International Civil Aviation Organization

MIDANPIRG AIM Task Force

Seventh Meeting (AIM TF/7)
(Cairo, 25 – 27 September 2012)

Agenda Item 3: **Global developments related to AIM**

OUTCOME OF THE AIS-AIM SG/6 MEETING

(Presented by the Secretariat)

SUMMARY

The aim of this paper is to inform the meeting of the outcome of the Sixth meeting of the Aeronautical Information Services-Aeronautical Information Management Study Group (AIS-AIMSG)

Action by the meeting is at paragraph 3.

REFERENCES

- AIS-AIMSG/6 SoD

1. INTRODUCTION

1.1 The Sixth meeting of the Aeronautical Information Services-Aeronautical Information Management Study Group (AIS-AIMSG/6) was held from 21 to 25 May 2012 in Buenos Aires, Argentina at the Panamericano Hotel.

2. DISCUSSION

2.1 The list of Study Notes and Information Papers issued for the AIS-AIMSG/6 meeting as well as the Summary of Discussion are available on the AIM website at http://www2.icao.int/en/ais-aimsg/.

Status of Annex 15 Amendment 37

2.2 The meeting received a briefing by the Secretary on the status and progress of Amendment 37 to Annex 15 and the consequential changes to other Annexes. The Secretary informed the meeting that despite being removed from the agenda of the 189th session of the Air Navigation Commission (ANC), the preliminary review by the Commission was scheduled for the 190th session on 19 June 2012.

2.3 The AIS-AIMSG/6 meeting noted the Secretariat initiative to develop a GIS “dashboard” to display the global progress of roadmap implementation. The website is still at a “beta” stage and most critically, needs more information as to actual implementation by States.

2.4 The group affirmed that the work on AIM is scrutinized at various levels within States and in particular, that there is a need for more guidance from ICAO. The secretary acknowledged this and informed the group that commensurate with availability of editorial resources, the 3rd amendment to Doc 8126, the quality manual, the training manual, and the eTOD manual were intended to be issued by 3rd quarter of 2012.

Global AIM Operational Concept and Roadmap

2.5 The group was presented with the latest draft of the *Aeronautical Information Management Operational Concept* at **Appendix A** to this working paper. The meeting noted with satisfaction that the draft incorporated many improvements and acknowledged that it had been a difficult task to assemble. The group was satisfied that the document now represented a form that could be collaboratively improved to a final draft.

2.6 The meeting observed that the current document did not include a transition plan. It was explained that as an operational concept it represented a view of future functions, benefits and operating modalities and that the transition plan for implementation would be a natural outcome. Furthermore, it was explained that the transition in part would be covered by the application of the *Aviation System Block Upgrades (ASBU)*. Nevertheless, it was accepted that transition considerations could be incorporated once the concept was considered mature and that the transition would extend from the end of the current roadmap and be in coordination with the ASBUs.

2.7 The meeting considered that to fully achieve the objective of the document, there is a need to fully articulate the scope of the AIM information and data domain, the role that AIM is intended to fulfill, and the functions that AIM is required to perform.

2.8 Another aspect that was considered desirable for the document to express is that the document should be able to give the reader a fuller understanding of the change that would be in place once a change to AIM is in place. That is to say, what will be different from today and what additional capabilities, efficiencies, and functions to be provided after fully integrated transition?

2.9 Considerable discussion revolved around the use of the term “single authoritative source” in the document to signify the central source of information and data compiled from multiple dives origins that fell under the aegis of state accountability prior to distribution. The group was uncomfortable with the use of “single” as it might be misconstrued and recommended that the document refer to “authoritative source” as opposed to “single authoritative source”.

Annex 15 and PANS-AIM Development

2.10 The AIS-AIMSG/6 meeting was apprised of the progress made by the Ad-hoc group on AIM development at their meeting in Brussels, Belgium 13 to 15 February. The group extended its appreciation for the scope of the work accomplished thus far. The meeting noted that after Amendment 37, the focus on Annex 15 would be the re-development of chapters 4 to 11 with the objective of restructuring the Annex and creating the structure to accept new material. It was proposed by the group that the future structure of Annex 15 to be incorporated could be realigned with new chapters 4 to 6 as follows:

Chapter 4 - Data and Information Scope

Chapter 5 - Temporality and Distribution

Chapter 6 - Information Services

2.11 The group noted that in the process of developing the future chapters for Annex 15 and corresponding provisions in the new PANS-AIM, that work on fundamental issues would be required to advance the new material to be incorporated. While it was understood that the process of incorporating the AIM focus into Annex 15 is part of an evolutionary transition of traditional AIS to AIM, it was nevertheless recognized that this would involve more than a modification of existing provisions or extensions to the current document. Some of these issues were categorised by the group as "big questions" which needed to be addressed as part of the work of the group to complete the evolution of Annex 15 and associated material. These "big questions" include:

- What is the Scope of AIM ?
- What is the role of AIM ?
- What are the functions of AIM ?
- What are the Products and Services of AIM ?
- What is the future of messaging and operational reporting?
- What is the future of the AIRAC cycle?

2.12 The group agreed that work on these conceptual issues was relevant to the vision under development in the AIM Operational concept but needed to be resolved in a manner that was appropriate to outline provisions for the next amendment of Annex 15, scheduled for 2016.

2.13 The meeting made some progress with an initial collection of elements that would be included in the future chapters 4, 5, and 6 of Annex 15, the new PANS-AIM, and what would be the role of Doc 8126 after the creation of PAN-AIM. The group recalled that it is a matter of ICAO assembly resolution that the provisions contained in the Annexes become more performance oriented while the more technical specifications, to the extent that they are needed would be found in other documents. The need for harmonized processes, for example NOTAM, forms a primary justification for PANS-AIM.

Roadmap development

2.14 The AIS-AIMSG/6 meeting was informed by the secretary that the AIM roadmap originally envisioned to be developed for and presented at the 12th Air Navigation Conference had been expanded to an IM roadmap. The Chairman was able to present the current IM roadmap to the Group. The development of a broader IM roadmap instead of an AIM roadmap was a result of an observation by the technical team developing the Aviation System Block Upgrades that information was a core enabler throughout the future AIM system and that this needed to be outlined in a broader framework. It was noted that the ad-hoc group on AIM development had the opportunity to provide input to the broader IM roadmap.

2.15 The meeting discussed the need for an AIM roadmap. It was observed that the current roadmap contained in the *Roadmap for Transition from AIS to AIM* had an intended implantation horizon of 2013. Moreover, it was noted that the activities associated with the current roadmap fall short of a full AIM capability, instead providing a path to digital provision of current AIS products and services. It was emphasized that the articulation any new roadmap should serve as an extension to the current roadmap and that it was not to represent a change in direction. In this connexion, the current roadmap serves as the evolutionary beginning of an eventual full transition to an AIM service fully integrated with other ATM services and functions.

AIM Domain Functions

2.16 The meeting reviewed the outcome of the ad-hoc group established to investigate the appropriateness, usage and impact of the description of the function stages specified in Annex 15 paragraph 3.1.7 (amendment 36) with particular reference to the inclusion of the term “and/or originate” in conjunction with “receive”.

2.17 The concern expressed by the meeting is that the phrase “receive and/or originate” incorporated in paragraph 3.1.7 of Annex 15 could infer an obligation on AIS to acquire information directly, for example by aerodrome survey, if it was not in “receipt” of such information. The ad-hoc group concluded that “the term ‘originate’ is out of place in Para 3.1.7, and it is unsupported within Annex 15”.

2.18 The meeting discussed the proposed removal of the term “and/or originate” at length and while there was general agreement with the conclusions reached by the ad-hoc group, there was concern that removal of the term could also generate undesirable consequences. Specifically, it was expressed that if “originate” was not included in the list of AIS functions, it could be interpreted in some States that functions assigned to an AIS could not include origination and that this could be problematic in some States. There was general agreement that the required functions of an AIS could be augmented by additional activities assigned to an AIS organizational unit. While this infers that an AIS would not be prohibited from additional activities including the origination of data and information, it was considered necessary that any change to the function list in paragraph 3.1.7 be accompanied by a note explicitly recognizing that origination could be performed by an AIS.

2.19 Since the amendment 37 proposal was still undergoing review in the ICAO Secretariat and had not yet been presented to the commission, the Secretary undertook to investigate whether a change to 3.1.7 dealing with “and/or originate” could be accomplished for amendment 37. In addition to the potential deletion of “and/or originate” the meeting agreed that this should be accompanied by a note stipulating that “AIS may include origination functions”.

2.20 Discussions covered also the geographic area of responsibility outlined in paragraph 3.1.7. The Secretary reported that this same responsibility area is outlined in (existing) paragraph 3.1.1.2. Specifically, the area of responsibility is described as “entire territory of the State as well as areas in which the State is responsible for air traffic services outside its territory”. The concerns with this coverage include the potential conflict with the State responsibilities outlined in paragraphs 3.1.1 and 3.1.1.1. A specific observation is that the use of the phrase “areas in which the State is responsible for air traffic services outside its territory” could be interpreted to infer that where a FIR boundary extended across State borders, it could be inferred that the responsibility for AIS information could reset with the State providing the FIR service. This could produce the consequence that the FIR State could be responsible for reporting “facts on the ground” information in the territory of another state.

2.21 The meeting discussed several existing scenario where there are FIRs that extend beyond state borders into other states and where there are aerodromes located on state borders or very close. There was general agreement that there is no intention to make a State responsible for information originating within the territory of another State unless there is an agreement facilitating the scenarios allowed for in paragraphs 3.1.1 and 3.1.1.1. It was considered by the meeting that the geographic responsibility areas outlined in Paragraphs 3.1.1.2 and 3.1.7 were intended to incorporate areas other than other State territory (e.g. over the high seas). It was also observed that Annex 3 contained language that was more specific in this regard.

Legal and Institutional Issues

2.22 The group concluded that it was still necessary to review and validate the current 3.4 and 3.5 in Annex 15 and that this issue should be added to the AIM development (amendment 38) priority list. The group also concluded that the issue of copyright and cost recovery, if not handled with care, could act as an obstacle to the flow of aeronautical data and information and would potentially act as an obstacle to the implementation of SWIM.

AIM Quality

2.23 The group was informed by the secretary that the Quality Management Manual was still undergoing review and that this work had been interrupted by other priorities within the Secretariat.

2.24 A discussion ensued concerning the importance of the quality management guidance and evolving to the need to assist some States in implementing quality management systems. It was observed that while most States were embracing the shift from AIS to AIM, was it was considered fundamental to the evolution that phase 1 of the *Roadmap for the Transition from AIS to AIM* be fully implemented. In particular, it was observed that AIRAC compliance, WGS-84 implementation, and the implementation of quality management systems were elements that still persisted in some states as requiring attention. It was acknowledged that the implementation of these changes was fundamental and required for the migration of AIS to AIM.

2.25 A related observation is that many states have difficulty assigning the resources necessary to implement QMS. This was attributed to the lack of support from Senior and executive management in Civil Aviation Administrations and provider organizations. The group suggested that ICAO might outreach to States at this level in order to encourage the implementation of an organized QMS system. It was also expressed that EUROCONTROL, CANSO and IFAIMA could be approached for expertise and communication with AIS management.

Data Integrity

2.26 It was observed and noted by the meeting that it was always intended that the deletion of the numeric values associated with data integrity would still leave the integrity classifications of “routine, essential, and critical”. Moreover, the integrity classifications assigned to data features would need to be accompanied by process and procedure requirements appropriate to data and information handling for each classification. The development of these procedures would be an important feature of the new PANS-AIM and would also require guidance in Doc 8126. Accordingly, it was recognized that this was important work to be considered in the development of PANS-AIM.

eTOD

2.27 The Chairman presented an update on recent eTOD related activities in Europe. Of considerable interest was the state of implementation in various States and how it related to the provisions not effected by Annex 15, Amendment 36.

2.28 The Chairman noted that while there was an expanding awareness of eTOD availability among prospective users there was a general assessment that the eTOD data that was necessary to meet current needs was less than the requirements specified in Annex 15. The consequence is that European States will be re-evaluating eTOD requirements to align with identified operational needs and will seek to implement a harmonised set of requirements, filing differences with Annex 15 provisions as required.

2.29 Another observation with respect to the use of eTOD in Europe is that the usages of the data involved applications, for example, synthetic vision, which were much more advanced than were anticipated to be available at this time. The deployment of advanced applications indicated an opportunity to develop an eTOD collection specification more closely aligned with operational needs.

2.30 It was also noted by the meeting that the current specifications for eTOD related to the definition of the datasets and the requirements for the data required to be collected. There is not, however sufficient provisions outlining the ongoing requirement to maintain the data. It was proposed that this would be appropriate to be outlined in PANS-AIM and should form part of future work.

2.31 Another issue that was raised was a perceived difference between the requirements of Annex 14 and Annex 15 with respect to data to be provided and other eTOD requirements. As noted earlier in the meeting there was already a recommendation from EANPG/53 to include eTOD in Annex 14. The meeting observed that the *Airport Services Manual* (Doc 9137) - Part 6, Control of Obstacles may also need to be reviewed with respect to eTOD as well as AMDB.

Airport Mapping Database (AMDB)

2.32 The AIS/AIMSG/6 meeting recalled previous discussions on the subject and the proposal to develop criteria for when AMDB is needed. The meeting was apprised of the criteria developed with the objective of providing guidance for the prioritization of AMDB implementation and to outline use cases for the consideration of the AMDB application provision that referenced "where States deemed relevant".

2.33 It was noted by the group that the draft criteria represented a considerable investment of work and contained a thorough list of aerodrome Operational factors. It was considered that one aspect missing was an assessment of equipment and applications that could use the data and an estimate of safety benefits to be achieved after availability of the data and at the percentage of estimated users. This last factor was very much related to a coordinated implementation plan to ensure that the justified use of the data was actually taken up by a user application in sufficient numbers to validate the initial assessment. It was expressed that as the criteria matured, it should be incorporated in the eTOD manual or a future eTOD/AMDB manual.

Charting

2.34 The group was given a verbal report by the Rapporteur of the ad-hoc group on charting outlining the work program being developed and the issues considered to be of immediate relevance by the group. The group noted that progress had been made by the secretariat in developing an electronic version of the *Aeronautical Chart Manual* (Doc 8697). The group appreciated that the availability of an updated manual would improve its distribution as well as having a document that was more easily maintained. Nevertheless, the group was informed that a new series of chart formats would likely be soon available as a consequence of the work of the Instrument Flight Procedures Panel (IFPP) and that a timely method to make them available would be necessary. The group considered that the use of circulars as a distribution mechanism should be explored.

2.35 The meeting discussed Annex 4 and the future of charting in relation to the ongoing evolution of AIM. With this in mind, some concepts resulting from the discussions held by the Ad-hoc group on AIM development at their meeting in Brussels, Belgium 13 to 15 February were outlined.

2.36 One outcome of those discussions was that it was possible that Annex 15 would evolve to an AIM focus that was concerned primarily with the acquisition of information from accountable sources, verifying and validating the information and managing it's availability for other users. In this concept, a primary focus would be the provision of information made available through a SWIM network for integration with information from other domains. However, it was considered that not all users of information would access information through SWIM and that there would be a continuing need for data and information that was assembled into AIS/AIM specific products. With this in mind, certain segments of the aeronautical community would still require aeronautical charts. Furthermore, it was considered that a potential evolution for Annex 4 could focus on the specification of AIS/AIM products and as well as charts Annex 4 could outline the specification for data sets assembled for specific purposes.

2.37 The meeting reviewed a paper from the IFPP/IWG (provided under "other documentation") which reported on trials that have been conducted to derive aeronautical charts from ARINC 424 structured data. The group noted that ARINC 424 was not originally conceived for this purpose and lacked a feature set rich enough to act as source that would fully meet the requirements of most currently specified charts to be included in the AIP. Notwithstanding, the work was considered to have potential application for the graphic display of data contained in the FMS. As the topic of procedure design and AIS/AIM link was deemed relevant, it was suggested to continue the work and aim at defining the data that are required for an efficient procedure encoding into integrated systems (e.g. FMS).

System Wide Information Management (SWIM)

2.38 The meeting received an update from the secretary on the development of a paper outlining the features of a Global SWIM Concept for presentation to the 12th Air Navigation Conference. The meeting was informed that the paper had been developed in consultation with the primary organizations in the FAA and Europe concerning SWIM development and was intended as a catalyst for further development of a globally applicable SWIM Concept.

Future Work Programme

2.39 The AIS-AIMSG/6 reviewed and updated its work programme as follows:

Date(s)/Timeframe		**Event/Milestone**	**Work Deliverables**
2012	Q3/4 2012	Secretariat review of completed manuals	o AIS Manual Amdt3 (Q3/2012) o Training Manual (Q3/2012) o Quality Manual (Q3/2012) o AIM Concept (Q3/2012) o Manual on Public Usage of the Internet update (Q4/2012) o TOD Manual (Q3/2012) o WGS-84 Manual (accuracy & heighting) □ Q4/2012 – 2013 – Full Word file prep o Charting Manual update Q4/2012
	End of July		Estimated Distribution of Amendment 37 State letter
	27-31 August	Concurrent with Air Transport Conference (Washington)	Ad-hoc group meeting on Monday/Friday to discuss AIM development

Date(s)/Timeframe		Event/Milestone	Work Deliverables
	October	Webex/Telephone conf	High Level - Comment Review ?
	7 November	WebEx	Focused sessions on 3 main working areas
	19-30 November 2012	AN-Conf/12 (Montreal)	
2013	14-18 January 2013	AIS-AIMSG/7 (Montreal)	
	4-8 Nov 2013	AIS-AIMSG/8 (…)	
	14 November 2013	Annex 15 Amendment 37 applicable	
2014	Q1/Q2 2014	AIS-AIMSG/9 (….)	
	September 2014	AIS-AIMSG/10 (Montreal)	Finalised (by SG) Amendment 38, PANS-AIM
2015	February 2015	AIM/IM Divisional Meeting (Montreal)	Draft Pans-AIM Draft Amendment 38 + SWIM elements?
2016	November 2016	Annex 15 Amendment 38 applicable & PANS-AIM introduced	Completion of AIS-AIMSG work program

3. ACTION BY THE MEETING

3.1 The meeting is invited to:

a) take into consideration the global AIM developments during the discussion of the progress made towards AIM implementation in the MID Region;

b) review the draft of the *Aeronautical Information Management Operational Concept* at **Appendix A** to this Working Paper and provide comments or suggestions, if any; and

c) follow-up the activities of the AIS-AIMSG through the documentation/ information posted on its website: http://www2.icao.int/en/ais-aimsg.

APPENDIX A

The Aeronautical Information Management Concept

Draft Version 0.9.1
May 2012
Alexander G. Pufahl

Table of Contents

1 Introduction

The Aeronautical Information Management (AIM) concept presents ICAO's vision for the origination, management, sharing and integration of time-sensitive, digital aeronautical information between and among all members of the global Air Traffic Management (ATM) community in a safe, secure and efficient manner. According to the Global Air Traffic Management Operational Concept (ICAO Doc.9854), information management was identified as a foundational enabler of the concept and said to underlie all seven of the concept components. As stated, the "operational concept defines seven interdependent concept components that will be integrated to form the future ATM system. […] The management, utilization and transmission of data and information are vital to the proper functioning of these components[1]". A comprehensive review of ATM-related documents confirms the importance attributable to information management in general, and aeronautical information management in particular[2]. The transition to the Aeronautical Information Management concept will be a gradual transition in parallel to the implementation of the System Wide Information Management (SWIM) network.

Vision Statement

Aeronautical Information Management encompasses the origination, management and distribution of time-sensitive, digital aeronautical information in a safe secure and efficient manner. Gradually, the distribution of aeronautical information will be via a global System Wide Information Management (SWIM) network. When needed, aeronautical information is readily integratable with other relevant information domains to provide shared situational awareness to all members of the global ATM community.

The Aeronautical Information Management concept spans the provision of aeronautical data from source data acquisition to its end users by ensuring the integrity of the data and information throughout all involved processes. Under AIM, aeronautical data and information will be increasingly in digital format, from origination to end use, and the primary role of the AIS office within this data chain will be one of verification and validation of the information.

As we gradually transition to AIM, aeronautical information is being made accessible in a timely fashion via the System Wide Information Management network, from which it can then be accessed by using SWIM-compliant applications to sort, filter and retrieve the information.

[1] ICAO, Global Air Traffic Management Operational Concept, Doc.9854, p.12

[2] See Chapter 12.1, Review Of ATM-Related Documentation.

2 Purpose Of Document

The purpose of the document is to lay down the conceptual foundation for Aeronautical Information Management in support of the Global Air Traffic Management Operational Concept. As such, the document will serve as a point of reference for the comprehensive review and restructure of ICAO Annex 15, Aeronautical Information Services (Amendment 38) as well as Doc.8126, Aeronautical Information Service Manual (Amendment 5) and the development of a new Procedures for Air Navigation – AIM Document (PANS-AIM)[3].

3 Reasons For Change

For decades, the air transportation system has served the purpose well to expeditiously transport people and goods around the world, thereby directly supporting the global economy. However, the demands of modern society are changing, and the complexity of the international air transportation network continues to increase, as does traffic density, especially around metropolitan areas. Already stringent requirements for punctuality and schedule reliability are getting tougher to meet in a tightly interconnected and globally networked route system that suffers from decreasing flexibility due to, for example, higher airplane load factors. Increases in air traffic volume and network complexity introduce gradually changing requirements that challenge the existing ATC concept.

In order to meet the requirements of the global ATM concepts of operation, several aspects of information management need to be improved upon, including operational needs, efficiency objectives and making use of emerging information technologies. The new requirements on aeronautical information encompass improved data quality (i.e., accuracy, resolution and integrity), timely distribution of information, digital exchange and processing of information, and more efficient management of aeronautical information to avoid, for example, manual data input, duplicate data entries, etc.

[3] The focus here is on aeronautical information, and hence ICAO Annex 15 and Doc.8126. However, as we will see throughout, information needs to be integratable across different information domains and as such the AIM concept will also have an impact on other related ICAO annexes and documents (e.g., Annex 4, Aeronautical Charts, Annex 11, Air Traffic Services, Annex 3, Meteorological Service for International Air Navigation, Doc.9750, Global Air Navigation Plan, Doc.4444, Air Traffic Management, Doc.9965, Flight and Flow – Information for a Collaborative Environment, and others).

3.1 Benefits Of Aeronautical Information Management

The intent of Aeronautical Information Management is to offer functional and operational benefits, both tangible and intangible, to the ATM community (defined in Chapter 5). The following table is outlining the causal relationship between AIM features (enablers) and the corresponding benefits.

Table 1: Features (enablers) of the AIM concept and their associated benefits.

Features (enablers) of AIM	Benefits
Aeronautical data and information is available in digital format	Aeronautical data and information is available in digital format throughout the entire data chain from data acquisition to the end users; Faster dissemination of digital data and information thereby reducing transactional friction; Digital data and information supports to maintain the integrity of the data throughout the data chain; Digital information can be tailored to individual operator's needs, thereby increasing operational value;
Aeronautical data and information complies with international standards and exchange formats	Benefits include that digital information can be manipulated more readily and cost effectively by use of automation; Information is more readily integratable with other information sources and other information domains, thereby increasing the operational value of the information;
Aeronautical information is displayed graphically	Relationships between information elements and between different information layers become evident, thereby increasing operational value and achieving greater (visual) transparency into quality issues;
Aeronautical information management processes are streamlined to become more efficient	Increases the quality and timely availability of information, and lower cost of information management by, for example, reducing transactional friction;
Aeronautical information is aggregated and provided by an accountable Single Authoritative Source	Increase in trust in the information user community; Ensures legitimacy and reliability of the information by being traceable to the data originators;
Aeronautical information is accessible system-wide and internationally by all stakeholders	Ready access to aeronautical information by all (authorized) end users results in shared situational awareness, and ultimately, better decision making;
More real-time and relevant aeronautical information is made available during in-flight phase	Increase in operational value due to better situational awareness and hence decision making by the pilot(s);
Aeronautical information is made available under different economic models	Increase in market transparency regarding availability of information; healthy competition to keep aeronautical information affordable to its end users;

Note that it is likely that additional feature–benefit pairs can be identified.

4 The Aeronautical Information Management Concept

The Aeronautical Information Management concept spans various information management processes, including:

- acquisition of aeronautical data from accredited data sources,
- management, verification and validation of aeronautical information,
- access to information via the SWIM network,
- consumption of information with the help of SWIM-compliant applications by end users.

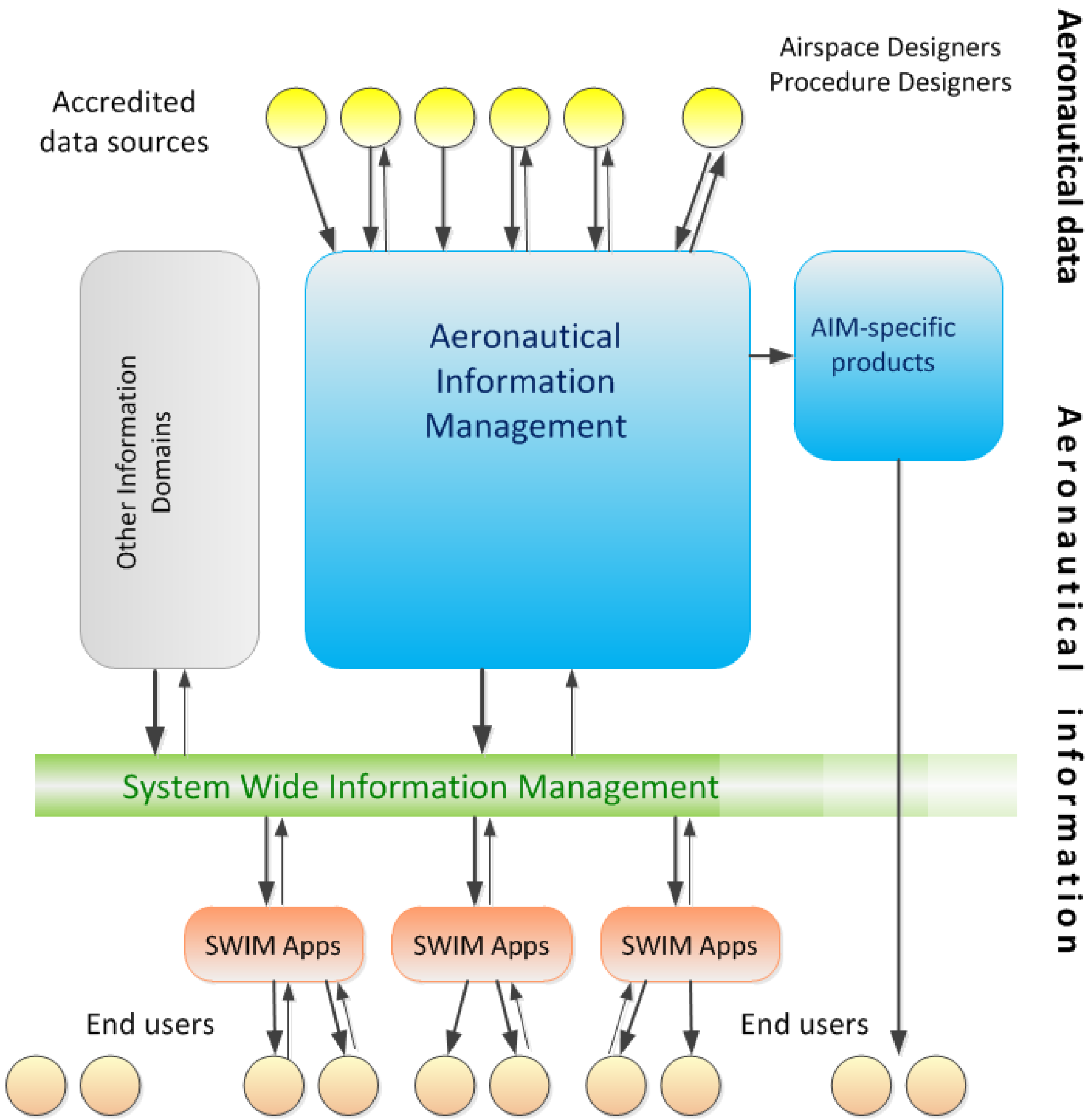

Figure 1 The AIM concept spans information management processes, including data acquisition, management, verification and validation of information, access via SWIM, and consumption of information by the end users through SWIM-compliant applications.

Note, however, that the AIM concept does not explicitly address the SWIM network, the SWIM-compliant applications, nor the definition of the other neighboring information domains, as shown in Figure 1. These subjects are being addressed in a separate but complementary document, to be developed, describing the SWIM concept.

In general, information is being consumed for decision making, including information from the aeronautical information domain. These information can be, if needed, readily integrated with information from other information domains, like meteorological, or flight and flow information. As we shall see in later chapters, this information can be further subdivided into classes, categories and subdomains. Within the aeronautical information domain, for example, it is possible to identify four categories with different characteristics. These categories comprise aeronautical source data, as well as terrain, obstacle and cultural data. However, distinguishing these categories does not imply that the data have to be stored in separate data bases, nor that the data do not complement each other. What it means is that it is possible to identify differences in data characteristics within each of these categories, and that there even are further sub-categories within a given data category. For example, aeronautical data comprise real and virtual data. In particular, virtual data describe non-physical, hence virtual aeronautical entities like airspace structures or airways, whereas “real” aeronautical data describe physical objects like airport and runways.

As shown in Figure 1, aeronautical information is being made accessible via the System Wide Information Network, from which it can then be accessed by using SWIM-compliant applications to sort, filter and retrieve the information. End users of the information include most all members of the ATM community, with pilots, controllers and dispatchers being the users who require operational access to aeronautical information. Even under the AIM concept, it is likely that some aeronautical information will continue to be provided directly to certain end users through AIM-specific products, like specific aeronautical charting products, and VFR charts in particular.

A notable exception to the predominantly linear relationship between the provision of source data and use of aeronautical information are airspace designers and instrument procedure designers. These user groups in particular are users as well as providers of aeronautical information as shown in Figure 1**.** Also shown in the figure are the important feedback mechanism through which the system can stay adaptive to changes in the requirements and operative conditions. However, not all end users, nor all data originators are required to provide feedback.

In summary, the AIM concept spans the provision of aeronautical data from source data acquisition to its end users by ensuring the integrity of the data and information throughout all involved processes. Under AIM, aeronautical data and information will be increasingly in digital format, from origination to end use, and the primary role of the AIS office within this data chain, will be one of verification and validation of the information.

5 Users of Aeronautical Information

The air transportation system is a complex network of people, systems and processes[4]. Collectively, the people involved in managing air traffic are referred to as the ATM community and, according to the Global Air Traffic Management Operational Concept (Doc. 9854, Appendix A) comprise, in alphabetical order:

- Aerodrome community
- Airspace providers
- Airspace users
- ATM service providers
- ATM support industry
- International Civil Aviation Organization
- Regulatory authorities
- States

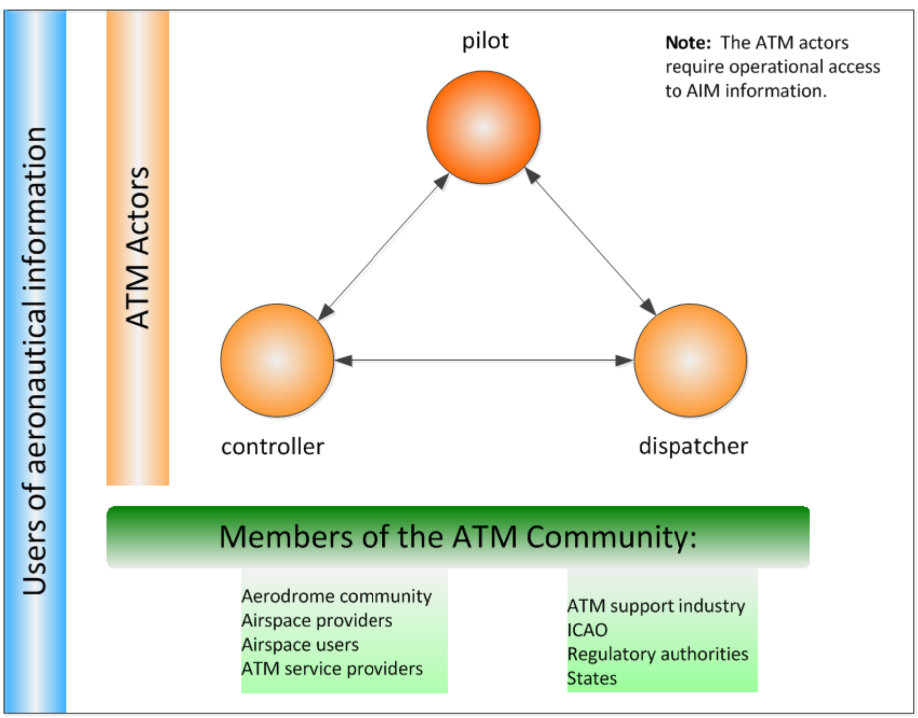

Figure 2 All members of the ATM community are users of aeronautical information; it is the ATM actors that require operational access to it.

[4] See Chapter 12.3 ATM Is A Complex System for a discussion of what constitutes a complex system.

Within that ATM community, there are producers and consumers of aeronautical data and information, and then there is a particular user group that is directly and actively engaged in all facets of flight operations. These end users are the controllers, pilots and dispatchers, and we refer to them as the ATM (operations) actors, as shown inFigure 2. These actors require direct operational access to aeronautical information. They are becoming increasingly and tightly interconnected, via broadband Internet Protocol (IP) connection or data link. In particular, by having continuous access to a plethora of aeronautical information, these ATM actors share common situational awareness within this global net-centric environment. Thus, they can now make better and faster operational decisions - collaboratively.

As mentioned in Chapter 6, some members of the ATM community are both, producers and consumers of aeronautical data and information, like airspace designers and instrument procedure designers, and yet others help shape the air transportation system from a more strategic perspective, the latter being, for example, airport planners, airspace planners, ATM reaserchers, etc.

Another way of looking at who within the ATM community is an end user of aeronautical information is shown in Table 2. Here, members of the ATM community are identified according to the different phases of the operation, namely Planning and Reference, Pre-flight, In-flight, Turn-around and Post-flight phase. The turn-around phase is mentioned here to help identify the information end users during this critical operational phase between subsequent flights. As we can see, all members of the ATM community are users of aeronautical information during planning and reference as well as during the post-flight phase. It is during the critical in-flight as well as the turn-around phase, that only the aforementioned ATM actors are information users.

Table 2 Analysis of who within the ATM community is a user of aeronautical information during the various phases of the operation.

	Planning & Reference	Pre-flight	In-flight	Turn-around	Post-flight
Aerodrome community	x	x		x	x
Airspace providers	x	x	x		x
Airspace users	x	x	x	x	x
ATM service providers	x	x	x	x	x
ATM support industry	x	x			x
ICAO	x				x
Regulatory authorities	x				x
States	x				x

As will be discussed in the following chapter, we note that, in general, there is a well-established, one-dimensional aeronautical data chain, from source data acquisition to end user, with the exception of airspace designers and instrument procedure designers who play a dual role as producers and consumers of aeronautical data and information, as mentioned previously.

6 Aeronautical Data Chain

The traditional aeronautical data chain, shown in Figure 3, is a "series of interrelated links wherein each link provides a function that facilitates the origination, transmission and use of aeronautical data for a specific purpose"[5]. It can be divided into upstream data operations, comprising source data originators and the State AIS offices, and the downstream data operation, encompassing commercial data and information providers as well as the end users, both in the air and on the ground. The main areas of concern within the aeronautical data chain include:

- non-harmonized origination of aeronautical source data;
- reliance on manual processing and manipulation of aeronautical data and information;
- insufficient awareness of the information quality requirements of end-use applications;
- need for enhanced validation and verification practices to assure the integrity levels for critical and essential data and information are achieved;
- potential lack of synchronization of aeronautical data in navigation databases (airborne and ground-based) and between these databases.

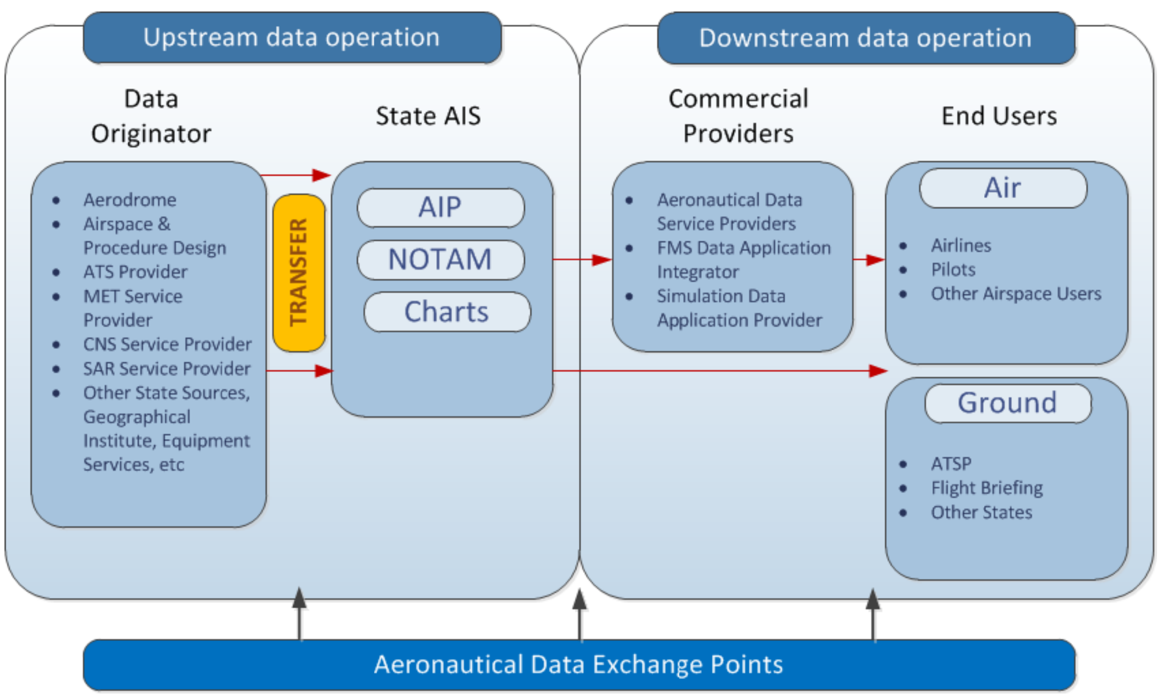

Figure 3 The traditional aeronautical data chain can be divided into upstream and downstream data operations.

5 RTCA DO-200A / EUROCAE ED-76, Standards for Processing Aeronautical Data.

Within this data chain, there are three distinct data exchange points that define the interface between the various entities. The use of non-harmonized media and formats across these interfaces leads to what has been termed "transactional friction". According to the ICAO Manual on Air Traffic Management System Requirements, Doc.9882, the ATM system shall "support a reduction in transactional friction for transmission of information across systems", implying the use of standardized information exchange formats. AIM supports the goal of a highly efficient aeronautical data chain, as discussed further in Chapter 6.

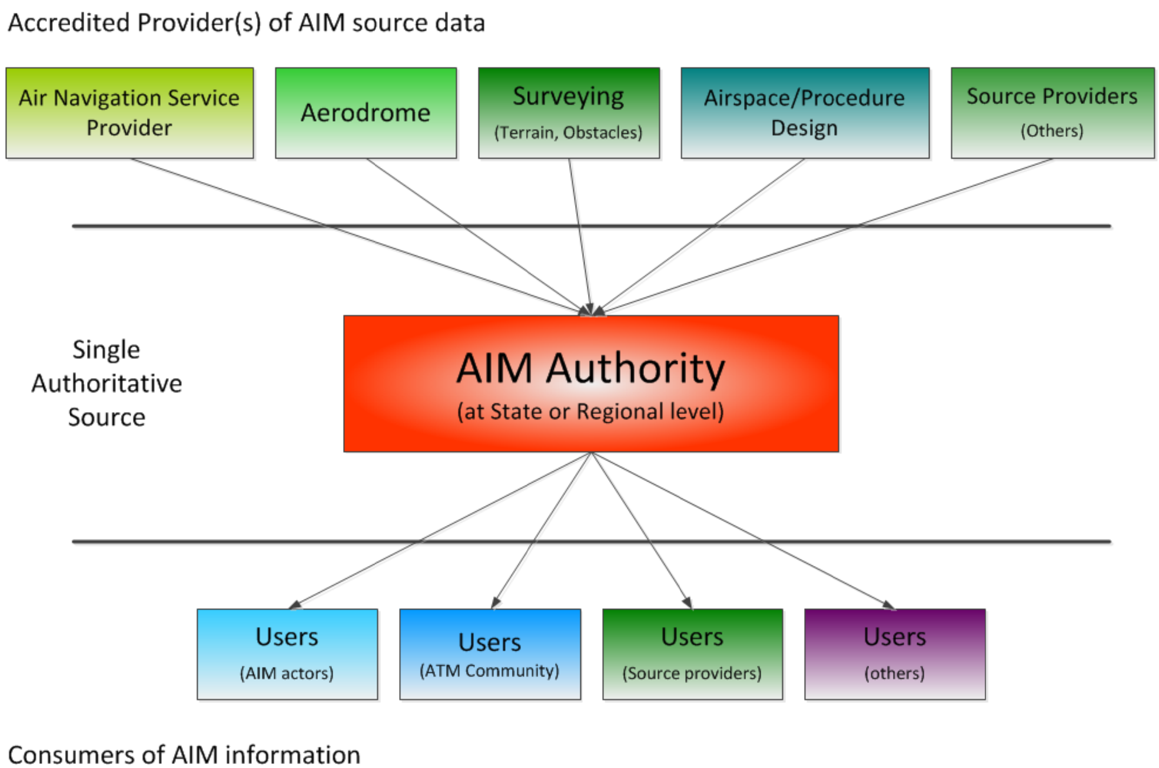

Figure 4 The intent of the Single Authoritative Source (SAS) is to have a single accountable entity that aggregates all aeronautical information from a variety of accredited information source providers.

The notion of Single Authoritative Source (SAS) for all aeronautical data and information is shown in Figure 4. The intent is to have a single accountable entity that aggregates all aeronautical data from a variety of accredited source data providers. The source data providers encompass surveyors, airspace and instrument procedure designer, airport personnel, as well as the Air Navigation Service Provider. The entity to act as Single Authoritative Source should be at the State (or regional) level and would, in most cases, be a State's Civil Aviation Authority (CAA). In either case, the establishment of appropriate Service Level Agreements (SLA) is very important to clearly assign roles and responsibilities. Ultimately, however, it is the Single Authoritative Source that is responsible and also held accountable for the provision of timely and quality-assured aeronautical information. In rare circumstance, however, a difficult situation arises when the Single Authoritative Source itself cannot resolve an issue like the determination of a state boundary in the case of a border dispute between neighboring states. In such a situation, it is the regional authority that needs to resolve the issue.

In this context, it is helpful to differentiate between authentication and authorization. Authentication here means to ensure that the AIM data source(s) are legitimate, i.e., looking upstream, whereas authorization means to ensure that the end users of AIM information are legitimate, i.e., looking downstream.

7 Characteristics of Aeronautical Information

Aeronautical information describes the reality of the air navigation infrastructure within its underlying geospatial context, and the status and condition of that infrastructure as it changes over time. Thus, aeronautical information is characterized, primarily, as:

- Geospatial information, i.e., expressible in the three dimensions x, y and z;
- Information that has temporality, i.e., it changes over time t.

An overarching criterion for aeronautical information is that it has to be “fit for its intended (operational) use”. This important criterion affects all subsequent characteristics of information, most notably quality. Despite the fact that we intuitively understand the notion “fit for its intended use”, the statement is difficult to pin down in terms of specific requirements. It implies that aeronautical information can cover the gamut from “nice to know” information to “highly critical” information. To make matters worse, sometimes, a piece of information can be both. For example, the localizer and glideslope information of an Instrument Landing System (ILS) when hand-flying a light aircraft under Visual Flight Rules on a perfectly beautiful day can be considered as “nice to know” information. However, that same piece of information is “highly critical” when a commercial airliner is flying a fully automated ILS Category III approach (also known as “autoland”) in zero visibility conditions under Instrument Flying Rules. In either case, the aeronautical information has to be “fit for its intended use”.

However, over time, new concepts of (intended) use can emerge, some of which can be anticipated without yet being able to formalize the associated information requirements. For example, new aircraft systems are soon to enter the air transport system, including unmanned aerial systems and commercial spacecraft. Additionally, the concepts of high-density operations around airports, trajectory based operations, continuous climb/descend operations, etc. will place yet undeterminable requirements upon aeronautical information, as do the notions of autonomous airspace within which it is planned to delegate separation, or to even conduct self-separation.

Other factors that affect whether information is "fit for its intended (operational) use" are dependent upon, for example, an aircraft's capabilities. In this case, it may be evident that the quality requirements of a terrain database for a stand-alone Synthetic Vision System (SVS) have to be higher than for an aircraft that features a Combined Vision System (CVS) comprising a Synthetic Vision System with an Enhanced (Flight) Vision System (EVS). In the latter case, the digitally generated imagine is constantly being "validated", on the fly, so to speak, by superimposing the enhanced real-life view of an advanced infrared or similar sensor. As such, the sole dependence on critically important information has been mitigated.

Other than the intended use of information, also the way we disseminate aeronautical information has an affect on its generic characteristics; these can be stated as:

- Digital – that is, information is provided in an adequate digital format thereby facilitating the manipulation, management, dissemination and graphical rendering of the information.
- Integratable – that is, information is based upon open standards that provide global definitions for information domains, information models, information exchange schemas, information lexicon, etc. The ready integration of information facilitates discovery of relationships between information elements, for example, in context, space or time.
- Graphical – that is, information is readily and graphically displayable which helps to increase the operational usability and potentially the ability to more readily spot quality issues.
- Seamless – that is, barriers between different systems are removed through common interfaces. Thereby, the function of System Wide Information Management becomes totally transparent to the end user(s).
- Discoverable – that is, information can be searched and filtered using geographic information for location-based filtering, temporal information for time-based filtering, and semantic filter for keyword-based filtering, and thereby help identify its relevance to a current or projected (i.e., in the future) operational situation;
- Accessible – that is, information is made available to all authenticated end users through different messaging mechanism and distributed via a range of information products and services to accommodate each end user's needs.
- Traceable – that is, the origin of every piece of information can be determined thereby permitting an assessment of, for example, the quality and reliability of information and whether it is from an accredited data source.
- Addressable – that is, every piece of information, for security or other reasons, can be targeted at a specific end user(s).

In addition to what fundamentally are more technical characteristics, information has to also fulfill certain important legal and economic requirements. These include copyright issues, liability as well as the cost of information and its associated administrative overhead.

7.1 Temporality Of Information

Temporality means "dependent on time". All aeronautical information changes over time, but to varying degrees in terms of frequency or magnitude.

Annex 15 states that the "AIP constitute the basic information source for permanent information and long duration temporary changes." It goes on to say that "Temporary changes of long duration (three months or longer) and information of short duration which contains extensive text and/or graphics shall be published as AIP Supplements[6]." Furthermore, "A NOTAM shall be originated and issued promptly whenever the information to be distributed is of a temporary nature and of short duration or when operationally significant permanent changes, or temporary changes of long duration are made at short notice, except for extensive text and/or graphics[7]." Thus, the AIP, AIP Supplements and NOTAM are different (paper) means to distribute aeronautical information with different temporalities.

The Aeronautical Information Services Manual, ICAO Doc.8126, introduces the notion of static, basic[8] and dynamic information "which can be made available in an automated AIS system centre database[9]", in the sense that "static", or permanent information is being published under the 28-day AIRAC cycle in the form of the AIP, and "dynamic" information is distributed in "real-time" as NOTAM. A critically important product based on data contained in the AIP is the assembly of certified navigation databases for Flight Management Systems (FMS)[10].

Under the Aeronautical Information Management concept, the notion of temporality also has to abide by the "fit for its intended use" criterion in the sense that information has to be available to its end user(s) when they need it. This requirement directly affects the means of information dissemination. Of course, this also depends on the criticality of the information. However, to determine all aspects of temporality for aeronautical information would require a complete functional

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[6] See ICAO Annex 15, 4.4.1 (Specifications for AIP Supplements)

[7] See ICAO Annex 15, 5.1.1 (NOTAM)

[8] ICAO Doc.8126, Chapter 2.2 states that "Basic information usually covers the more permanent or static material destined for inclusion in the AIP and, as such, should preferably be authorized by the policy branches at headquarters level in order to ensure uniform format and compliance with present or future policy. All basic information should be supplied well in advance to the AIS to permit enough time for processing and distribution, thus affording reasonable advance notice to operators."

[9] See ICAO Doc.8126, 9.5.1 (Database contents)

[10] The primary function of the Flight Management System is to guide the aircraft along the flight plan utilizing a variety of sensors, including Inertial Navigation System (INS), Global Position System (GPS) and radio navigation aids.

decomposition of every piece of information, from the view of every single stakeholder, taking into account available technologies and distribution mechanism, and the intended use of that particular piece of information. Based on that analysis, the associated criticality and temporal requirement would be derived. Needless to say that this would be an enormous (if not impossible) endeavor.

Ultimately, the purpose of information is to reduce uncertainty and to increase the predictability of the air traffic management system; one means of achieving this is through the timely availability of information. Certain large scale, big impact changes to the air navigation system, for example, do benefit from being announced 56 days (or even longer) in advance of the effective date[11]. This oftentimes involves more strategic stakeholders like airport planners, airspace planners, airline route planners, and possibly commercial data providers. The operational purpose of advance notification up to and including permanent data is what we refer to as Planning and Reference, whereas the operational purpose during Pre-flight involves a combination of permanent information and temporary changes, including NOTAM. During the In-flight phase, the temporality of the information needed falls into the realm of operationally directly applicable information and these temporary changes closer to near-real-time involving pilots and air traffic controllers.

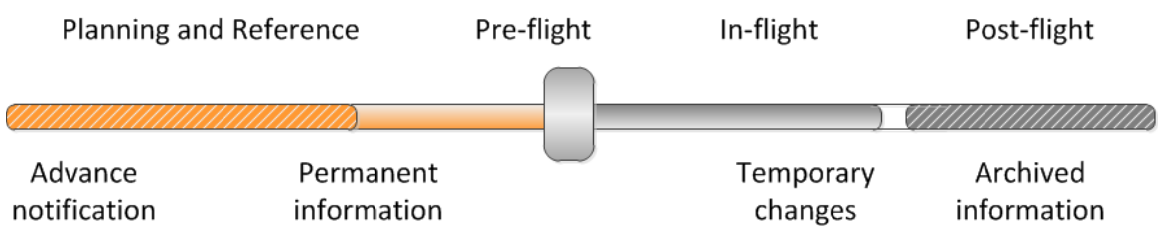

Figure 5: The time continuum of information across the various operational phases, including Planning and Reference, Pre-flight, In-flight and Post-flight, acts like a slider going from advance notification via permanent to temporary changes. Archived information is used primarily for post-flight analysis.

Finally, the Post-flight phase provides an important feedback mechanism back into the system. It thereby serves as a fully integrated mechanism of the SWIM network to stabilize what may turn into a self-regulating adaptive system[12]. Post-flight also provides an opportunity for analysis of single or aggregate trajectories using archived information.

A challenging aspect of temporality is to know who is having access to what information for decision-making purposes. The temporalities need to either be transparent, i.e., known to the system or somehow be synchronized. For what

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11 See ICAO (2003). Aeronautical Information Services Manual, 6th edition. Chapter 2.6.7.

12 Also referred to as *autopoiesis*. See Horx, M. (2011). Das Buch des Wandels. Pantheon Press. pp.257 and http://en.wikipedia.org/wiki/Autopoiesis

should not happen is that critical information is not transmitted based on the assumption, “They already know that”. For example, air traffic control is issuing a clearance to land, based on the wrong assumption that the pilot is already aware of the status of the runway. In either case, appropriate regulations, systems and processes need to be in place to ensure the timely delivery of the information to all its users, and for the system to “know” who is using what information.

Furthermore, there is an expectation for more real-time information being provided to the end users under the Aeronautical Information Management concept. However, real-time information is not a panacea to solving the problem of unpredictability inherent in a complex system like ATM. As a matter of fact, more real-time information will turn into a problem itself while being applied as the solution.

7.2 Quality Of Information

According to Annex 15, data quality is defined as a degree or level of confidence that the data provided meets the requirements of the end user(s) in terms of accuracy, resolution and integrity. Ultimately, the quality of aeronautical information depends on its intended use and needs to be determined from this perspective. However, as we have seen in Chapter 7, it is difficult to determine the “intended use” of the information, or to avoid misuse.

In either case, quality always comes with cost, and the higher the quality of the source data, the higher the cost involved in obtaining it. However, if a set of information is obtained at one level of quality for user group A, and at a higher level of quality for user group B, as is common practice today, then user group A may be have the benefit of cheaper access to information and user group B the benefit of higher accuracy information, but collectively, they pay the high price of duplicating the information. In addition, they run the risk of creating disparate sources of aeronautical data that do not integrate. As a matter of practical consideration, one could compare the cost of obtaining all data with the highest required level of quality against the cost of creating disparate sources. In the end, it may be a balance of these two approaches that works best.

In addition, the quality of information becomes more transparent when integrating different data sources. For example, the production of digital aeronautical charts saw the integration of several electronic databases, including terrain database, obstacle database, aeronautical information database, airport mapping database, cultural database, etc. In this case, it quickly becomes obvious, when a piece of information from one database does not reconcile with another piece of information from another database.

The opportunity of integrating and graphically displaying the information throughout all information management processes, and the transparency that this creates, will help to reduce discrepancies and hence improve overall quality of aeronautical information. This, together with the integrated feedback mechanism of the SWIM network is an important aspect of self-regulating adaptive systems.

8 Aeronautical Information Domain

Aeronautical Information is one of several information domains that will be managed and disseminated via the SWIM network (for a discussion of other information domains, see Chapter 12.6). Aeronautical information describes the physical (visible) and virtual (non-visible) air navigation infrastructure in a geospatial and temporal context, and the status and condition of that infrastructure (e.g., runway status “open” or “closed”, airport condition “VFR”, “MVFR” or “IFR”).

As stated in the Roadmap for the Transition from AIS to AIM, “the transition to AIM will not require many changes in the scope of aeronautical information to be distributed.”[13] Assuming this to be a true statement, aeronautical information will therefore continue to encompass all data elements as presently contained in the Aeronautical Information Publication and its supplements, terrain and obstacle data, airport data, cultural data, and all data elements that are currently transmitted via NOTAM, as well as its related metadata[14].

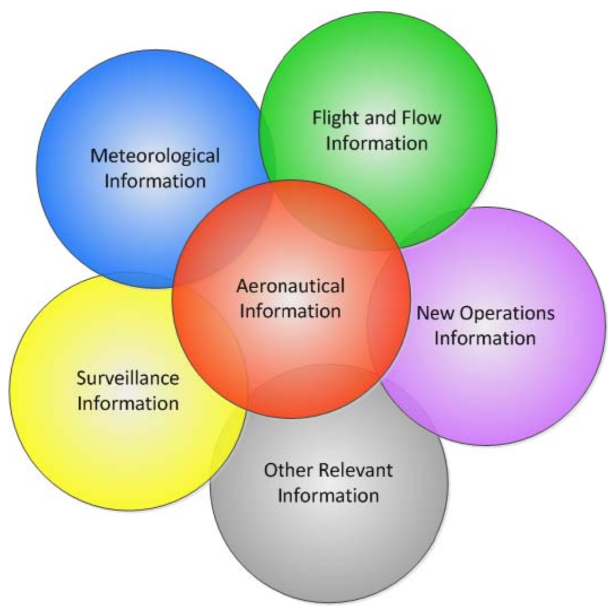

Figure 6: Aeronautical information shown in relation to other information domains. Note that depending on one's individual perspective, that perspective becomes the “central” information domain.

It is important to highlight the uniqueness of aeronautical information when compared to other information domains in that it not only describes physical air navigation features, like airports, runways and navigational radio transmitters, but also virtual features, like airspace, airways and instrument procedures. Virtual features exist only as data and have to be rendered graphically to become visible, like on an Instrument

[13] ICAO, Roadmap for the Transition from AIS to AIM, first edition, 2009. p.(v)

[14] Metadata is “a structured description of the content, quality, condition or other characteristics of data”, as defined in ICAO, Roadmap for the Transition from AIS to AIM, first edition, 2009.

Approach plate. Unlike physical features, however, virtual features are completely and holistically described by their data. On the other hand, the reality of physical features is oftentimes such that they can only partially be captured by their data. Trying to completely and holistically capture the Earth's surface via a Digital Elevation Model is an example of such an impossible undertaking.

Another important aspect of aeronautical information is that the information content does not change as frequently or as rapidly as the technology utilizing it. For example, the vast majority of the information content of present-day Aeronautical Information Services (Annex 15) and Meteorological Services (Annex 3), is still as applicable as it was when AIS and MET were first conceived. Tomorrow's pilots still need to know where an airport is located, what runway and what kinds of services are available. The same holds true for meteorological information like wind speed and direction, temperature and dew point, as well as barometric pressure. What will change, however, are some of the information requirements, like data quality and integrity, or how quickly that data should be made available. In addition, an assessment of the operational impact of the information becomes increasingly important rather than simply providing the information itself.

The key characteristics of aeronautical information as per the AIM concept can be stated as follows:

- Aeronautical data is captured digitally at origination;
- Aeronautical information is digitally represented, stored in a digital database, from which it can be retrieved in order to be sorted, filtered, graphically displayed, or otherwise manipulated and digitally disseminated;
- Aeronautical information is readily integrated, or integratable with other information domains; the integration of aeronautical information also encompasses air-ground integration, as well as the usability by automated information systems and decision support tools;
- The integrity of aeronautical information is maintained throughout the aeronautical data chain;
- Aeronautical information is graphically displayable thereby showing relationships between information and between different information layers, thereby exposing potential quality issues;
- Aeronautical information is globally harmonized via common data definitions, data models, data exchange formats, measured using agreed upon units of measurement and common frames of reference;
- Aeronautical information can be transmitted via data link to, from and between aircraft, and via SWIM among all ATM stakeholders;
- The temporality of aeronautical information is adequate for operational decision making throughout all phases of flight, and includes Planning and Reference, Pre-flight, Inflight, Turn-around and Post-flight;
- Aeronautical information is operationally relevant and directly supports operational decision making processes;

9 Modeling Aeronautical Information

At some point, when the information one is dealing with exceeds a certain volume or level of complexity, and there are multiple users trying to access, sort, filter, or otherwise manipulate the information, irrespective of whether it is in paper or in digital format, one will definitely want to structure the information. The laborious task of creating such a structured information framework is called information modeling, and the people performing that task are referred to as information architects. Information modeling requires an appreciation and understanding of the domain(s) to be analyzed. Only then can consistent naming conventions be established, data definitions be developed, certain information be identified as key entities of that domain, other information recognized as providing important supplemental data about the data, which is known as metadata, or information placed into a nested hierarchy of interrelated categories and sub-categories, sometimes referred to as a taxonomy. Additionally, dynamic relationships between information elements can oftentimes be identified that are expressible via sophisticated business rules, or other rules that directly impact the quality of the information itself.

Managing large quantities of information is a primary function of information systems. A *data model* describes structured data for storage in data management systems such as relational databases. A data model is an abstract model that organizes, structures and documents data for communication between primarily information systems. It is used for developing software applications, database models, as well as for enabling the exchange of data.

According to the American National Standards Institute (ANSI), a data model may be one of three kinds:

- *Conceptual data model* describes the semantics of a domain. Also referred to as a semantic data model, it is an abstraction that defines the meaning of data within the context of its interrelationships with other data. A semantic data model is an abstraction that defines how the stored symbols relate to the real world. The real world, in terms of stakeholders, resources, operations, etc., is symbolically defined within physical data stores. Thus, the model must be a (close enough) representation of the real world. The Aeronautical Information Conceptual Model (AICM) was an example of a conceptual data model in an early version of AIXM[15].
- *Logical data model* is an abstract representation of a particular domain's data based on the structures identified in the preceding conceptual data model. It is organized, for example, in terms of entities and relationships and is

[15] In newer versions of AIXM (Version 4.0 and beyond), the conceptual models are now created by NextGen (OV-7) and SESAR (AIRM). Note that Operational View 7 (OV-7) is the Logical Data Model under the U.S. Department of Defense Architecture Framework (DoDAF), whereas the ATM Information Reference Model (AIRM) contains all the information constructs that will be used throughout SESAR (http://www.sesarju.eu/sites/default/files/documents/events/AIRM_Executive_Summary.pdf).

independent of any particular data management technology. However, the logical data model of a database management system (DBMS) cannot totally satisfy the requirements for a conceptual definition of data, because it is limited in scope and biased toward the implementation strategy employed by the database management system. The Aeronautical Information eXchange Model (AIXM[16]) is an example of a logical data model.

- *Physical data model* is a term used in relation to data management. It describes the physical means (i.e., files and indices) by which data is stored in a particular DBMS (e.g., Oracle, Microsoft SQL).

An information architect uses a variety of different models and methodologies, including those described above, in order to capture the tremendous information density that is characteristic of a complex system like the global air transportation system [17]. It is not surprising that a lot of effort has already been put into modeling aeronautical information. Since 1997, EUROCONTROL has worked on the Aeronautical Information eXchange Model (AIXM) and has been joined in 2003 by the FAA. Their modeling activities also include the Aeronautical Information Conceptual Model (AICM) as well as the Aeronautical Information Reference Model (AIRM).

In general, a *model* is, by definition, an approximation to the infinite complexity of reality. A model can therefore never capture the pluriformity and diversity or the entire spectrum of variations encountered in the real world. At best, a model describes the gross characteristics of reality, or some particular aspects of a reality that one is interested in. A model, therefore, is simplification. However, a model is trying to capture essential aspects of reality when looked at from a certain singular perspective. Ultimately, the goodness of a model depends upon whether it fulfills its use case. Therefore, one has to be constantly cognizant of the limitations of a model, and to use it accordingly.

The purpose of modeling information is to facilitate and harmonize the management and distribution of digital information. One of the assumptions is that a harmonized information exchange model will help reduce transactional friction inherent in the information management processes and thereby increase the efficiency of the aeronautical data chain. A result of this is to improve the timeliness of information and reduce the cost of information management. However, an information exchange model also has implicit limitations.

A popular way of modeling structured information is to use the eXtensible Markup Language (XML). Initially designed for modeling of documents, it is now increasingly and successfully being used for the representation of arbitrary data structures. A common criticism of XML is its verbosity and complexity, which make it

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[16] Note that the AIXM term encompasses both the logical data model (AIXM UML) and the physical date encoding format (AIXM XML Schema).

[17] See Chapter 12.3, ATM Is A Complex System, for a discussion of what constitutes a complex system.

cumbersome, at times, to manipulate, to transmit, or to store[18]. In addition, information models undergo evolutionary changes, and version control is always a challenge in dynamically evolving environments. The management of aeronautical information worldwide needs to be cognizant of these challenges.

It is a known fact, that the global aeronautical infrastructure is far from being uniform. Despite international Standards and Recommended Practices (SARP), aviation is a system that is characterized by having many exceptions to every rule. And even if the aeronautical infrastructure itself would be fairly harmonized, for example, the airspace classification scheme, then there is diversity in how it is being used operationally in different parts of the world. The challenge that the information model faces is how to be harmonized if the underlying aeronautical infrastructure, or its operational use is not.

Another unique aspect of aviation is that certification of onboard avionics is a lengthy and very costly endeavor. According to the Joint Planning and Development Office's (JPDO) NextGen Avionics Roadmap, this process takes on average between 15-20 years to develop design standards, build, certify, and install aircraft equipment[19]. It is therefore an understandable and needed desire to minimize transactional friction and introduce tight information standards the closer to the airplane's flight deck the information gets. However, the same requirements do not apply equally across all aeronautical information management processes.

An often-heard argument is that information modeling permits taking a data-centric rather than a product-centric perspective. In essence, however, this statement is a fallacy. Information modeling will always, at least in part, reflect the operational use and user of the information. For the most part, information will be modeled such as to facilitate its intended use, be it to be searched, sorted, accessed, retrieved, displayed, disseminated, stored, ingested, or otherwise manipulated by man or machine, including its integration into various products and services. Information will also be structured differently for different user groups since they use the information differently, sometimes even call it differently, assign it different priorities, or consider different quality requirements. Of course, the point is not to create a different model for aeronautical information depending if a procedure designer is using it, or an air traffic flow manager, a pilot, or a ground handler, but one needs to carefully balance the variety of different perspectives and requirements.

In addition, it is not possible to model operational concepts that do not yet exist. For example, the information requirements of Trajectory Based Operations are not yet well understood and hence it is unknown whether the information models in existence today or in development will accommodate the information requirements

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[18] Retrieved from http://en.wikipedia.org/wiki/XML_Schema_(W3C)#Criticism and www.sgmlopen.org/tag/criticisms-of-xml-schema

[19] Joint Planning and Development (2011). NextGen Avionics Roadmap, Version 2.0. pp.4

of the future. Therefore, information models need to be agile and adjustable enough to adapt with the emerging new operational concepts that aviation faces, like Continuous Descent and Climb Operations, planning and execution of ground trajectories, etc.

Clearly, the information exchange between sub-systems of the ATM system needs to be facilitated, and ideally be harmonized. However, to what extend and at what level will be a challenge. An over-specified or too unwieldy information exchange model, however, may prove to be inflexible and create a too rigid interface that may jeopardize the cohesiveness of a tightly interconnected complex system. Striking the right balance is probably the greatest challenge for information architects and regulators alike.

10 Distribution Of Aeronautical Information

Aeronautical information needs to be correct, complete, accurate and reliable, discoverable, searchable, secure, affordable, and come from a trustworthy source. It needs to abide by open standards such that it is readily integratable with other information sources and that it can also be readily exchanged among different stakeholders and their systems. Information needs to be displayable graphically, in color, in two or more dimensions, and using moving map displays. Information needs to be timely, and it needs to reach the users where needed, worldwide. That last point concerns the distribution of information.

The traditional distribution channels had aeronautical information published on paper medium and shipped by mail to its end users. This process is described in detail in Annex 15, Aeronautical Information Services, and the corresponding Aeronautical Information Services Manual (Doc.8126). This process has been successfully practiced for the past few decades. Pilots around the world carry big heavy bags full of paper charts and other aeronautical documents with them wherever they went, including folders containing printouts of NOTAM, flight plan forms, weight and balance sheets, as well as printed weather briefings. In short, aeronautical information was published on paper and distributed by mail or by hand, everywhere.

Over time, data houses began to manually transcribe the information for storage in databases to subsequently serve as input into a range of digital products, including navigation databases, airport mapping databases, terrain and obstacle databases, etc. and electronic applications like data-driven charting, procedure design tools, or flight planning software. Historically, one of the first digital products in aviation was the navigation database for the Flight Management System. But even then, the onboard electronic navigation data cards are still sometimes distributed by mail and have to be manually uploaded on the flight deck by the pilot or by maintenance personal every 28 days. In short, the traditional distribution channel was by mail or by hand, using as distribution medium primarily paper. The speed of distribution was oftentimes measured in days, if not weeks.

Table 3: Distribution of aeronautical information under the traditional product-centered Aeronautical Information Services concept is listed per Distribution Medium, Distribution Channel, Connection Type, Involved Actors, and Speed of Distribution.

Aeronautical Information Products	Distribution Medium	Distribution Channel		Connection Type	Involved Actors	Speed of Distribution
Aeronautical Information Service						
AIP, AIP SUPs, AIC, charts	Paper	Mail		G-G	AIS office, data house, airline, pilot	Very slow
			Hand	G-G	ANSP, airport, data house, airline, pilot	Slow
Some relevant aeronautical information, e.g., ATIS	Voice	VHF/HF		A-G	Controller, pilot	Fast
NOTAM	Telex, digital	AFTN		G-G	ANSP, AOC	Fast
Some relevant aeronautical information			ACARS	A-G	Dispatch, pilot	Fast

The goal of the aeronautical information management concept, on the other hand, is to formalize, on a global basis, digital media and electronic distribution channels. Thus, the ATM community can leverage the high speed of broadband Internet Protocol (IP) or data link connectivity whether by satellite or ground-based infrastructure. In either case, transmission speeds are measured in milliseconds for transferring the gamut of digital products and services. In addition, digital distribution of information will also fully leverage the associated benefits of increasingly popular mobile devices or social networks.

The distribution of aeronautical information under the AIM concept is summarized in the following table (Note that instructions by ATC will still be conducted by voice over VHF/HF radio; however, the transmission of aeronautical information will be entirely by data link services):

Table 4: The distribution of aeronautical information under the Aeronautical Information Management concept is listed per Distribution Medium, Distribution Channel, Connection Type, Involved Actors, and Speed of Distribution.

Aeronautical Information Products	Distribution Medium	Distribution Channel		Connection Type	Involved Actors	Speed of Distribution
Aeronautical Information Management						
All aeronautical information	Digital	Broadband IP		G-G	Entire ATM community	Ultra fast
All operationally relevant aeronautical information			Data link	A-G	Pilot, controller, dispatch	Very fast

Throughout aviation's history, it has always been a challenge to communicate with the pilot(s) onboard aircraft. Hand signals and light signals were used initially, and capabilities expanded tremendously with the advent of VHF/HF radio communication. Until this day, and depending on the operational need, each of these methods can be used as the primary or back-up means of communication with aircraft while airborne or on the ground.

Based on the emerging technology of globally available, high-bandwidth data link communications, as shown in Table 4, an initial set of data link services has evolved to the point to reliably communicate with aircraft. Irrespective of where they are, during what phase of flight, or what information they need, data link services can provide high-quality, time- and flight-critical information to the pilot(s), every time, all the time.

To make data services operationally viable, information must be collected and carefully pre-processed on the ground to ensure that stringent quality requirements are consistently being met. The information is then transmitted to the aircraft via data link, where it is received, stored and processed by onboard information management systems. Depending on its operational use or applicability, the information can be retrieved and displayed graphically to the pilots, or via other appropriate onboard visual or aural system interfaces. In either case, data linked information supports the pilots in their myriad of operational decision making processes, day in, day out.

As discussed in Chapter 5, aeronautical information needs to be distributed among all members of the ATM community, in particular those referred to as the ATM (operations) actors, namely pilot, controller and dispatcher. This requires bi-directional distribution channels of sufficient bandwidth between stakeholders on the ground and in the air, i.e., ground-ground (G-G), as well as air-ground (A-G) connectivity. The end points of these distribution channels, in either direction, can be man or machine. This means that aeronautical information needs to be structured such as to be optimized for digital transmission, that it can be readily ingested by the corresponding information management systems, as well as capable of being displayed in a way that meets the operational requirements of its end users, including textual or graphical display of the information. The corresponding information management processes need to be such as to minimize transactional friction, like converters that simply translate from one data format to another, or process steps that require the manual input of the information.

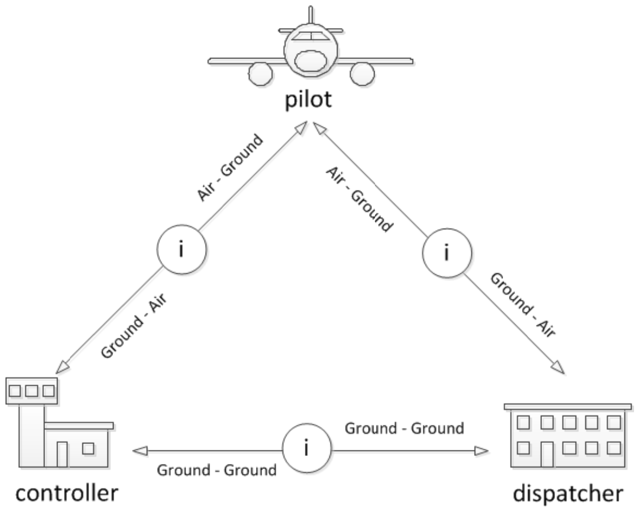

Figure 7: The ATM actors, pilot, controller and dispatcher are tightly interconnected via bi-directional, high bandwidth air-ground (A-G) as well as ground-ground (G-G) connections.

Furthermore, as the concept of System Wide Information Management evolves, access to the needed information will continue to enable safe and efficient operations. Within a SWIM network, information will be distributed as traditional or electronic products (e.g., Aeronautical Information Publication, NOTAM, digital charts) and services (e.g., information services, web feature services) via different messaging mechanism, like publish/subscribe, push and pull mechanism. These mechanisms are also sometimes referred to as contract, demand and broadcast services[20].

[20] EUROCAE (2007). Operational Services and Environment Definition (OSED) of Aeronautical Information Services (AIS) and Meteorological (MET) Data Link Services. ED-151.

11 Aeronautical Information Products And Services

Products and/or services are outputs of any economic activity that consumers consume and are willing to pay for (see Chapter 12.7 for a definition of products and services). Similarly, aeronautical information management constitutes an (economic) activity that brings forth certain information products and services. Sometimes, an economic entity (producer) generates both, products and services, like an Air Navigation Service Provider generating products, like aeronautical charts and the Aeronautical Information Publication, but also rendering services, like airspace design and Air Traffic Control. An aeronautical chart, however, is not simply a product since it requires a regular charting update service for it to remain current, and therefore (legally) usable.

When information is a key raw material in the creation of products and services, in which case we can refer to them as information products and information services, it appears that there is a direct correlation between the temporality of the information and whether or not it may turn into an information product or service. Intuitively, it makes little (economic) sense to create a physical product based to a large extend on temporary changes (of short duration). For example, an Aeronautical Information Publication is a paper product meant for the distribution of what fundamentally constitutes permanent aeronautical data and long duration temporary changes. Similarly, a paper aeronautical chart, which is another information product, does not depict NOTAM information that represent temporary changes (that is, of short duration). A digital aeronautical charting application, on the other hand, like some of the FAA's AeroNav[21] products and other publicly[22] or commercially[23] available applications, could automatically ingest and graphically display temporary aeronautical information superimposed on a more permanent aeronautical information layer. This is an example of a software application that

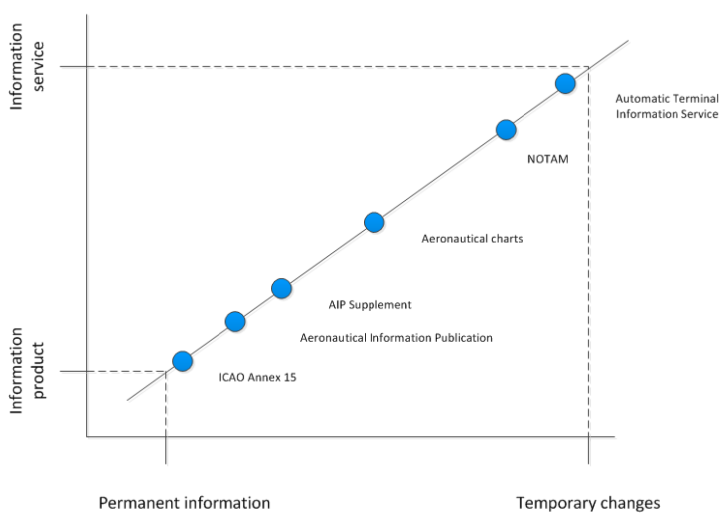

Figure 8: Correlation between the temporality of information and whether or not it turns into an information product or an information service.

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21 See www.faa.gov/air_traffic/flight_info/aeronav/

22 See, for example, www.vfrmap.com

23 See, for example, http://itunes.apple.com/us/app/lido-iroutemanual-aeronautical/id413078249?mt=8, or http://itunes.apple.com/app/jeppesen-mobile-tc/id382536356?mt=8

blends the notions of information product and service in the sense that it integrates different information sources (provided, for example, via a subscription service). Automatic Terminal Information Service (ATIS) is a continuous broadcast over VHF radio frequency of recorded non-control information in selected high activity terminal (airport) areas; as such, it is a means of a near-real-time aeronautical information service.

In either case, aeronautical information goes through distinct stages of its life cycle as illustrated in Figure 9. From identifying potential information end users and to (re-)assess whether the information is adequate for its intended use, via the collection of information from the Single Authoritative Source (possibly supplemented with information from commercial 3rd party providers), to verification of whether the information has changed and needs updating, to making it accessible and available via the System Wide Information Management network, to finally consuming the information through a range of products and services. This life cycle, however, would not be complete without closing the loop by providing feedback of whether the information has been complete, accurate and adequate for its intended use. And thus closes the life cycle of aeronautical information, and begins anew.

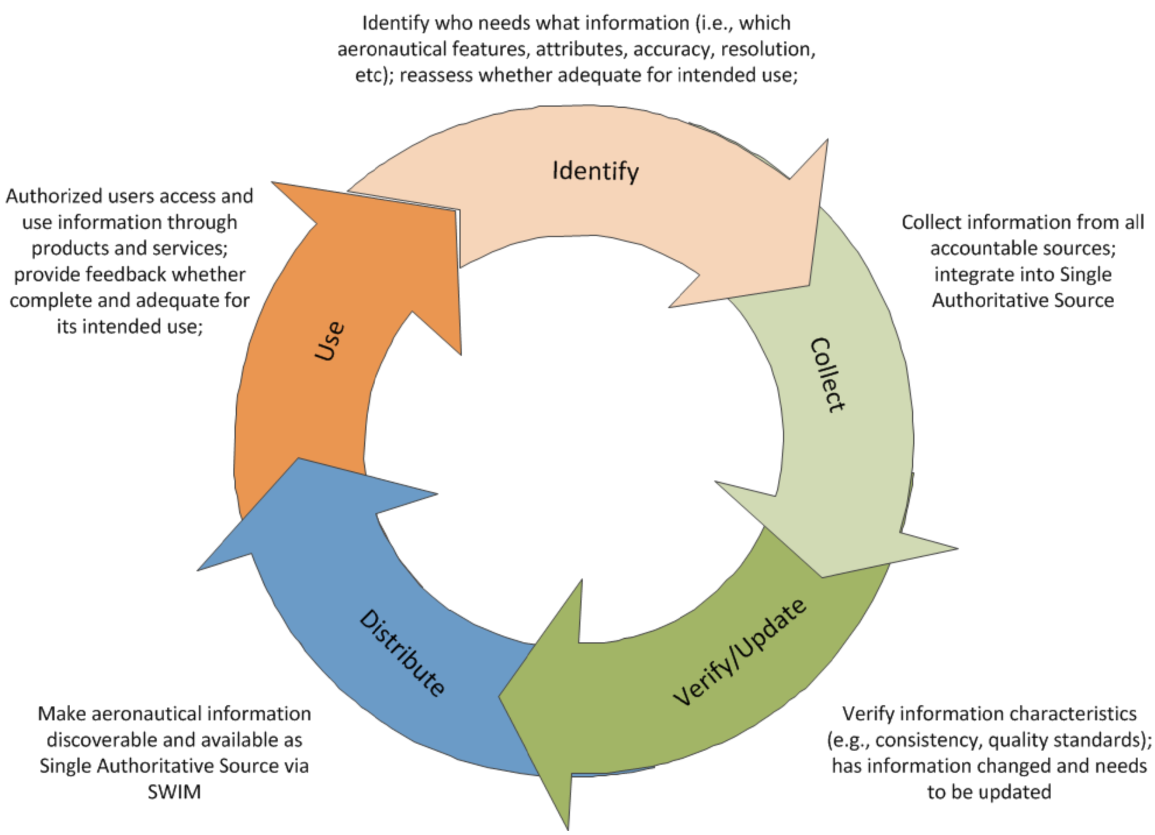

Figure 9: The various stages of the information life cycle are: identify - collect - verify/update - distribute - use, and closes the loop to re-identify, etc.

A different way of presenting the aeronautical information products and services is shown in Table 5. This time, the continuum of temporalities is subdivided into the categories of Planning and Reference, Pre-flight and In-flight. The temporal requirements of the Post-flight category are such that the information that was consumed during a specific time of operation has been archived and can be uniquely identified. Currently, the way post-flight feedback is provided back into the system is through ad-hoc anecdotal reports made by pilots. The table also shows how the current set of AIS products and services will evolve into a future set of AIM products and services.

Table 5: The continuum of temporalities is subdivided into the categories of Planning and Reference, Pre-flight, In-flight and Post-flight. The table also shows how the current set of AIS products and services will evolve into a future set of AIM products and services.

Temporality	Planning and Reference	Pre-flight	In-flight	Post-flight
Description	Permanent information	Temporary changes		Archived information
Current **AIS** products and services	AIP AIP Supplement AIC Aeronautical charts	NOTAM SNOWTAM ASHTAM PIB	No specific AIS products, with the exception of possibly aeronautical charts; Information updates disseminated by voice (e.g., ATIS) and emerging data link (e.g., FIS-B)	No specific AIS products; Opportunity for pilots to provide ad-hoc anecdotal feedback;
Future **AIM** products and services	Aeronautical information via Single Authoritative Source (aggregating information from multiple accredited sources)	Fully integrated and up-to-date digital PIB	Critical information disseminated (as text and/or graphic) via broad-band data link services	Fully integrated self-regulating feedback mechanism, e.g., analysis of trajectories for systemic improvements;

In general, under the AIM concept, there is a trend for increasing the availability of more real-time information in order to meet the more stringent needs of in-flight information. In addition, there is a need for integration of traditional information products (e.g., aeronautical charts based on more permanent information) with regularly updated information services. This also facilitates a seamless transition from legacy (charting) products to an increasing service orientation. The future AIM products and services will also see changes in the scope of information (to address operationally relevant issues, like GPS outages, RAIM, or ETOPS). Under AIM, there will also be more offerings of information applications (i.e., blending of an information product with a service). For example, a digital charting application that combines graphical rendering of permanent aeronautical information with additional information services (including, for example, NOTAM, traffic, weather, etc.).

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12 Appendices

12.1 Review Of ATM-Related Documentation

A review was conducted of ATM-related documentation dealing with information management. It was found that every document recognizes and promotes (System Wide) Information Management as an essential prerequisite and key enabler for the Global Air Traffic Management Operational Concept. The review included works by ICAO, SESAR Consortium, EUROCONTROL, FAA's NextGen Program Office, Joint Planning and Development Office, IATA, IFATCA, CANSO, Airservices Australia, Airport Authority of India, Japan's Civil Aviation Bureau, to name but a few. A few select extracts from these documents are reproduced here:

The notion of Information Management was introduced by the Global Air Traffic Management Operational Concept, Doc.9854, which proposes the implementation of System Wide Information Management (SWIM) aimed at integrating the ATM network in the information sense, and not just in the system sense. Accordingly, Information Management (IM) provides accredited, quality-assured and timely information, integrated or readily integratable, and shared system-wide, in support of ATM operations.[24]

The SESAR Consortium's ATM Target Concept[25] describes System Wide Information Management as the underpinning of the entire ATM system essential to its efficient operation. It goes on to say that the SWIM environment includes aircraft as well as all ground facilities in support of collaborative decision-making processes using efficient end-user applications to exploit the power of shared information.
The SESAR Master Plan[26] confirms that SWIM is indeed at the heart of the plan since it creates the conditions for advanced end-user applications based on extensive information sharing and the capability of finding the most appropriate source of information.

The FAA's NextGen Implementation Plan[27] names System Wide Information Management as an information technology program that identifies industry standards and commercially available products to ensure interoperability between systems in the National Airspace System (NAS). This will improve operational decision making because it will be easier to share data between systems. The program's first segment focuses on applications related to flight and flow management, aeronautical information management, and weather data dissemination. Under the header of Aeronautical Information Management

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[24] ICAO (2005). Global Air Traffic Management Operational Concept, Doc.9854. See: Appendix I-11. Information Management; and Section 2.9 Information Services

[25] SESAR Consortium (2007). The ATM Target Concept – D3.

[26] SESAR Consortium (2007). SESAR Master Plan – D5. Also: www.atmmasterplan.eu

[27] FAA (2008). NextGen's Implementation Plan.

modernization, the report goes on to say that the AIM system represents the evolution of the acquisition, storage, processing, and dissemination of aeronautical information in the NAS. Aeronautical Information is defined as any information concerning the establishment, condition, or change in any component (facility, service, procedure, or hazard) of the NAS.

One of the earliest ATM strategies, the Australian ATM Strategic Plan[28] developed by the Australian Strategic Air Traffic Management Group (ASTRA), refers to information management as the Decision Information Network that is based on the strategic and tactical provision of quality assured and timely operational data in support of ATM operations. This network provides data collection and integration and ensures data quality and integrity, to provide an information-rich planning and operating environment. It involves the best integration of real-time, historical and prospective ATM data and information, and the management, sharing and distribution of that data between and to shareholders.

The Airport Authority of India published its ATM Strategy in a report developed by the Ajay Prasad committee[29]. In this report it says that the present ATM concept is a strategic architecture of System Wide Information Management and network-enabled operation of CNS/ATM system. It goes on to quote one of ICAO's Global Plan Initiatives with states that ATM depends extensively and increasingly on the availability of real-time or near real-time, relevant, accurate, accredited and quality-assured information to make informed decisions. The report recognizes that the aeronautical communication network infrastructure should accommodate the growing need for information collection and exchange within a transparent network in which all stakeholders can participate.

Japan's long-term vision for the future Air Traffic Systems, called the Collaborative Actions for Renovation of Air Traffic Systems (CARATS)[30], points out that in ATM operations, information-sharing among ATC facilities, aircraft operators, airport administrators, pilots, and other agents is most important. However, collaborative decision-making (CDM) is not yet fully implemented as required information is currently only partially shared. Japan recognizes that in order to accurately predict the trajectory of an aircraft in all flight phases, it is necessary to enhance situational awareness by integrating and sharing information between ground facilities and the aircraft.

Under the heading of complete information-sharing and Collaborative Decision Making (CDM), the report proposes to establish a network where all information related to operation is comprehensively managed and necessary information can be

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[28] Airservices Australia (2003). Air Traffic Management, A Strategic Plan for Australia, Vol.2: ATM Operational Futures. See also: www.astra.aero

[29] Airport Authority of India (2009). ATM Strategy for India. Report prepared by the Ajay Prasad Committee.

[30] Japan Civil Aviation Bureau (2010). Collaborative Actions for Renovation of Air Traffic Services (CARATS) – a long-term vision for the future Air Traffic Systems.

accessed by any party when necessary; this is identified as System Wide Information Management. At the international level, information sharing and coordinated operation will be encouraged through data exchanges among control facilities.

12.2 About Abstraction And How To Develop A Concept

The task of human communication becomes infinitely more difficult when trying to convey ideas, concepts, or abstract thoughts rather than a physical reality. That is, communication is dependent upon the content of the message being transmitted.

A tree, for example, is an object of physical reality that most humans can easily relate to even though they may picture a completely different tree when asked to visualize one. Whenever it is desirable or necessary for a group of people to visualize the same tree when they hear the word, one way of achieving this is to provide a descriptive definition together with the word. Another effective way of achieving common understanding is to provide an image of a tree, or a pictorial representation, such that when communicating about a tree, using words or a representative symbol, those people have the same picture in their mind.

At this point, it may be helpful to define what is meant by *abstraction*. If it is so hard to communicate abstract thought, then why are we even thinking in abstract terms? In mathematics, abstraction is the process of extracting the underlying essence of a concept, removing any dependence on real world objects with which it might originally have been connected, and generalizing it so that it has wider applications. One possible application of abstraction is that by removing the national particularities of aeronautical information management, the concept thereby becomes internationally applicable. Another example is computer scientists using abstraction to communicate their ideas with the automation in some particular computer language. Now, the concept becomes implementable using information technologies.

The main disadvantage of abstraction, however, is that highly abstract concepts are more difficult to learn, harder to communicate, and require a high degree of knowledge and experience before they can be understood.

Development of a *concept* in and by itself is an abstraction in that higher concepts are derived from subordinate concepts, or first principles. In particular, the concept of data is an important subordinate concept upon which the AIM operational concept is being built. As shown in Figure 10, the operational implementation of the global ATM concept, as seen from the aircraft's perspective, can be summarized as four-dimensional trajectory-based operations (TBO). In a hierarchy of concepts, the operational concept of a trajectory builds upon the subordinate concept of Collaborative Decision Making (CDM), which in turn depends on the concept of

Shared Situational Awareness (SSA), which again depends on System Wide Information Management (SWIM). The SWIM concept can be further deconstructed into the AIM concept that, as mentioned earlier, builds on the concepts of data, information, data definitions, etc.

The robustness of a highly complex and abstract operational concept, such as trajectory-based operations is strongly dependent upon the validity and hierarchy of all underlying subordinate concepts. Therefore, care has to be taken in developing the intellectual constructs like CDM, SSA, SWIM, AIM, and especially the lower level concepts like data and information. Like a house of cards, a highly complex operational concept will crumble if the underlying concepts are fraught with mistakes or shortcomings. In the context of aviation, this means that the operational concepts have to be globally applicable, scalable, flexible, as well as be robust in normal, rare-normal as well as abnormal operational situations.

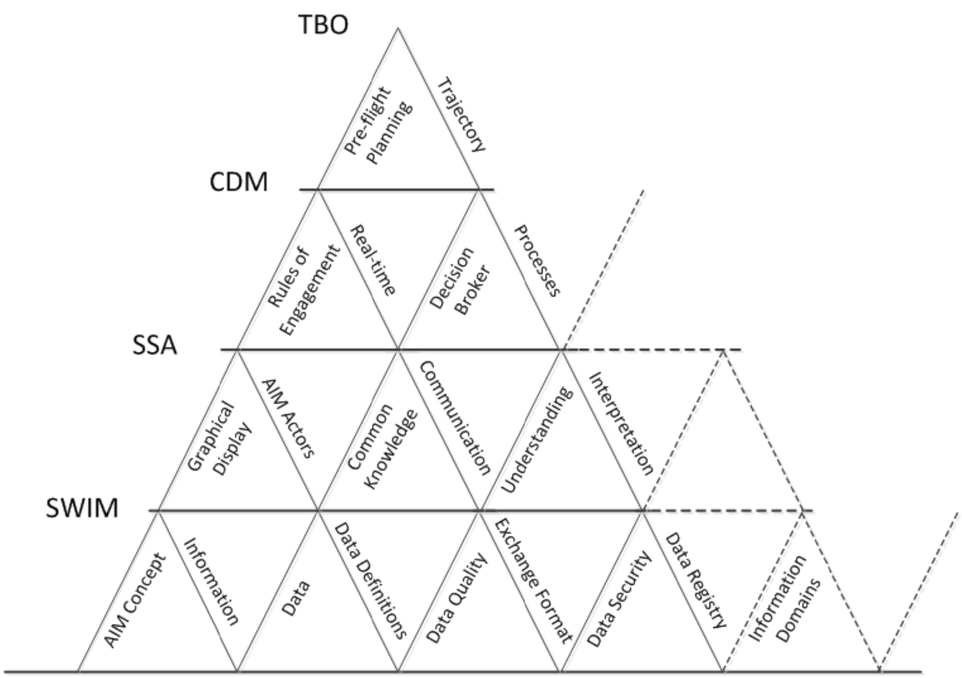

Figure 10: Development of a concept is an abstraction itself, in that higher concepts are derived from subordinate concepts, or first principles. In this hierarchy of concepts, we show how System Wide Information Management (SWIM) forms the conceptual foundation for Shared Situational Awareness (SSA), which enables Collaborative Decision Making (CDM), which is the prerequisite for Trajectory Based Operations (TBO). Note that the concept of SWIM can be further deconstructed, with the AIM concept being one aspect of it, which builds on the concepts of data, and information, and so on…

To recap, the intent of aeronautical information management, therefore, is to make available the essential information content such that it can be readily exchanged among ATM stakeholders, and their supporting information systems and decision support tools, for the purpose of (re-)creating a common situational awareness of the operational reality for the purpose of collaborative decision making. All this, in turn, serves as enablers of trajectory-based operations as promoted by the global air traffic management operational concept.

12.3 ATM Is A Complex System

Today's air transportation system has turned into a more tightly coupled, highly interdependent complex system and society is demanding from the route network greater resilience to system disruptions due to, for example, mechanical failure, labor disputes, natural disasters or hazardous weather phenomena. The well-publicized ripple effects that these disruptions cause throughout the network result in delayed or cancelled flights, missed connections, aircraft and passengers stranded on the tarmac for hours, lost luggage, and a lot of disgruntled people. Matters are made worse since many of aviation's regulations, processes and technologies comprising the air traffic infrastructure are based on concepts that date back to World War II. This places an increasingly heavy burden on a system based on the outdated air traffic control and management concepts.

Transformation of the entire global air traffic system is, of course, a massive undertaking. Technology programs involve the transition from a ground-based to a space-based infrastructure for Communication, Navigation and Surveillance (CNS). What became known as CNS is laying the technological foundation for the Air Traffic Management system of the future. An integral part of the comprehensive overhaul is the more efficient management and rapid dissemination of aeronautical information. This is seen as one of the key enablers for the envisioned operational concepts of Air Traffic Management. In a world**,** when aircraft will be operated along 4-dimensional trajectories, the wide range of actors within the air transportation system will require access to more information, of a higher quality and with faster access, in order to successfully manage increasingly complex situations. The ATM (operations) actors include pilots, controllers, and dispatchers who all need to have the situational awareness of the underlying air navigation infrastructure and its corresponding status and condition. Sharing this knowledge is essential not only for planning and reference purposes but throughout the entire flight operations. Being able to rapidly exchange information is key, and this is aided by having access to powerful mobile devices. In today's world, the level of coordination required for executing efficient operations is unprecedented, and the sharing of highly reliable and timely information is quintessential for collaborative decision-making.

The concept of aeronautical information management needs to be framed with an awareness of the Air Traffic Management (ATM) system as a whole and the purpose of information management within that system. As such, it is essential to recognize ATM as a complex system, because its complexity is a key differentiator from what we may refer to as the traditional ATC concept, that is, the concept of reactively controlling air traffic rather than to proactively manage it.

According to F. Heylighen (1996)[31], complexity has turned out to be very difficult to define. The dozens of definitions that have been offered fall short in one respect or another, classifying something as complex which we intuitively would see as simple, or denying an obviously complex phenomenon the label of complexity. Moreover, these definitions are either only applicable to a very restricted domain, such as computer algorithms or genomes, or so vague as to be almost meaningless. Edmonds (1996), on the other hand, gives a good review of the different definitions and their shortcomings, concluding that complexity necessarily depends on the language that is used to model the system. Still, there appears to be a common "objective" core in the different concepts of complexity.

The original Latin word *complexus* signifies "entwined", "twisted together". This may be interpreted in the following way: in order to have a complex you need two or more components, which are joined in such a way that it is difficult to separate them. Similarly, the Oxford Dictionary defines something as "complex" if it is "made of (usually several) closely connected parts". Here we find the basic duality between parts that are at the same time distinct and connected. Intuitively then, a system would be more complex if more parts could be distinguished, and if more connections between them existed. More parts to be represented means more extensive (mental, algorithmic) models, which, from a computational perspective, require more time to be searched or computed. Since the components of a complex cannot be separated without destroying it, the method of analysis or decomposition into independent modules cannot be used to develop or simplify such models. This implies that complex entities will be difficult to model, that eventual models will be difficult to use for prediction or control, and that problems will be difficult to solve. This accounts for the connotation of difficult, which the word "complex" has received in later periods. This also implies that implementation of complex systems, from a programmatic perspective, like SWIM[32], ADS-B, ERAM, or the global ATM network in general, will be very difficult, if not outright impossible when tackled with traditional program management practices that adopt a divide-and-conquer methodology.

The aspects of distinction and connection determine two dimensions characterizing complexity. Distinction corresponds to variety, to heterogeneity, to the fact that different parts of the complex behave differently. Connection corresponds to constraint, to redundancy, to the fact that different parts are not independent, but that the knowledge of one part allows the determination of features of the other parts. Distinction leads in the limit to disorder, chaos or entropy, like in free-flight (enroute) airspace where the position of any aircraft is completely independent of the position of the other aircraft. Connection leads to order or negentropy, like in perfectly executed arrival streams to closely spaced parallel runways in terminal

31 Heylighen, F. (1996). What is Complexity? Principa Cybernetica Web. Retrieved from http://pespmc1.vub.ac.be/COMPLEXI.html

32 FAA (2011). FAA's approach to SWIM has led to cost and schedule uncertainty and no clear path for achieving NextGen goals. Office of Inspector General Audit Report, No. AV-2011-131.

airspace where the position of an aircraft is completely determined by the positions of the neighboring aircraft.

As such, the air traffic management system can be defined as a complex system since both aspects co-exist. Complexity can only exist if both aspects are present: neither perfect disorder (which can be described statistically through the law of large numbers), nor perfect order (which can be described by traditional deterministic methods) are complex. It thus can be said to be situated in between order and disorder, or, using a recently fashionable expression, "on the edge of chaos". To complicate matters, the definition of complexity as midpoint between order and disorder depends on the level of representation: what seems complex in one representation may seem ordered or disordered in a representation at a different scale.

Complexity increases when the variety (distinction), and dependency (connection) of parts or aspects increase, and this in several dimensions. These include at least the ordinary three dimensions of spatial scale and the dimension of time or temporal scale. In order to show that complexity has increased overall, it suffices to show, that - all other things being equal - variety and/or connection have increased in at least one dimension.

The process of increase of variety may be called differentiation, the process of increase in the number or strength of connections may be called integration. Evolution automatically produces differentiation and integration, and this at least along the dimensions of space and time. The complexity produced by differentiation and integration in the spatial dimension may be called "structural", in the temporal dimension "functional"[33].

Although there will always be a subjective element involved in the observer's choice of which aspects of a system are worth modeling, the reliability of models will critically depend on the degree of independence between the features included in the model and the ones that were not included. That degree of independence will be determined by the "objective" complexity of the system. Though we are in principle unable to build a complete model of a system, the introduction of the different dimensions discussed above helps us at least to get a better grasp of its intrinsic complexity, by reminding us to include at least distinctions on different scales and in different temporal and spatial domains.

In conclusion, the ATM system is a complex system characterized by non-linear, highly dynamic behavior. Even though one can achieve more complex tasks with a

33 Traditionally, systems theory has focused more on the *structure* of systems and their models, whereas cybernetics has focused more on how systems *function*, that is to say how they control their actions, how they communicate with other systems or with their own components, ... Since structure and function of a system cannot be understood in separation, it is clear that cybernetics and systems theory should be viewed as two facets of a single approach. Retrieved from http://pespmc1.vub.ac.be/CYBSWHAT.html

complex system, which clearly is a benefit, unfortunately there is a price to pay in that the complex system exhibits increasing vulnerability to system disruptions. In short, due to its inherent complexity, the ATM system has a high degree of uncertainty and becomes increasingly difficult to predict. Needless to say, it is very difficult, if not impossible, to reliably manage air traffic operations in a complex system.

12.3.1 Complexity And Predictability

The following figure shows system complexity as a function of information management's level of sophistication, ranging from Data Management, to Information Management, to Knowledge Management. As can be seen, maintaining manageability of a complex system like the Air Traffic Management system of the future is the reason for change to the Aeronautical Information Management concept, and hence being able to stay south of the "Edge of Uncertainty".

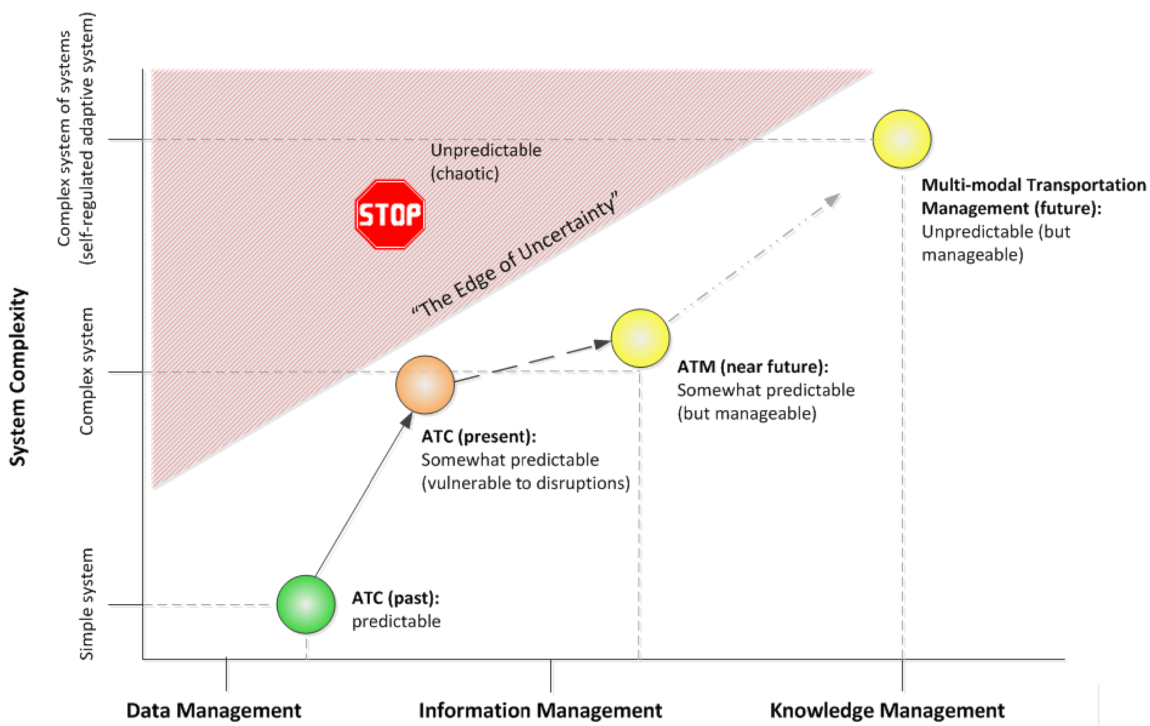

Figure 11 Increasing system complexity as the reason for changing to increasingly sophisticated Information Management concepts like AIM

The figure shows how the ATC system of the past, classified as a simple and predictable system, was served well by Data Management which itself was simple, primarily static and complete. As the ATC system grew in system complexity, Aeronautical Information Services, a precursor to Information Management, comprised static and dynamic data, published as AIP and NOTAM, in paper and primarily textual format. Today, a modern Information Management (IM) concept is needed to cope with the increasingly complex demands of an Air Traffic Management system of the near future. The intent is for such a complex system to still be manageable, even though only somewhat predictable, and less prone to system disruptions as is the case today. More and better information will help reduce variability and minimize uncertainty. Aeronautical information management deals with the integration of permanent and temporary digital information, rapidly disseminated and oftentimes displayed graphically to the users.

In the more distant future, the trend indicates increasing levels of sophistication in information management principles, leading up to Knowledge Management which itself is a precursor to artificial intelligence. Here, information will be managed and shared within a highly interconnected neural network, leveraging advanced business rules, and by blending temporalities ranging from real-time to permanent into a continuous information stream. This will provide the needed information backbone for a highly complex mega-system like a global Multi-Modal Transportation Management (MTM) system[34].

What this figure also shows is what may be termed the "Edge of Uncertainty". We know from experience that today's air traffic control system is vulnerable to disruptions. The transition to Aeronautical Information Management will not make the system more predictable, but the challenge is how to make it more manageable, or to hide system complexity and thereby make it more accessible to the users. However, what also becomes evident from this figure is that close attention needs to be paid to the complexity of the system as such, reducing it, simplifying it as much as possible. Regulations, for example, play an important role in governing a system. However, at some critical point, too many regulations render a system too rigid, and inflexible to accommodate further growth. Another example is the increasing complexity on the flight deck. Gone beyond system redundancy, today's avionics begin to replicate information and/or functionality on not-coordinated systems leading to serious human factors issues[35]. In short, as we transition to AIM, attention has to be paid not only to a transition to information (knowledge) management principles, but also to try and reduce system complexity as such. Failure to do both may get us precariously closer, or even push us beyond the "Edge of Uncertainty"!

The above figure is giving the larger (if somewhat simplified) perspective of the past, present, and future state of our global air transportation system. Seen within this context, the reason for change is that Aeronautical Information Management is a

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[34] Fundamentally, the Global Air Traffic Management Operational Concept is a gate-to-gate concept, thereby including the airport surface operations whereas traditional thinking has been more "runway end-to-runway end". From a system of systems perspective, however, this concept is further expandable to a curb-to-curb concept, thereby including the airport's landside in addition to the airside. Ultimately, a door-to-door concept encompasses all modes of transportation including pedestrians, bicycle, automobile, bus, subway, train, boat, plane, space transporter, etc. Multi-Modal Transportation Management would be the reason to rewrite the global ATM concept – from ATM to MTM!

[35] For example, flight plan functionality is increasingly being replicated on (data linked) Electronic Flight Bags, either installed or portable devices. That functionality is not synchronized with similar functionality of the Flight Management System (FMS) that is displayed on the Nav Page of the Multi-Function Display (MFD).

stepping-stone on the evolutionary path towards Aeronautical Knowledge Management. The transportation system of the future is, by the way, not only focused on meeting the demands of the traveling public[36], but also appropriate for the anticipated population density and heightened environmental awareness of future generations.

12.4 Theoretical Foundation Of Information Management

Thinking and writing about information management is hard. One reason is that information management is a highly abstract subject area. Another reason is linked to the fact that there are no consistent or coherent terms and terminologies, as discussed in a subsequent chapter, to even frame the subject. Terms and concepts related to information management are oftentimes ill defined or ambiguous, like the terms data and information themselves, which can lead to confusion and misunderstanding. When discussing aeronautical information management concepts, it is therefore essential to establish a theoretical foundation of information management.

12.4.1 Information As Means To Communicate

Humans continuously sample their surrounding, that is, the physical reality of the world they live in, using their given five senses (namely, sight, sound, smell, taste, and touch). Natural *language* is the primary means of human communication in order to describe that physical reality, and to convey emotions as well as thoughts and ideas. Simply put, language conveys meaning provided the sender (speaker, writer) and the receiver (listener, reader) talk about the same thing (law of identity). Meaning is inferred not only from the message's verbal (or written) form, but also from the current context. This assumes that the receiver interprets the message in terms of prior knowledge, which determines how much, or what is being understood from the message. Therefore, meaning is rooted in understanding based on knowledge. In other words, by exchanging information among participants who share common knowledge, it should be possible, at least in theory, to recreate a common picture, or understanding.

Communication, however, does not necessarily involve humans only but can also comprise automated information systems as intermediaries in the process. In this case, the information that collectively make up the message content is being transmitted in machine-readable, digital form. The information system then processes the information and presents it to the human user in textual and/or graphical format. Especially in an information-rich environment as envisioned by the global ATM operational concept, it is essential for automated information

[36] The word "passenger" is mentioned six times in the Global Air Traffic Management Operational Concept. However, none of these instances focus on the concerns of the passenger. This is indicative of an inward focus, rather than an outward focus on real passenger requirements.

systems and decision support tools to play an increasingly important role in the communication processes between controllers, pilots and dispatchers. It is likely that communication between man and machine under the AIM operational concept will be a combination of voice and digital data messages transmitted via a combination of different data link technologies and transmission protocols.

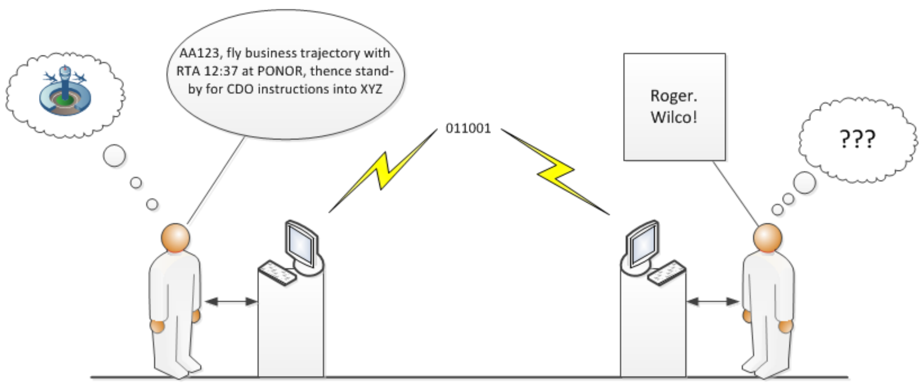

Figure 12: Communication between ATM stakeholders involving a combination of natural language and digital messages requires common knowledge in order to avoid potential misunderstanding. The goal is to (re-)create a common situational awareness.

For humans, natural language is still the predominant means of communication. It is, however, imprecise in that words, phrases and sentences are oftentimes open to interpretation and can be misconstrued. Proper understanding varies, sometimes dramatically, based on, for example, a person's unique perspective, education or cultural background. This can and does lead to misunderstanding, i.e., breaking the law of identity.

After discussing the basic elements of communication, it is important to introduce the notion of telecommunication, which is the transmission of information across significant distances. This requires consideration of the transmission medium for communication, e.g., various data link technologies. Also, the message can be transmitted as an analog or digital signal.

12.4.2 Communication Theory And Information Theory

Communication theory is a field of information and mathematics that studies the technical process of information and the human process of communication. The origins of communication theory is linked to the development of information theory. These fields are at the intersection of mathematics, statistics and probability, computer science, physics, neurobiology, and electrical engineering. Communication theory is concerned with the exchange of information, and uses the word information as a measurable quantity, reflecting the receiver's ability to distinguish one sequence of symbols from any other. The natural unit of information is therefore the decimal digit, as a unit or scale or measure of information.

Information theory, on the other hand, involves the quantification of information, and is concerned with finding fundamental limits on signal processing operations such as compressing data and on reliably storing and communicating data.

The main concepts of information theory can be better understood by again considering the most widespread means of human communication: language. First, the most common words (e.g., "a", "the") should be shorter than less common words (e.g., "benefit", "operator"), so that sentences are concise yet meaningful. Such a tradeoff in word length is analogous to data compression and is the essential aspect of *source coding*. Second, if part of a sentence is unheard or misheard due to ambient noise the receiver should still be able to glean the meaning of the underlying message. Such robustness is as essential for an electronic information system as it is for natural language; properly building such robustness into communications is done by *channel coding*. Source coding and channel coding are the fundamental concerns of information theory.

12.5 Defining The Concept Of Information

Let us try and define the concept of information. The notion is that once we have a clear concept of information, we can introduce related terms and terminology. A similar approach has been presented by Jehlen (2011)[37] based on work by Cowell and Buchanan (2011)[38] who also recognize that the concept of information is oftentimes not studied in isolation but viewed in relationship to the concepts of data, information, knowledge and wisdom.

The following Table 6 is reproduced from ATMRPP Working Paper 492 and lists some proposed definitions for data, information and knowledge:

Table 6: Adopted from ATMRPP Working Paper 492, this table lists various terms together with proposed definitions.

TERM	DEFINITION
Data	A representation of fact, concept, or instruction represented in a formalized form suitable for communication, interpretation or processing either by human and/or by automated systems. Note. — This is the lowest level of abstraction, compared to information and knowledge. [ICAO AIS-AIMSG/3-SN6 Appendix A] A subset of information in an electronic format that allows it to be retrieved or transmitted. [NIST (2011). Glossary of Key Information Security Terms. NIST IR 7298 Revision 1.Kissel, R. (Ed.)]

37 Jehlen, R. (2011). Information Domains. Air Traffic Management Requirements and Performance Panel Working Paper 492 (ATMRPP-WG/WHL/16-WP/492)

38 Cowell, D. and Buchanan, C. (2011). FAA Aeronautical Information Management. Personal communication.

TERM	DEFINITION
	Representation of facts, concepts, or instructions in a formalized manner suitable for communication, interpretation, or processing by humans or by automatic means. Any representations such as characters or analog quantities to which meaning is or might be assigned. [DOD (2010). Department of Defense Dictionary of Military and Associated Terms. Joint Publication 1-02; Amdt (01-31-20110]
information	Data that: (1) has been verified to be accurate and timely, (2) is specific and organized for a purpose, (3) is presented within a context that gives it meaning and relevance, and which (4) leads to increase in understanding and decrease in uncertainty. The value of information lies solely in its ability to affect a behavior, decision, or outcome. [ICAO AIS-AIMSG/3-SN6 Appendix A] Any communication or representation of knowledge such as facts, data, or opinions in any medium or form, including textual, numerical, graphic, cartographic, narrative, or audiovisual. [NIST (2011). Glossary of Key Information Security Terms. NIST IR 7298 Revision 1.Kissel, R. (Ed.)] Like many researchers who have studied information, we will describe it as a message, usually in the form of a document or an audible or visible communication. As with any message, it has a sender and a receiver. Information is meant to change the way the receiver perceives something, to have an impact on his judgment and behavior. It must inform; it's data that makes a difference. The word 'inform' originally meant 'to give shape to' and information is meant to shape the person who gets it, to make some difference in his outlook or insight. Strictly speaking, then, it follows that the receiver, not the sender, decides whether the message he gets is really information – that is, if it truly informs him… Unlike data, information has meaning – the 'relevance and purpose' of Drucker's definition …it has a shape: it is organized to some purpose. Data becomes information when its creator adds meaning." [Davenport & Prusak, pp. 3-4]
knowledge	…a justified true belief, the know-what/-how/-who/-why that individuals use to solve problems, make predictions or decisions, or take actions. (Martin Eppler) [IAIDQ Glossary] …'knowledge' is the capacity for effective action or decision making in the context of organized activity …Information is data that is structured so that it is transferable, but its immediate value depends on the potential user's ability to sort, interpret, and integrate it with their own experience. Knowledge goes a step further and implies the combining of information with the user's own experiences to create the capacity for action. [Delong, pp. 21-22] …a working definition of knowledge, [is] a pragmatic description that helps us communicate what we mean when we talk about knowledge in organizations. Our definition expresses the characteristics that make knowledge valuable and the characteristics – often the same ones – make it difficult to manage well: Knowledge is a fluid mix of framed experience, values, contextual information, and expert insight that provides a framework for evaluating and incorporating new experiences and information. It originates and is applied in the minds of knowers. In organizations, it often becomes embedded not only in documents or repositories but also in organizational routines, processes, practices, and norms.

TERM	DEFINITION
	What this definition immediately makes clear is that knowledge is not neat or simple. It is a mixture of various elements; it is fluid as well as formally structured; it is intuitive and therefore hard to capture in words or understand completely in logical terms. Knowledge exists within people, part and parcel of human complexity and unpredictability ...Knowledge derives from information as information derives from data. If information is to become knowledge, humans must do virtually all the work. [Davenport & Prusak, pp. 5-6]

Also interesting is that Cowell and Buchanan (2011)[39], leveraging the work of Davenport and Prusak (1998)[40], arrive at the finding that since the steps in the process of going from data to information are different from the steps necessary to go from information to knowledge, hence the output from each is different. A corollary is that if the input into a process is different, then the output is different. Note that the inputs and processes are different for the data to information transformation and the information to knowledge transformation. This line of argumentation shows, therefore, that there has to be a difference between data and information and knowledge.

12.5.1 What About This Thing Called Wisdom?

It is interesting to note that *Wisdom* is oftentimes excluded from such technical or scientific discussions; the argument being that it falls more into the realm of metaphysics and spirituality. Regardless, we claim that the relationship between data, information and knowledge is not complete without also considering wisdom. This becomes evident when considering Stonier (1993, 1997)[41], according to whom data is a series of disconnected facts and observations. These may be converted to information by analyzing, cross-referring, selecting, sorting, summarizing, or in some way organizing the data. Or, in other words, information is when one understands relationships

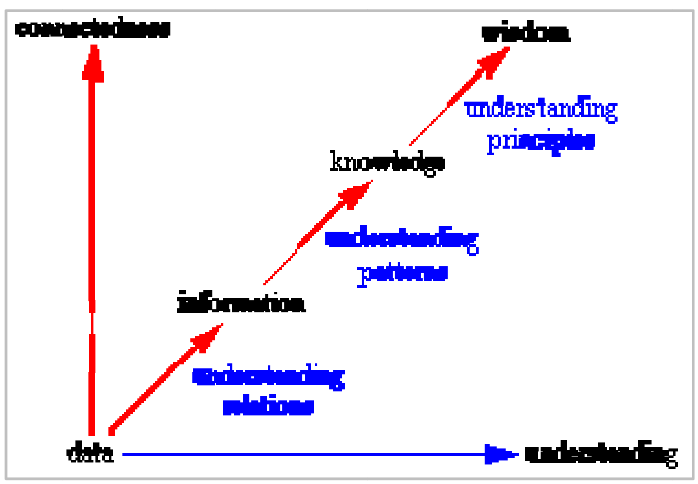

Figure 13: The DIKW model, that is, the transition from Data to Information to Knowledge to Wisdom, is shown here as increasing understanding with increasing "connectedness".

39 Cowell, D. and Buchanan, C. (2011). FAA Aeronautical Information Management. Personal communication.

40 Davenport, T. and Prusak, L. (1998). Working Knowledge: How organizations manage what they know. Harvard Business School Press: Boston, MA.

41 Stonier, T. (1993). The wealth of information. London: Thames/Methuen.
Stonier, T. (1997). Information and meaning - An evolutionary perspective. Berlin: Springer.

between data, as shown in Figure 13. Patterns of information, in turn, can be worked up into a coherent body of knowledge. Knowledge consists of an organized body of information, such information patterns forming the basis of the kinds of insights and judgments, or principles, which we call wisdom.

The above conceptualization may be made a little more concrete by using a physical analogy (Stonier, 1993): consider spinning fleece into yarn, and then weaving yarn into cloth. The fleece can be considered analogous to data, the yarn to information and the cloth to knowledge. Cutting and sewing the cloth into a useful garment is analogous to creating insight and judgment (wisdom). This analogy emphasizes two important points: (1) going from fleece to garment involves, at each step, an input of work, and (2) at each step, this input of work leads to an increase in organization, thereby producing a hierarchy of organization[42].

12.5.2 Are We "Data Creatures" In A World Of Information?

The proposed argument is that a new level of awareness may be required to fully comprehend the concept of information. Therefore, and in analogy to the DIKW model, we construct a model where each layer of the DIKW model has its corresponding level of cognitive understanding, or awareness. As shown in Figure 14, the notion is that in order to conceptualize at a certain layer requires the corresponding level of awareness, including the language needed to verbalize those abstract concepts.

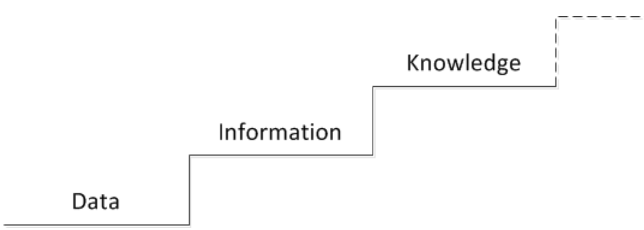

Figure 14: Each layer of the DIKW model corresponds to a higher level of awareness. With this higher level of awareness also comes the language to verbalize the corresponding abstract concepts.

Then, for argument's sake, if we place the Aeronautical Information Service (AIS) concept at the data layer, and the Aeronautical Information Management (AIM) concept at the information layer, this implies that our level of understanding, our terms and definitions, correspond to different levels of awareness. Needless to say that in order to conceptualize AIM would require a different, a higher level of awareness, and this also implies that the language, including the terms and definitions of AIS, do not apply to AIM. This means that one cannot "extrapolate" a concept from a lower level up to a higher level of awareness. However, the reverse seems to be true in that, from the vantage point of a higher level of awareness, the lower level(s) appear inclusive.

As an example, imagine being a two-dimensional creature trying to figure out the concept of three-dimensional space. In order to think spatially, or to even draw a

[42] Adopted from Zins, C. (2007). Conceptual Approaches for Defining Data, Information, and Knowledge. Wiley InterScience.

picture using spatial perspective, requires the higher level of awareness of three-dimensions. Even the terms height, vertical, or altitude, are foreign to the two-dimensional creature, and those words don't even exist in their vocabulary. The two-dimensional creature living in x,y space can try to imagine three-dimensional space by arguing that the new dimension is just like the dimensions x and y, but turned on its side, i.e. now pointing into the vertical, but it still cannot "see" it. The three-dimensional creature, however, with its higher level of awareness, finds that its concept and even its language, adequate to conceptualize and describe three-dimensional space, also encompass the entire two-dimensional world.

Since it seems so difficult trying to conceptualize information, to define information, it may well be that we fundamentally are still just "data creatures", thinking and arguing at that level of awareness? Our efforts must appear futile to the "knowledge creature" who looks down upon those lower levels of awareness and completely understands the world of both data and information, as well as the concept of knowledge. Using the model of awareness, these "knowledge creatures" are those who will be capable of creating artificial life and artificial intelligence, responsibly. Then what about this "wisdom creature"?

12.5.3 A New Way Of Thinking Is Needed

Reductionist thinking is a way to dissect a problem into either-or entities. Something either is, or is not a member of a certain category, has, or has not certain properties. By doing so, we can break a problem down into smaller pieces; hence reductionist. We also call this the divide-and-conquer method. This is also the tried-and-proven method of project management.

Causality, on the other hand, is a way to describe how events relate to one another. Suppose there are two events A and B. If A happened because of B, then B is the cause of A, or A is the effect of B. This is also referred to as cause-and-effect. Another way to look at it is that there is a (linear) causal, one-to-one relationship between events A and B. In project management terms, this means that task A has to happen because of task B, etc. and they are (linearly) dependent on each other.

Human thinking, of course, constitutes much more and more complex cognitive processes than reductionist thinking and causality alone. However, they work great for analyzing, understanding and managing linear systems up to a certain level of complexity. These thinking patterns fail, however, when the complexity of the system(s) we are dealing with exceed a critical level of complexity. In this case, a new way of thinking is required. Sometimes referred to as "fluid thinking"[43], it expresses a way of thinking in relationships, in terms of both-and rather than either-or, to think in terms of system(s) of systems rather than isolated domains, to think

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43 Horx, M. (2011). Das Buch des Wandels. Pantheon Press. pp.224.
For a practical example of what "fluid thinking" is, see the article "Fluid Thinking" by Peter-Paul Koch, retrieved on Jan.28, 2012 from www.digital-web.com/articles/fluid_thinking/

holistically (body, mind, heart and soul) rather than simply rationally, and to not be afraid of making mistakes for erring is not failure but integral to progress[44], and to accept the slightly uncomfortable feeling when dealing with phenomena like pluriformity and unpredictability.

We claim that thinking about Aeronautical Information Management requires the application of an entirely "new" way of thinking, fluid thinking, to the problem of information management. Without it we will not be able to understand the complexity of the ATM system and the role that information management has to play within that system. With other words, when thinking about AIM, it is not the (AIS) scenery that has changed, but the way we look at it. And herein lies the paradigm shift; everything else of the transition from AIS to AIM is evolutionary.

12.5.4 Entropy And Information

> Statistical entropy is a probabilistic measure of uncertainty or ignorance; information is a measure of a reduction in that uncertainty.

Entropy (or uncertainty) and its complement, *information*, are perhaps the most fundamental quantitative measures in cybernetics, extending the more qualitative concepts of variety and constraint to the probabilistic domain[45].

Variety and constraint, the basic concepts of cybernetics, can be measured in a more general form by introducing probabilities. Assume that we do not know the precise state *s* of a system, but only the probability distribution *P(s)* that the system would be in state *s*. Variety V can then be expressed as entropy H (as originally defined by Boltzmann for statistical mechanics):

$$H(P) = -\sum_{s \in S} P(s).\log P(s)$$

H reaches its maximum value if all states are equiprobable, that is, if we have no indication whatsoever to assume that one state is more probable than another state. Thus it is natural that in this case entropy H reduces to variety V. Like variety, H expresses our uncertainty or ignorance about the system's state. It is clear that H = 0, if and only if the probability of a certain state is 1 (and of all other states 0). In that case we have maximal certainty or complete information about what state the system is in.

We define constraint as that which reduces uncertainty, that is, the difference between maximal and actual uncertainty. This difference can also be interpreted in a different way, as information, and historically H was introduced by Shannon as a

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[44] One way to minimize the (potential) cost of mistakes is to think through what-if scenarios.

[45] Retrieved on January 23, 2012 from: http://pespmc1.vub.ac.be/ENTRINFO.html

measure of the capacity for information transmission of a communication channel. Indeed, if we get some information about the state of the system (e.g. through observation), then this will reduce our uncertainty about the system's state, by excluding – or reducing the probability of – a number of states. The information I we receive from an observation is equal to the degree to which uncertainty is reduced:

$I = H(before) - H(after)$

If the observation completely determines the state of the system ($H(after) = 0$), then information I reduces to the initial entropy or uncertainty H.

Although C. Shannon came to disavow the use of the term "information" to describe this measure, because it is purely syntactic and ignores the meaning of the signal, his theory came to be known as *Information Theory* nonetheless. H has been vigorously pursued as a measure for a number of higher-order relational concepts, including complexity and organization.

We also note that there are other methods of weighting the state of a system which do not adhere to probability theory's additivity condition that the sum of the probabilities must be 1. These methods, involving concepts from fuzzy systems theory and possibility theory, lead to alternative information theories. Together with probability theory these are called Generalized Information Theory (GIT). While GIT methods are under development, the probabilistic approach to information theory still dominates applications.

12.5.5 The Observer Becomes Part Of The Observed

When trying to identify why defining information is such a difficult task, we discover that one reason for this is the multitude of different conceptual approaches, even within the field of information science alone, that one can turn to in order to understand information. These different approaches, according to Zins (2007), include metaphysical versus non-metaphysical, human-centered versus machine-centered, cognitive-based or propositional exclusive versus nonexclusive approaches, subjective versus universal, etc. Each one of these approaches, as obscure as they may appear to the uninitiated reader, offers a different (but legitimate and valid) perspective and, in turn, a different meaning and hence definition.

One conclusion from this is that information is a multi-faceted concept that changes its properties, and hence its definition, according to one’s unique perspective. Or, in other words, the observer becomes part of the observed system. It is rather perplexing to discover that this is the very definition of Heisenberg’s uncertainty principle of quantum theory[46]. In other words, the “former”, that is he who gives shape, becomes part of the form, hence “in form”.

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[46] See http://www.thebigview.com/spacetime/uncertainty.html

12.6 Aeronautical Information Domain

Aeronautical Information is one of several information domains that will be managed and disseminated via the SWIM environment. Aeronautical information describes the physical (visible) and virtual (non-visible) air navigation infrastructure in a geospatial context, and the status and condition of that infrastructure (e.g., runway status "open" or "closed", airport condition "VFR", "MVFR" or "IFR").

12.6.1 Meteorological Information Domain

Meteorological information clearly has and will continue to have great operational impact and importance for the safety and efficiency of the air transportation system. Meteorological information identifies and describes the observation, processing, interpretation, storage, forecasting, and distribution of aviation weather information. The derived meteorological products and services directly support the operational aspects of all phases of flight.

12.6.2 Flight And Flow Information Domain

Flight information is a collection of flight-operational data elements describing an individual flight from pre-planning to planning, and through in-flight to post-flight analysis[47]. Flight information also include an operators preferences and constraints. At a macro level, the aggregate of multiple flights can be expressed as flow information. Flow information contains data elements that describe the characteristics affecting the flow, for example, through a particular airspace, or into and out of a specific airport.

12.6.3 Surveillance Information Domain

Surveillance information, by definition, describes the real-time position of aircraft for the primary purpose of separation. This information is communicated by a continuous data stream. With Automatic Dependent Surveillance – Broadcast (ADS-B In), surveillance information is supplemented by the aircraft's intent information to support future advanced trajectory based operations, interval management, merging and spacing, in-trail procedures, or self-separation.

12.6.4 Other Information Domains

The global air transportation system and all related decision-making necessary for its safe and efficient functioning are highly dependent on the provision of other

[47] ICAO (2011). Flight and Flow Information for a Collaborative Environment – a concept. Prepared by the Air Traffic Management Requirements and Performance Panel (ATMRPP).

candidate information domains. In addition to the above-mentioned information domains, these other domains contain information related to, for example, aerodrome operations, airspace operations, aircraft registry of capabilities, finance, environment, regulatory and legal, etc. Depending on a particular application, some of these additional information domains would need to be accessed and integrated with the primary aeronautical information domain.

12.7 Products and Services - defined

Products and/or services are outputs of any economic activity that consumers consume and are willing to pay for. Similarly, aeronautical information management constitutes an (economic) activity that brings forth certain information products and services. As we know from market economics, whether or not and how much money consumers are willing to pay for these products and services depends on the perceived value and will be discussed in Chapter 12.8.

The word *product* stems from the verb *to produce*, which is derived from the Latin *producere*, "to lead or bring forth". Simply speaking, the word product refers to "a thing or things produced" by which we oftentimes mean a physical or tangible good. A typical (industrial) production process involves the transformation of raw materials into finished goods, which may then be used for manufacturing other, more complex products such as automobiles, consumer electronics or aircraft[48].

In contrast, a *service* is an intangible commodity. Service provision is an economic activity where the service consumer does not generally obtain exclusive ownership of the service rendered. Often quoted key characteristics of a service[49] are:

- Intangibility – services are intangible in the sense that they cannot be touched, handled, smelled, tasted or looked at. Furthermore, a service cannot be sold or owned by somebody, it cannot be returned to the service provider.
- Perishability – services are perishable in two regards:
  - All service-related resources, processes and systems are assigned for service delivery during a definite period in time only.
  - When the service has been rendered to the requesting service consumer, this particular service irreversibly vanishes.
- Inseparability – the service provider is inseparable from service delivery, as he must assign resources and systems to maintain service delivery readiness. The service consumer is inseparable from service delivery through requesting it up to consuming the rendered benefits.
- Simultaneity – As soon as the service consumer requests delivery, services are provided and consumed during the same period of time, directly affecting the service consumer's related tasks or activities.

48 Retrieved from http://en.wikipedia.org/wiki/Product_(business)

49 Retrieved from http://en.wikipedia.org/wiki/Service_(economics)

- Variability – Each service is unique; it is one-time generated, rendered and consumed and can never be exactly repeated as the point in time, location, circumstances, conditions, or assigned resources will be different.

The seeming dichotomy between physical goods (products) and intangible services as discrete categories is, however, ill perceived as they span a continuum from pure products on one end of the spectrum to pure services on the other.

12.8 Shift In Business Models (And Possible Impact On AIM)

In a market economy, every time there is a (real or perceived) value creation that consumers are willing to pay money for, there is an associated business model. How much money consumers are asked to pay, that is, the prices they are charged, are determined in a free price system by the interchange of supply and demand. This economic model is in contrast to what is known as planned economy, with a fixed price system, where the government sets the prices.

The provision of aeronautical information services, from the perspective of the end user, has traditionally been a combination of both; governments (planned economy) have been setting the prices for publicly available products (e.g., AIP, charts) and services (e.g., overflight fees for aircraft that fly in controlled airspace[50]), whereas market economy and its free price system has been setting the prices for value-added and commercially available products (e.g., navigation databases for FMS) and services (e.g., global NOTAM service tailored to individual operations). The concept of aeronautical information management will begin to challenge this established economic distinction in the sense that Air Navigation Service Providers increasingly are in the business of creating value-added products and services. The transition from aeronautical data to aeronautical information, as well as the integration of different information sources (for example, thematically or regionally), constitute a value creation process that incurs not only additional costs for the provider but also constitutes value for the consumer. Hence, the business model for Aeronautical Information Management will be different than that for AIS in the sense that some ANSP may begin to compete in a free price market.

In addition, the advent of the Internet also (re-)introduced another powerful economic model, known as the gift economy. As a matter of history, long before market or planned economies ever existed, humans lived by hunting and gathering in what anthropologists call gift economies[51]. In a gift economy, valuable goods and

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50 For an example of fees in U.S.-controlled airspace, see http://www.faa.gov/about/office_org/headquarters_offices/aba/overflight_fees/

51 Today we still enjoy vestiges of the gift economy, notably in the family. We don't keep close tabs on how much we are spending on our three-year-old child in an effort to make sure that accounts are settled at some later date; instead, we provide food, shelter, education and more as free gifts, out of love. Retrieved on Jan.26, 2012 from http://richardheinberg.com/215-economic-history-in-10-minutes

services are shared without any explicit agreement for reward. Information is particularly suited to gift economies, as information is a non-rival good and can be gifted at practically no cost[52]. One noteworthy example is the free on-line encyclopedia called Wikipedia where innumerable authors and editors contribute without any direct material reward whatsoever. It is anticipated that the network-centric environment, which Aeronautical Information Management will be part of, is conducive to increasingly form social networks that do one thing best, and that is the sharing of information – for free. Therefore, it is probably not unrealistic to assume that aeronautically focused social networks, which form part of the information gift economy, will play an important role in the creation and also quality monitoring of aeronautical information, provided the information management processes under AIM permit (controlled) feedback mechanism and are adaptive enough to react to the feedback.

Another notable difference under the Aeronautical Information Management concept, therefore, is for stakeholders to adopt one or more of these economic models rather to simply rely on their traditional model. For example, an Air Navigation Service Provider provides its Aeronautical Information Publications according to a fixed price scheme, and competes in a market economy with sophisticated airport mapping databases that can be integrated with other information sources with the help of a free web application. International regulations, however, will determine which minimum set of AIM products and services need to be provided and may also offer guidance pertaining as to the price model being used.

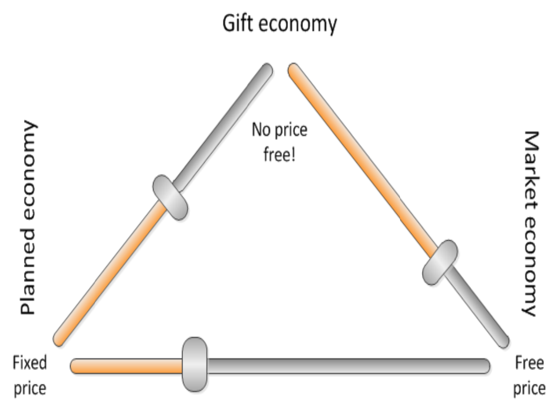

Figure 15: The three different economic models that may determine the affordability of aeronautical information.

52 For examples of information gift economies, see http://en.wikipedia.org/wiki/Gift_economy

12.9 Evolution to Aeronautical Information Management

The evolution from Aeronautical Information Services to Aeronautical Information Management takes place within the larger context of the global ATM system. The following figures portray the ATM system's view and place the evolution to AIM within it. Three distinct phases of transition are shown, labeled Phases I, II and III, as introduced in the "Transition Roadmap for the Transition from AIS to AIM", an ICAO document published in 2009.

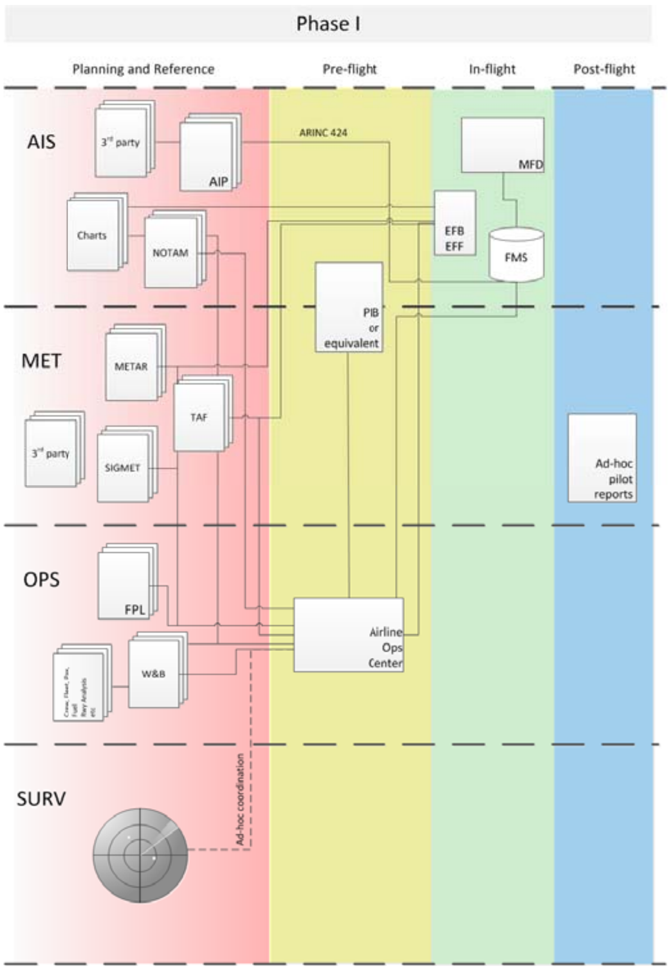

Figure 16 Phase I shows the consolidation phase of AIM within the larger ATM system's view. It depicts the as-is state of what is referred to as Aeronautical Information Services (AIS).

In these figures, each phase is shown across the spectrum of temporalities, ranging from Planning and Reference, to Pre-flight, In-flight and Post-flight. An important aspect is how aeronautical information (AIS) interacts with other information domains, namely meteorological information (MET), information of flight operational relevance (OPS), and surveillance information (SURV). The topic of information domains is discussed in more detail in Chapter 12.6.

In Phase I, also known as the consolidation phase, we recognize the as-is state of what is referred to as Aeronautical Information Services (AIS). In this information domain, the AIP, NOTAM and Charts, as well as aeronautical information provided by 3rd party providers are made available to the various users, including the pilots, Airline Operations Centers, airports, and Air Navigation Service Providers (ANSP).

An information product of operational significance, the Pre-flight Information Bulletin (PIB) or equivalent, contains aeronautical information (NOTAM), meteorological information (METAR, TAF, SIGMET, etc.) and flight plan-related information. It is made available during the pre-flight phase when briefing the pilots. During the in-flight phase, aeronautical information is provided as a preloaded FMS database that is being updated every 28 days. During the post-flight phase, ad-hoc pilot reports constitute the only flow of aeronautical information.

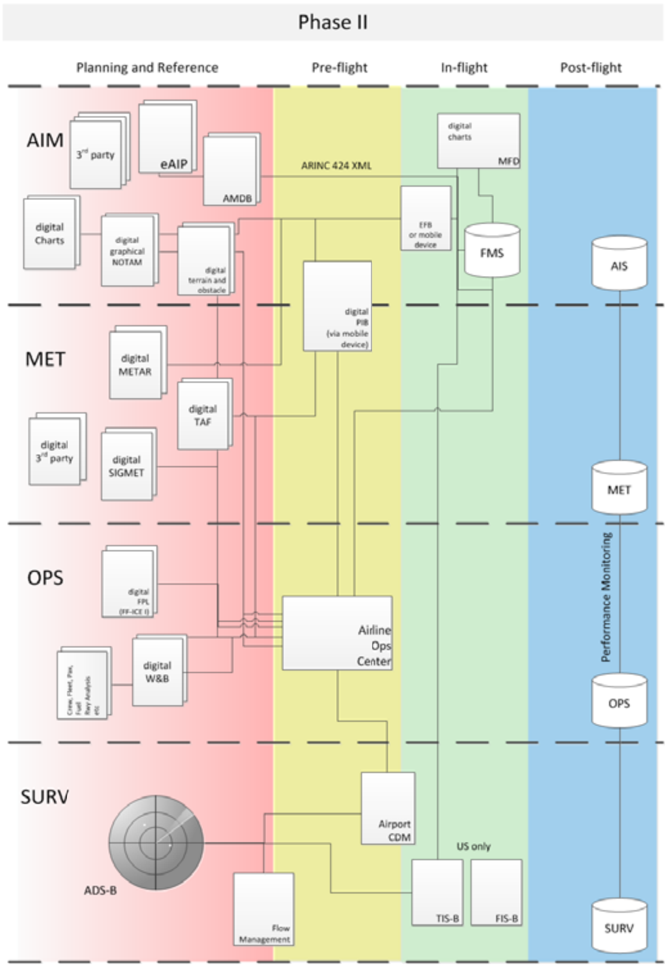

Figure 17 Phase II is the step to going digital, when information is being managed and exchanged digitally.

Phases I and II are important preparatory phases of the final transition to AIM. As mentioned earlier, consolidation is the main theme of Phase I, whereas Phase II is the step to going digital, when information is increasingly being managed and exchanged digitally. Phase II, shown in Figure 17, can be characterized as being the most critical in the transition since it fundamentally is AIM, in terms of availability and scope of information, but without the benefits of an underlying SWIM infrastructure. The criticality of this phase is due to the fact that the ATM system's complexity is probably the closest to what we called "The Edge of Uncertainty" in Figure 11. This phase should therefore be kept as short as possible and needed research results, critical standards development and funding, among other things, have to be in place to ensure steady progress towards SWIM implementation.

Operational benefits for the airspace users, however, begin to accrue in Phase II with aircraft flying Continuous Climb Operations (CCO) and Continuous Descent Operations (CDO), merging and spacing, In-Trail Procedures (ITP), to name but a few of what could be called the pre-cursors to Trajectory Based Operations.

Another important, but possibly overlooked aspect of Phase II is the implementation of post-flight analyses for performance monitoring. Monitoring of Key Performance Indicators (KPI), as promoted by the Manual on Global Performance of the Air Navigation System, ICAO Doc.9883, is an essential aspect of Performance Based Operations. However, what is not well known is that this may actually lay the infrastructural foundation of the integrated feedback mechanism back into the SWIM network. It is this aspect that will turn SWIM into a self-regulating, adaptive system.

Figure 18 is showing Phase III, the final phase in the evolution to AIM, that is also known as (System Wide) Information Management. Keywords of this phase are integration, collaboration and self-regulation. The important aspect of information quality may turn into a “non-issue” in a world of full transparency, visual representation of information throughout its life cycle, and integrated feedback mechanism to permit quick resolution of any erroneous information that somehow got into the system.

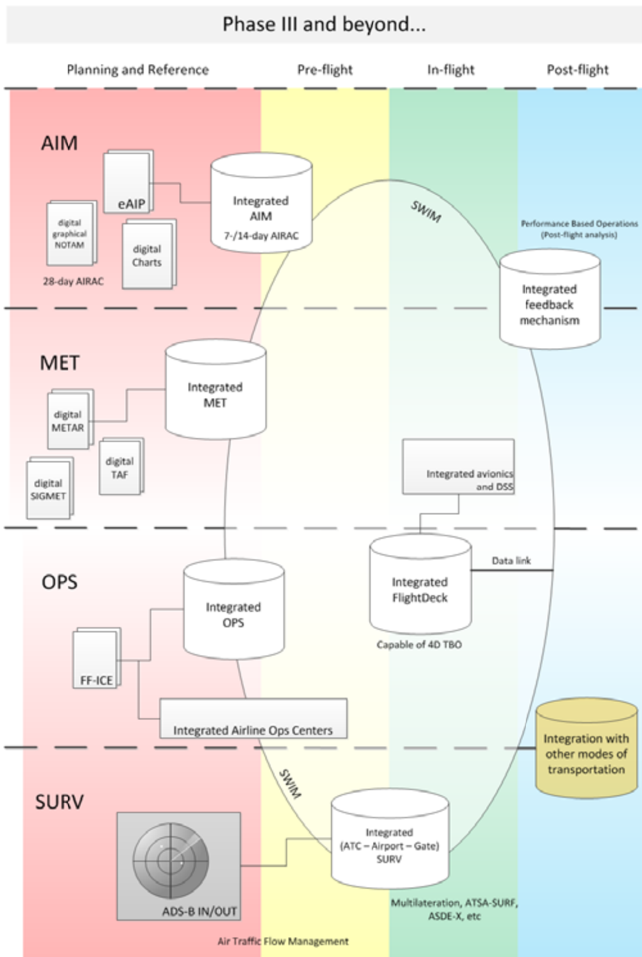

Figure 18 Phase III is (System Wide) Information Management. Keywords of this phase are integration, collaboration and self-regulation.

What is likely to happen, though, is that not all States will be able to participate in Phase III and will continue to provide information either in paper or in digital format, but not connected to the SWIM network. This could open the door for 3rd party providers to offer the service of integrating these information sources into the SWIM network. In such a scenario, information of the various information domains will be provided either as traditional information products, like an eAIP or digital NOTAM in the AIM information domain, or as part of an integrated information database that is connected to the global SWIM network. The integrated flight deck forms part of the SWIM network by being connected via broadband data link connectivity. For all of the information domains, a range of supporting information applications will be discoverable and made available to all authorized users on the SWIM network.

In the AIM information domain, a fundamental change may occur in Phase III and beyond, when the need for reducing the AIRAC cycle may present itself. At this point in the evolution, there will be widely available on the flight deck data linked portable devices displaying up-to-date information to the pilot(s) that may, at times, contradict the information contained in the Flight Management System. The FMS is, of course, still updated every 28-days according to the AIRAC cycle. This information discrepancy may lead to a potential human factors and safety issue by compromising situational awareness. A possible solution to this could be a reduction of the AIRAC cycle based on a modified avionics architecture and data linkable database updates.

Ultimately, of course, this decision depends on operators' requirements and projected operational benefits. The AIRAC cycle could be reduced to, for example, 14 or 7 days. At this point, a tiered AIRAC system is imaginable depending on traffic density, airspace complexity, or other performance requirements. For example, in order to conduct High Density Operations (HDO) like Closely Spaced Parallel Runway Operations (CSPO) at a high-density international hub airport during peak times, a 7-day FMS update cycle and RNP-.1 capability may become a performance requirement.

In the OPS information domain, fully implemented Flight and Flow Information for a Collaborative Environment (FF-ICE) will provide all the information necessary for managing 4-dimensional Trajectory Based Operations (TBO). The Integrated Airline Operations Center is an important orchestrator on the operator's side, closely coordinating their objectives and constraints with the flow management units of the Air Navigation Service Providers. All modern aircraft will be equipped with broadband data link and capable of flying highly efficient 4-dimensional trajectories. The integrated flight deck information architecture that can be found onboard airliners of the future will feed a suite of sophisticated avionics that incorporates powerful Decision Support Systems (DSS) which advise the pilot(s) of how best, for example, to circumnavigate a dangerous weather situation, or to calculate advanced runway analyses based on actual conditions.

FF-ICE will not only provide the information for single aircraft trajectories, but more importantly permit comprehensive Air Traffic Flow Management (ATFM) function that is fully integrated with its counterpart on the ground, Airport Collaborative Decision Making (A-CDM).

In general, flight operations are supported by continuously updated integrated global weather information, also known as the 4D weather cube. Probabilistic weather forecasts and more reliable weather reports, when integrated with AIM, provide the needed status and condition of the aeronautical infrastructure. For example, Runway Visual Range (RVR) information is transmitted as a real-time data link service to the inbound aircrafts' avionics systems and taken into account by the onboard Decision Support Systems to advise on go/no-go decision.

Surveillance information will be available via ADS-B In/Out and provide seamless situational awareness whether in oceanic, remote, enroute, or terminal airspace, and fully integrated with airport surface movements all the way to the gate. Ground surveillance technologies like Multilateration and Airport Surface Detection Equipment (ASDE-X) will be widely available and provide needed ground surveillance. Together with applications like Enhanced Traffic Situational Awareness on the Airport Surface (ATSA-SURF) and Final Approach and Runway

Occupancy Awareness (FAROA) that found initial use during Phase II, Phase III will see advanced versions of these applications and their widespread use to facilitate highly efficient airport ground operations.

Finally, during Phase III and beyond, we may also see the beginning integration with other transportation modes, and for aviation to become an integral part of a global multi-modal transportation system, also from an information sense.

12.10 Appendix F: List Of Abbreviations

To facilitate readability, the use of abbreviations has been largely omitted throughout the document. Most abbreviations were defined when introduced. The following provides an alphabetic listing of all abbreviations:

ACARS	Aircraft Communications Addressing and Reporting System
A-CDM	Airport Collaborative Decision Making
ADS-B	Automatic Dependent Surveillance - Broadcast
A-G	Air – Ground (data link)
AIC	Aeronautical Information Circular
AICM	Aeronautical Information Conceptual Model
AIXM	Aeronautical Information eXchange Model
AIP	Aeronautical Information Publication
AIS	Aeronautical Information Service
AIM	Aeronautical Information Management
AFTN	Aeronautical Fixed Telecommunication Network
AKM	Aeronautical Knowledge Management
ANSI	American National Standards Institute
ANSP	Air Navigation Service Provider
AOC	Airline Operations Center
ASDE-X	Airport Surface Detection Equipment
ASTRA	Australian Strategic Air Traffic Management Group
ATFM	Air Traffic Flow Management
ATIS	Automatic Terminal Information Service
ATC	Air Traffic Control
ATM	Air Traffic Management
ATMRPP	Air Traffic Management Requirements and Performance Panel
ATSA-SURF	Enhanced Traffic Situational Awareness on the Airport Surface
CANSO	Civil Air Navigation Services Organization
CARATS	Collaborative Action for Renovation of Air Transport Systems
CCO	Continuous Climb Operations
CDM	Collaborative Decision Making
CDO	Continuous Descent Operations
CEN	European Committee for Standardization
CNS	Communication, Navigation, Surveillance
CVS	Combined Vision System
DBMS	Database Management System
DIKW	Data, Information, Knowledge, Wisdom
DOD	Department of Defense
DSS	Decision Support System
EFF	Electronic Flight Folder
EUROCAE	European Council of Aerospace Engineering
ERAM	En-Route Automation Modernization
ETOPS	Extended Operations
EVS	Enhanced Vision System
FAA	Federal Aviation Administration
FAROA	Final Approach and Runway Occupancy Awareness
FF-ICE	Flight and Flow Information for a Collaborative Environment
FIS-B	Flight Information Services - Broadcast
FIXM	Flight Information eXchange Model

FMS	Flight Management System
G-G	Ground – Ground (data link)
GIT	Generalized Information Theory
GPS	Global Positioning System
HF	High Frequency
HFT	High Frequency Trader
IATA	International Air Transportation Association
ICAO	International Civil Aviation Organization
IFATCA	International Federation of Air Traffic Control Association
IFR	Instrument Flight Rules
ILS	Instrument Landing System
IM	Information Management
INS	Inertial Navigation System
IP	Internet Protocol
ISO	International Standards Organization
ITP	In-Trail Procedure
KPI	Key Performance Indicator
MET	Meteorological Services
METAR	Aerodrome Routine Meteorological Report
MFD	Multi-Function Display
MTM	Multi-Modal Transportation Management
MVFR	Minimum Visual Flight Rules
NAS	National Airspace System
NCO	Network-Centric Operations
NIST	National Institute of Science and Technology
NOTAM	Notices To Airmen
OGC	Open Geospatial Consortium
OSED	Operational Services and Environment Definition
PIB	Pre-flight Information Bulletin
RSS	Really Simple Syndication
RTCA	Radio Technical Commission for Aeronautics
RVR	Runway Visual Range
SAE	Society of Automotive Engineering
SARP	Standards And Recommended Practices
SAS	Single Authoritative Source
SESAR	Single European Sky Air Traffic Management Research
SIGMET	Significant meteorological weather phenomena
SSA	Shared Situational Awareness
SVS	Synthetic Vision System
SWIM	System Wide Information Management
TAF	Aerodrome Forecast
TIS-B	Traffic Information Services – Broadcast
TBO	Trajectory Based Operations
VFR	Visual Flight Rules
VHF	Very High Frequency
WXXM	Weather eXchange Model
XML	eXtensible Markup Language

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