Analysis* (a more advanced version of *Synoptic Meteorology*). The sequence ends with a capstone course, *Weather Operations Seminar*, which introduces students to simulated and real-world forecast operations environments representative of various career paths that they may take upon graduation.

As students begin their senior year (the typical timeframe for taking WX 427), it is important that they develop the proper conceptual models[2] as various topics from previous courses start "coming together" in the forecasting exercises of WX 427. The model helps the students self-organize as they learn about the complex processes involved in producing different types of weather forecasts. It is mainly for this reason that the business process model is used as the central organizing construct for WX 427 and is employed throughout the entire course. In the classroom, the model is employed for these additional educational goals:

1) To present weather forecasting as an orderly, organized process in order to help students focus the application of their knowledge obtained in previous meteorology courses;

2) To allow the subject of weather forecasting to be

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[1] According to the American Meteorological Society, *synoptic meteorology* refers to the use of meteorological data obtained simultaneously over a wide geographic area for the purpose of presenting a comprehensive and nearly instantaneous picture of the state of the atmosphere. (See http://amsglossary.allenpress.com/glossary/search?id=synoptic1)

[2] In meteorology, a *conceptual model* is an idealized representation of atmospheric structure and evolution. Meteorologists use conceptual models in analysis and prediction because they often provide effective explanations for atmospheric behavior in certain situations (e.g., cold frontal passages, thunderstorm formation and dissipation). A good repository of meteorological conceptual models can be found at http://www.zamg.ac.at/docu/Manual/SatManu/main.htm?/docu/Manual/SatManu/.

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examined from the points of view of both a scientific process as well as a business operations problem;

3) To introduce the students to the use of business process models, which they would not have seen in their other meteorology courses, but will be helpful to them in their professional careers.

The current version of the business process model employed in WX 427 is shown in Figure 2. The process model was adapted from a flowchart-based model used by the U.S. Air Force (USAF) to describe its weather operations (see Massie, Pearson, Smith, and Szymber, 1995, and Lanicci, 1998). The model employs aspects of Business Process Modeling Notation (BPMN) described by White (2004). The WIPC, shown as a rectangle in Figure 2, represents a process that is "owned" by the public sector (primarily in the Collection, Analysis, and Prediction phases), and by private-sector firms (primarily in the Tailoring, Dissemination, and User Integration phases). The solid arrows between the WIPC phases denote raw data moving through the production cycle and being transformed into "actionable" information by the User. The PUR portion of the model shows the interaction between the Provider and User (dashed arrows denoting feedback on product quality/service), and also illustrates key components of the relationship, which are summarized by short statements within the Provider and User boxes, respectively. On the Provider side, it is vitally important to develop specific meteorological skill sets (e.g., knowledge of a region's climatology, weather phenomena, and effects of local topography) in order to provide accurate and relevant products to the User. It is equally important that the Provider understand the User's operation, and especially how weather impacts that operation. On the User's side, his/her level of meteorological knowledge is important because it affects how well the User understands the impacts of weather on his/her operation, the extent and limits of the Provider's services, and how well he/she can articulate requirements for products and services, and convey feedback to the Provider on those products and services.

The linkages between the WIPC and PUR are important for understanding development of new weather products and services and marketing them to potential Users. However, there are several principles that must be followed to do this effectively:

1) The Provider must perform a thorough User requirements analysis in order to determine types of *tailored weather information*;

2) The Provider must determine the appropriate method of weather product *dissemination* to the User;

3) Effective *Integration* of the weather information into the User's decision-making process is only possible when the Provider has a good understanding of the User's business operations and the User understands his/her weather sensitivities.

These principles were derived from the author's 30 years of operational experience in the aviation meteorological community, and are included in WX 427 because these ideas are not normally covered in traditional atmospheric science courses. Based on the author's experience at multiple levels of leadership, there is a need to introduce these principles to professionals early in their young careers, as many scientific professionals are unprepared to develop user requirements and product specifications when they move into technical management positions later in their careers.

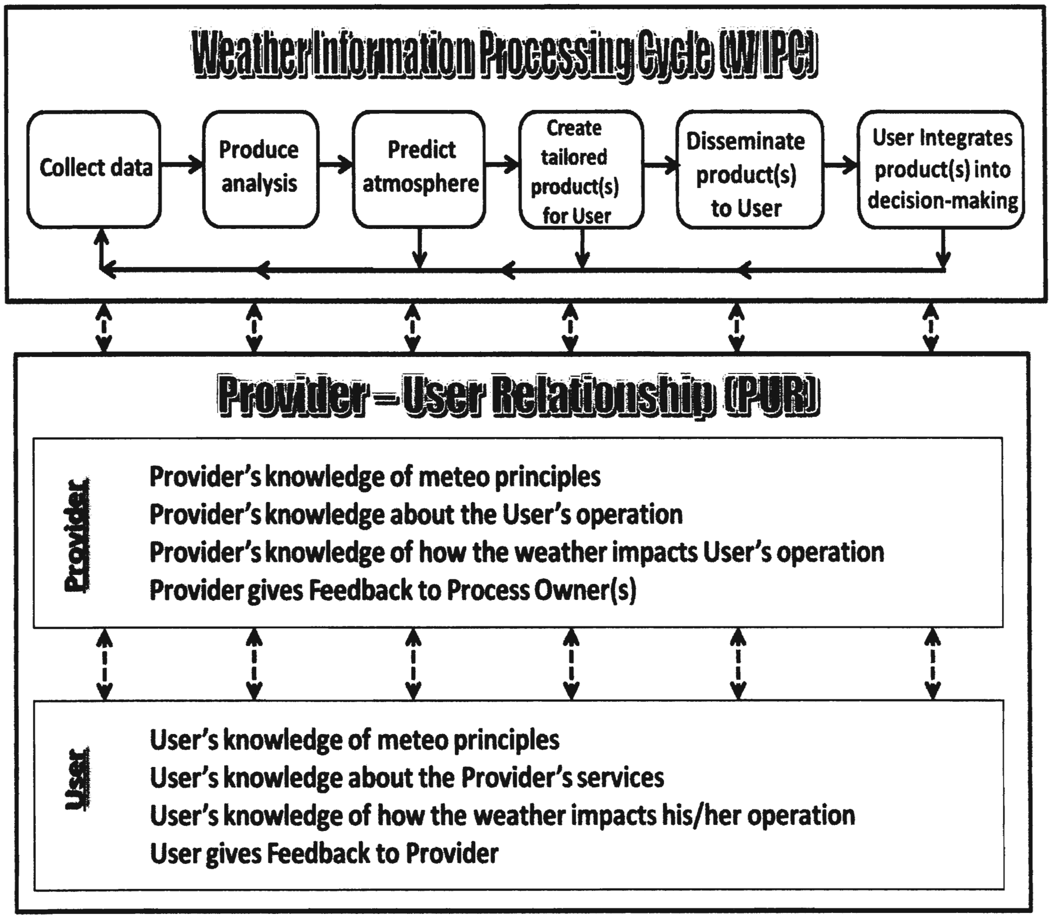

Figure 2. Business process model employed in WX 427. The top portion of the model labeled "WIPC" is the Weather Information Processing Cycle, and the bottom portion entitled "Provider" and "User" describes the Provider-User Relationship (PUR).

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Application of the Process Model to Aviation Meteorology

Given the heavy usage of weather information by the aviation community and the promise of improved aviation weather products from the NextGen program, it is logical to examine the utility of the WIPC/PUR model as an analytical tool within the context of this program. Before applying the model, it is necessary to provide some background on the NextGen weather program. The NextGen Implementation Plan (FAA, 2010) has two important weather components: 1) NextGen Network-Enabled Weather (NNEW), considered one of six "transformational" programs (see pp. 45-47); and 2) Reduce Weather Impacts (RWI), listed as one of seven NextGen "solution sets" (see pp. 65-66).

NNEW, the Four-dimensional Data Cube, and the WIPC

The NextGen Network Enabled Weather (NNEW) program is an interagency effort among the FAA, NWS, and DoD intended to provide improved access to weather information by aviation community users (FAA, 2009). A key component of NNEW is the Four-dimensional Data Cube (hereafter referred to as the Data Cube), which will provide the necessary weather data to build a common weather picture for users such as aircrews, air traffic managers, and airline operations centers. The information contained in the Data Cube will also be integrated into automated support tools that will assist operational decision-makers (JPDO, 2009). Miner, Abelman, and Stobie (2009) produced a concept model of the Data Cube, reproduced here as Figure 3. The Data Cube depiction shown in Figure 3 bears a remarkable resemblance to certain portions of the WIPC model from Figure 2. For instance, the observations going into the Data Cube from platforms such as weather satellites are similar to what is shown in the WIPC Collection stage. The portion of the Data Cube containing observations, analyses, and forecasts from various sources is analogous to the WIPC Analysis and Prediction stages. The Integration in User Decisions portion of the Data Cube model also has a lot in common with the Integration into User Decisions stage in the WIPC. Additionally, the Data Cube is envisioned to be a continuously updating repository of information; the WIPC is also a cyclic process, indicated by the arrows in Figure 2. Based on a comparison of Figures 2 and 3, the WIPC portion of the business process model looks to be a promising analytical tool for the NNEW and Data Cube portions of the NextGen weather program.

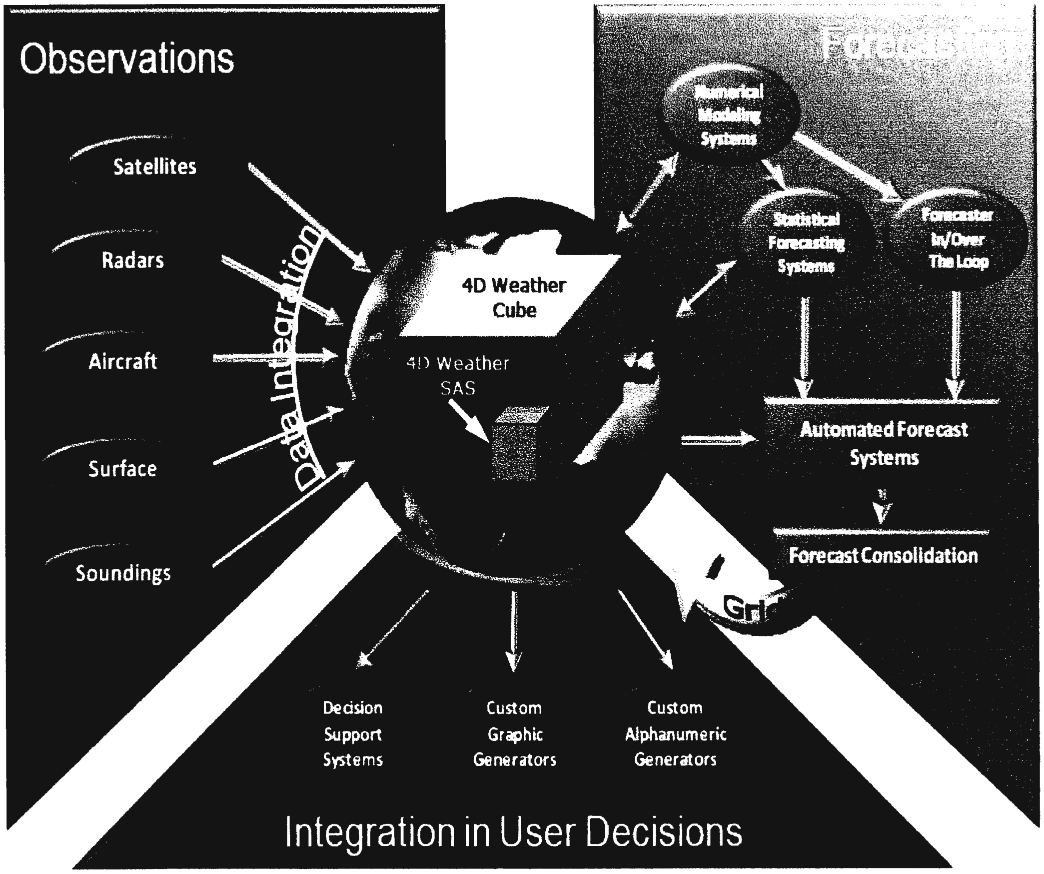

Figure 3. Conceptual view of Four-dimensional Data Cube by Miner, Abelman, and Stobie (2009).

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RWI and the PUR.

The Reduce Weather Impacts (RWI) solution set contains both observational and forecast components. The observational component will support creation of a common weather picture by providing new capabilities to monitor weather more efficiently, continuously, and thoroughly. The forecast portion of RWI involves developing probability-based forecast products that will convey a degree of certainty in prediction.

However, RWI implementation by the ATM community will not be straightforward for several reasons. First, today's ATM decisions are made at multiple levels (Air Traffic Control System Command Center, Air Route Regional Traffic Centers, Terminal Radar Approach Control, and Control Tower), and collaboration is paramount. Second, while there is collaboration among various ATM levels, with NWS forecasters, and with airline operations centers, it is an extremely manually intensive process. Third, nearly all of the information integration by decision-makers is done manually using a combination of weather forecast products, Command Center playbook plays[3], and is heavily influenced by experience and subjectivity (e.g., lack of confidence in weather forecast accuracy). It will be difficult to replace or augment portions of these processes with automated decision-assistance tools, yet that is the NextGen program's intent.

The creation of probabilistic forecasts for use by aviation decision makers is one of the key parts of RWI. However, today's users are tied to deterministic[4] forecasts and are hampered by a lack of confidence in their accuracy. The WIPC/PUR model can be used to analyze the problems associated with the transition from deterministic to probabilistic forecasts by both the Providers and Users of the information. The following scenario is used to illustrate how the model can be applied to RWI: *Suppose that a probability of moderate turbulence (PoT) over the Continental U.S. is proposed as a NextGen weather product.* This would be considered a Tailored Product in the WIPC and would likely be displayed in the Data Cube as a set of grid points in a three-dimensional airspace, with each grid point having a PoT percentage between 0 and 100. When the product is proposed, a PUR analysis is done to determine User requirements such as frequency of issuance, flight levels, turbulence type (e.g., clear-air versus in-cloud turbulence, convectively induced versus non-convective) and other technical product specifications. Another critical part of the PUR analysis would be the education and training of the Users. This segment would examine how product training should differ between aircrews, air traffic managers, and dispatchers. The Dissemination portion of the WIPC could be employed to determine which NAS users should be notified immediately of the product issuance, and whether issuance should be based on a threshold probability (e.g., issue a notification if PoT > 40%), or by some other means.

Continuing this scenario, let us suppose that an automated ATM decision tool is developed from the turbulence product and other inputs. The PUR also has an important role in the development of the ATM decision tool, even though the tool is more of an ATM aid vice a weather product. An automated ATM decision tool must have appropriate threshold information based on multiple sources (e.g., historical traffic volume, pilot behavior, climatology of the hazard) in order to produce a recommendation that a User can understand and act upon. The PUR could be utilized to determine the extent of ATM user education and training needed on the decision tool, and how the introduction of the automated ATM decision tool will affect the collaboration between aviation meteorologists and ATM. For instance, scenarios could be developed for examining how the tool would influence the decision to close off or restrict airspace. The PUR could also be used to develop questions such as those below:

1. Do other NAS users need to be trained on using probabilistic weather products?
2. Should probabilistic weather products be sent to the cockpit for real-time decision-making by aircrews?

While none of these questions have easy solutions, the WIPC/PUR model can provide a template for analysis of the issues, and the development of pertinent questions that could otherwise go unasked until it is too late. Figure 4 illustrates the use of the WIPC/PUR model in this scenario.

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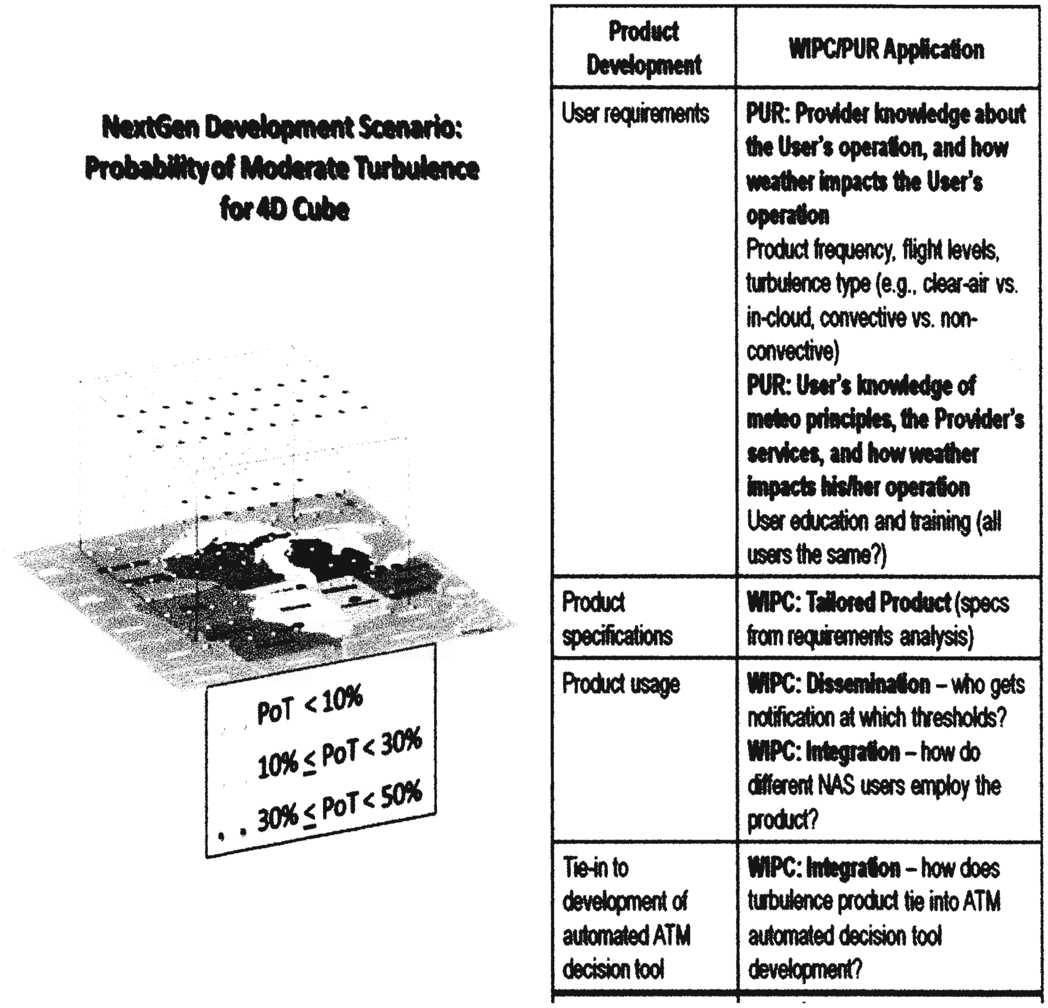
[3] See http://www.fly.faa.gov/PLAYBOOK/pbindex.html for a complete listing of "plays" used to reduce delays from severe aviation weather conditions on any given day in the U.S. National Airspace System.

[4] In this paper, a deterministic forecast is defined as one which is depicted by a single "answer" for the forecast variable(s) during the forecast period. For example, a forecast of "30 OVC" on a TAF means overcast cloud cover at 3,000 feet. This is in contrast to a probabilistic forecast, which assigns a value of the probability of a certain condition occurring. An example would be "40% probability of ceilings below 3,000 feet." These two forecasts are not equivalent, and the plan in NextGen is to make increasing use of probabilistic versus deterministic forecasts.



Product Development	WIPC/PUR Application
User requirements	**PUR: Provider knowledge about the User's operation, and how weather impacts the User's operation** Product frequency, flight levels, turbulence type (e.g., clear-air vs. in-cloud, convective vs. non-convective) **PUR: User's knowledge of meteo principles, the Provider's services, and how weather impacts his/her operation** User education and training (all users the same?)
Product specifications	**WIPC: Tailored Product** (specs from requirements analysis)
Product usage	**WIPC: Dissemination** – who gets notification at which thresholds? **WIPC: Integration** – how do different NAS users employ the product?
Tie-in to development of automated ATM decision tool	**WIPC: Integration** – how does turbulence product tie into ATM automated decision tool development?

Figure 4. Use of WIPC/PUR model in development of a hypothetical NextGen weather product. Schematic diagram of product is shown at left. Table at right illustrates application of pertinent WIPC/PUR model segments (bold lettering in right column) to aspects of product development (left column) such as requirements determination, product specifications and usage, and follow-on development of automated ATM decision tool.

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Summary and Conclusions

This paper presents a business process model for the weather forecasting enterprise that encompasses both its technical and business-operations aspects. The model, adapted from the USAF, is used in ERAU's *Forecasting Techniques* course as a central organizing construct, and aiding students to bring together various concepts from previous coursework, prepaing them for scientific and business challenges in the future. The model contains two primary parts, a Weather Information Processing Cycle (WIPC) and Provider-User Relationship (PUR). The WIPC describes the transition of meteorological information from raw data collection through forecasting, development of user-tailored products, their dissemination, and integration by users in their decision-making processes. The PUR provides an appreciation for the complexity of the business relationship between meteorological providers and the various user communities. The PUR introduces students to concepts seldom-taught at the undergraduate level, such as requirements determination and mission analysis, which will serve them well as they transition into the job market.

The business process model described in this paper has been used successfully by the author during the last five years to describe the scientific and business aspects of the modern weather forecasting practice. A number of weather and climate-sensitive industries, aviation among them, requires critical effects and impacts information, which is increasingly supplied by private-sector interests that are focused on user needs and outcomes. Thus, the author proposes the WIPC/PUR model contains applications outside the classroom for analyzing user needs. The NextGen weather program is used as an illustrative example of such an application. The creation of a real-time, four-dimensional meteorological database is an important component of the NextGen weather plan, and is proposed as one way to improve aviation decision making, reduce delays, and create a safer system; handling the increased capacity predicted over the next 15-20 years (JPDO, 2010; Executive Summary).

The hypothetical example of a probability-based turbulence product for NextGen application illustrates how the WIPC and PUR will be used as an analytical template to identify issues and develop research questions for further investigation. The model shows utility beyond the meteorological application, as it was also used to examine issues associated with development of an automated ATM decision aid whose inputs include more than just the weather. Such a use for the business process model allows various NextGen issues and problems to be analyzed from a holistic perspective, thus avoiding the problems often associated with specialized research studies. ✈

John M. Lanicci has been an associate professor of applied meteorology at Embry-Riddle Aeronautical University in Daytona Beach, Florida since 2006. He teaches courses in introductory and aviation meteorology, advanced weather analysis, forecasting techniques, environmental security, and weather and air traffic management integration. His research has encompassed investigating causes of general aviation weather encounters and accidents, and he is just completing a study for the FAA on general aviation pilot education and training issues associated with use of weather technology in the cockpit. He is a 27-year U.S. Air Force veteran and was Commander of the Air Force Weather Agency at Offutt AFB, Nebraska from 2004-2006.

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Appendix

List of Acronyms

ATC/M	Air Traffic Control/Management
ATM	Air Traffic Management
BPMN	Business Process Modeling Notation
DoD	Department of Defense
ERAU	Embry-Riddle Aeronautical University
FAA	Federal Aviation Administration
JPDO	Joint Program and Development Office
NAS	National Airspace System
NextGen	Next Generation Air Transportation System
NNEW	NextGen Network Enabled Weather
NWS	National Weather Service
PoT	Probability of (Moderate) Turbulence
PUR	Provider-User Relationship
RWI	Reduce Weather Impacts
TAF	Terminal Aerodrome Forecast
USAF	U.S. Air Force
WIPC	Weather Information Processing Cycle