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An Interoperability Assessment Model for CNS/ATM Systems

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Abstract

Next Generation Air Traffic Management (NG-ATM) modernisation programs such as SESAR in Europe and NextGen in the US are introducing novel system designs to meet the requirements for increasing air traffic growth. In the Communication, Navigation, Surveillance /Air Traffic Management (CNS/ATM) and Avionics (CNS+A) context, innovative concepts such as Four Dimensional Trajectories (4DT), System Wide Information Management (SWIM) based network architectures and higher levels of automation are introduced. With the access of unmanned aircraft in various classes of airspace, interoperability between airborne, ground and supporting systems such as satellite communication and navigation are essential for a successful implementation of the next generation concepts. In the CNS/ATM framework, interoperability is defined as the ability of systems to provide services to and accept services from other systems and to use the services that are exchanged to enable them to operate effectively. In this paper, a comparative analysis on existing interoperability models is presented and a comprehensive interoperability model is recommended for CNS/ATM systems. The recommended models are based on the ontology of Signal in Space (SIS), System and the Human Machine Interface (HMI) levels of interoperability. This assessment study provides a novel framework to define a certification process to assess the interoperability levels between various CNS/ATM systems.

Keywords: Interoperability, Air Traffic Management, Avionics

1. Introduction

Air transport is progressing rapidly, and a number of programs such as the Single European Sky Air Traffic Management Research (SESAR) of Europe and Next Generation Air Transport System (NextGen) (FAA, 2015) of the US are addressing the modernisation efforts required for future Air Traffic Management (ATM) systems. As part of a global consolidation effort, Aviation System Block Upgrades (ASBU) are introduced as part of the Global Air Navigation Plan (GANP) for the period from 2013 to 2028 by the International Civil Aviation Organisation (ICAO, 2013). The ASBU provide a baseline for the technology roadmap required in the Communication, Navigation, Surveillance/Air Traffic Management (CNS/ATM) and Avionics context (CNS+A). ASBU presents four performance improvement areas namely (ICAO, 2013):

- Airport operations
- Globally interoperable systems and data
- Optimum capacity and flexible flight
- Efficient flight paths

In addition to the ongoing global air traffic modernisation efforts, a number of regional air navigation improvement programmes are being undertaken including CARATS in Japan, SIRIUS in Brazil, OneSky in Australia and others in Canada, China, India and the Russian Federation. These programmes map their development plans to respective ASBU modules, in order to ensure near and long term global interoperability of air navigation solution (ICAO, 2013). Hence globally interoperable systems and data is a key performance improvement area that requires substantial research and development efforts from the aviation community.

Interoperability is essential to the realisation of CNS+A concepts considering the large number of stakeholders and extensive investments required in the next two decades. It is an important attribute to be considered at system conceptualisation and design stage. Investments in aviation infrastructure are hardly reversible (requiring upgrades as and when required) and any gap in technological interoperability generates consequences in the medium and long-term considerations (ICAO, 2013).

Interoperability in the CNS/ATM context can be subject to a number of interpretations based on the systems and interfaces considered. An aircraft flying across national and international regions would be receiving services of a number of Air Navigation Service Providers (ANSP), Air Traffic Control Operators (ATCO) and Airline Operations Centres (AOC). To maintain a consistent level of operation, the aircraft systems should be interoperable with the various ground service providers connected together to perform Collaborative Decision Makings (CDM). In order to perform information sharing and interoperation, ground systems should be interoperable with airborne systems. Furthermore, for optimal use of communication data links, for air-to-air surveillance information exchange or broadcast, for performing cooperative collision avoidance and separation between aircraft, the on board avionics should also be interoperable with one another. With the introduction of unmanned aircraft into all classes of airspace, unmanned aircraft must also be able to operate seamlessly with manned counterparts and ground systems (Clothier et al., 2011, Gardi et al., 2014). Satellites provide both communication and navigation functions through SATCOM and SATNAV systems and thus introduce another dimension for interoperability. Therefore an improved and effective ontology for interoperability is required to address the CNS+A system requirements.

This paper proposes an interoperability assessment model for CNS/ATM systems, which could be used in the entire system development lifecycle, especially at system design and development stages. At present, an established safety assessment model provides a baseline to ensure safety requirements are captured at the design stage as part of the aircraft certification process (SAE International, 1996). Additionally, it is envisaged that a fully developed interoperability assessment model would be vital for certification of future CNS/ATM systems.

2. Interoperability requirements of CNS/ATM Systems

Within "Globally interoperable systems and data – through globally interoperable System Wide Information management (SWIM)" performance improvement area identified by ICAO, the following requirements have been identified to be met over a 15 year period as described below (ICAO, 2013):

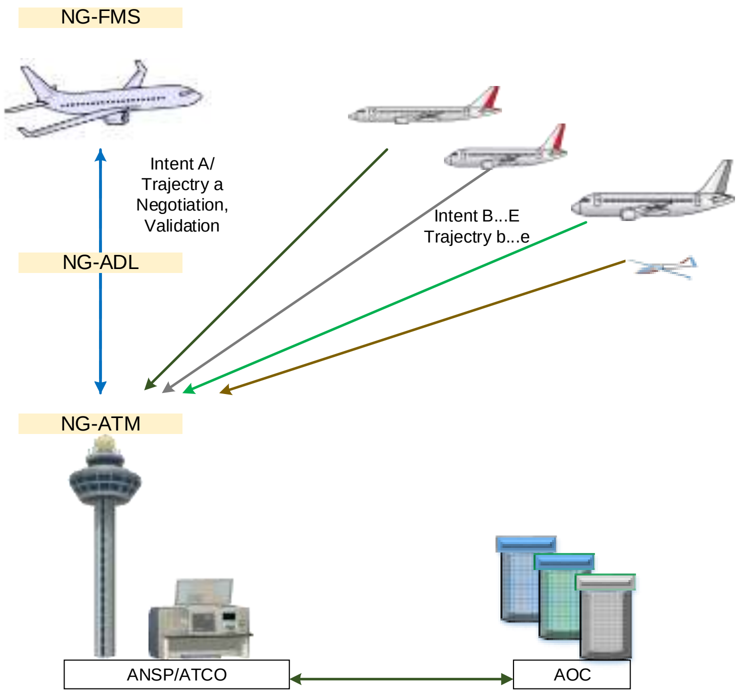
- Increased Interoperability, efficiency and capacity through ground-to-ground system integration supporting the coordination of ground-to-ground data communications between Air Traffic Services Units (ATSU) based on Air Traffic Services (ATS) Inter-facility Data communication (AIDS) defined in ICAO Doc 9694. This extends to implementation of common flight information reference model and flight object used before departure, and further into supporting Trajectory Based Operations (TBO). This ultimately requires all data for relevant flights to be systematically shared between air and ground systems using SWIM.
- Service Improvement through digital aeronautical information management with initial introduction of digital processing and management of information, by the implementation of Aeronautical Information Services (AIS)/Aeronautical Information Management (AIM) moving to electronic Aeronautical Information Publication (AIP) and better quality as well as availability of data. This extends further to the adoption

of Transmission Control Protocols (TCP) and/or Internet Protocols (IP) 4 and 6 protocols for data exchange.
- Implementation of SWIM services (applications and infrastructure) creating an aviation intranet based on standard data models, and internet-based protocols to maximize interoperability. As a future enhancement, airborne participation in collaborative ATM will be enabled through SWIM.
- Meteorological information provided by world area forecast centres and other advisory centres, supporting enhanced operational efficient and safety. This would be further developed to enhance operational decisions through integrated meteorological information to support automated demission processes and implement weather mitigation strategies.

In addition to above interoperability requirements related in specific to the implementation of SWIM as presented by ICAO, other technological evolutions are also envisaged as described below (Sabatini et al.) These applications require increased interoperability between airborne and ground based systems.

- Four-dimensional (4D) Trajectory-Based Operations (TBO).
- Performance Based Operations (PBO), which includes Performance Based Communication, Navigation and Surveillance (PBC/PBN/PBS).
- Aircraft Separation Assistance Systems (ASAS).
- Aircraft Collision Avoidance System (ACAS).
- Enhanced ground- and satellite-based aeronautical communication systems involving a highly developed data link technology.
- Ground-, avionics-, and satellite-based augmentation systems (GBAS/ABAS/SBAS) enabling Global Navigation Satellite System (GNSS) as a means of navigation.
- Enhanced ground-based and satellite-based surveillance, including Automatic Dependent Surveillance (ADS) and self-separation.
- Collaborative Decision Making (CDM).
- Improved Human Machine Interface and Interaction (HMI[2]) for greater interoperability and higher levels of automation.

Figure 1: 4D-TBO Concept [Adapted from (Sabatini et al.)]

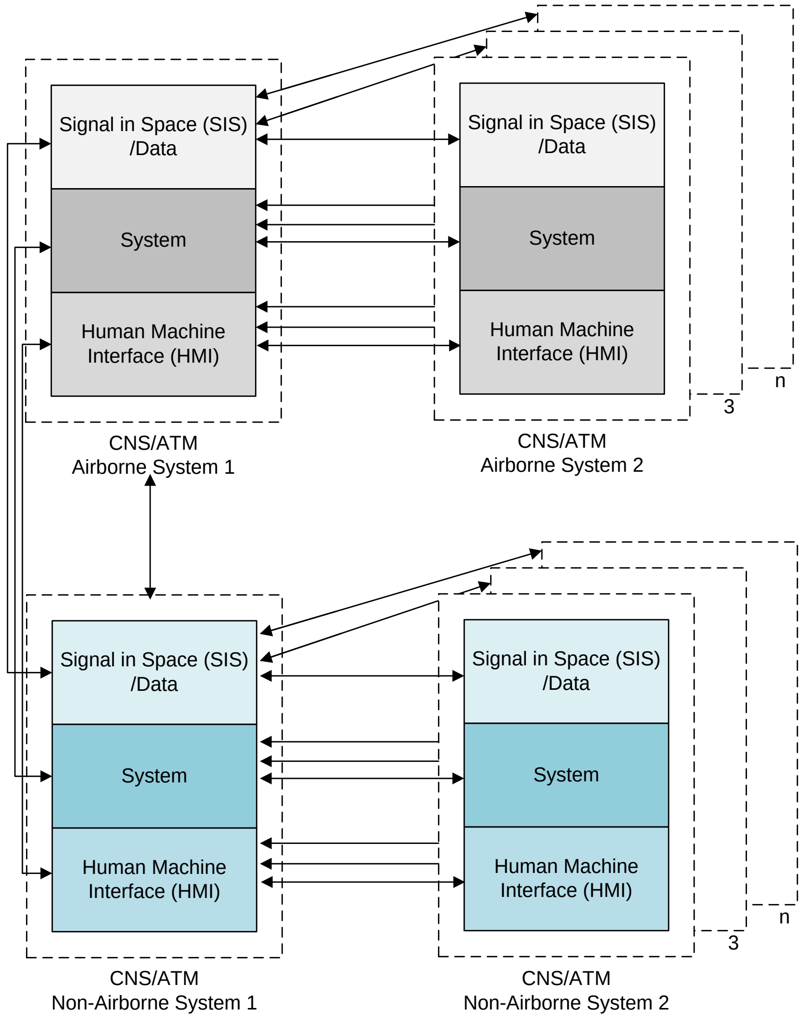


The concept of 4D-TBO is illustrated in Figure 1. The Next-Generation Flight Management System (NG-FMS) on board the aircraft exchanges information with the Next Generation Air Traffic Management Systems (NG-ATM) on ground via the Next Generation Aeronautical Data Link (NG-ADL) for 4D-TBO. Planning, Negotiation and Validation (PNV) of 4DT are performed considering 3D space and time of arrival at specific points along the trajectory. This requires aircraft-to-ground system interoperability as well as ground-to-ground system interoperability.

Figure 2 presents the ontology of interoperability between CNS/ATM systems, considering airborne and non-airborne systems. The main constituents of the CNS+A systems considered are the Signal in Space (SIS) containing the data element, the System (electronic hardware and software) and the Human Machine Interface (HMI).

While standardisation would be a fundamental building block to achieve interoperability, the capability to measure and assess interoperability between systems to identify the gap between the required and current levels of interoperability would be essential. Interoperability would need to be achieved in both technical and operational dimensions.

Figure 2: CNS/ATM system interoperability requirements



3. Comparison of existing models of interoperability assessment

According to IEEE definitions, interoperability is (Breitfelder and Messina, Radatz et al., 1990, Rezaei et al., 2013),

(1) “The ability of two or more systems or elements to exchange information to use the information that has been exchanged”;
(2) The capability for units of equipment to work efficient together to provide useful functions”;
(3) The capability- promoted but not guaranteed-achieved through joint conformance with a given set of standards, that enable heterogeneous equipment, generally built by various vendors, to work together in a network environment;
(4) The ability of two or more systems or components to exchange and use the exchanged information in a heterogeneous network.

Several other definitions for interoperability have been presented by the US Department of Defence (DoD), which include “The ability of systems, units, or forces to provide services to and accept services from other systems, units, or forces and to use the services exchanged to enable them to operate effectively together” (Rezaei et al., 2013).

Several interoperability models have been discussed in the past for various interoperability requirements, mainly focussing on information, communication and/or electronic system (technical), enterprise or organisational interoperability. Models for measuring interoperability between any two or more systems have been proposed in the literature (Rezaei et al., 2013). A comparison of main interoperability models developed is given in Table 1 (Ford, 2008, Rezaei et al., 2013). This comparison is based on the type of interoperability measurement of each model, whether technical or organisation or both and also the attributes of the model. Some models offer a measurement for technical interoperability such as communication and or electronic system interoperability, which is vital for CNS/ATM system interoperability measurement. The attributes of each model are assessed based on interoperability measurement criteria of each model, and the modelling of measured parameters. Table 1: Comparison of interoperability assessment models

Interoperability Assessment Model	Type of Interoperability Measurement	Attributes of the Model
Levels of information systems interoperability (LISI)	Technical	Measurement of information systems ‘interoperability
Spectrum of interoperability model	Technical	Measurement of interoperability in terms of levels
Quantification of interoperability methodology	Technical	Effectiveness measurement is correlated to interoperability
Military communications and information systems interoperability	Technical	Interoperability measured through spatial distance between points in the modelled system.
Interoperability assessment methodology	Technical, Organisational	Uses different number and non-number measures per attribute.
Stoplight	Technical	Measurement of interoperability through colour coding
The layered interoperability score (i-score)	Technical	Measurement based on operational thread (a sequence of activities where each activity is supported by exactly one system) and an interoperability spin (an intrinsic property of a system pair which indicates the quality of the pair’s interoperation).
An approach for enterprise interoperability measurement	Technical, Organisational	Measurement of enterprise interoperability

4. Proposed interoperability assessment model for CNS/ATM systems

The proposed interoperability assessment model for CNS/ATM systems is based on the concept of the layered interoperability score (i-score) model (Ford et al., 2007). It attempts to measure the interoperability between two systems of the three possible scenarios of interoperability, namely air-to-air, air-to-ground and ground-to-ground systems.

Considering the scenario of assessment of air-to-ground system interoperability, the three essential constituents required to demonstrate interoperability are defined as Signal in Space (SIS), the System (electronic hardware and software) and the Human Machine Interface (HMI). For the purpose of interoperability assessment, the measurable for SIS would be taken as the data that is transmitted/received.

Below interoperability assessment model is demonstrated using the 4D-TBO concept.

Interoperability of Data – For information sharing and communication between two systems, the systems should be able to exchange data. For 4D-TBO, data needs to be continuously exchanged between the airborne NG-FMS and the ground NG-ATM for the purpose intended flight trajectory communicated with ground systems, ground ATM responding with available optimum trajectory, NG-FMS either accepting and validating the trajectory or negotiating for another trajectory, and subsequently validating.

Interoperability of System Electronic Hardware and Software – For deriving globally optimal trajectories, taking into consideration the aircraft performance envelope, aircraft dynamics model, the weather, noise, engine emissions, demographic data-base, terrain data-base, airframe systems model, contrails model, airspace model together with airline operational business model, the algorithms of the NG-FMS should be interoperable with those of NG-ATM on ground.

Interoperability of the Human Machine Interface (HMI) – For accurate interpretation of data display, and execution of human data entry and control functions; system functional and operational performance together with the most crucial human factors should be taken into consideration when designing HMI. With the level of automation and supervisory functions demanded from both the pilot and the air traffic controller, accurate interpretation of information displayed will assist to facilitate interoperability between the HMI.

The interoperability of two systems, taking into consideration the attributes of data, system electronic hardware and software and the HMI, following total interoperability of systems S1 and S2 can be presented by the following empirical formula.

$$I_{S1,S2} = I_{S1(data),S2(data)} + I_{S1(system),S2(system)} + I_{S1(HMI),S2(HMI)} \quad (1)$$

Based on the i-score model, the level of interoperability between two constituents of the system is given by (Ford et al., 2007)

$$I = \sum_{i=1}^{n} \sum_{j=1}^{n} mij \quad (2)$$

Considering the dependence of interoperability on avionics technology upgrades (AV), ATM technology upgrades (AT), system failures (F) and system degradation (D), interoperability varies over time.

$$\int_{t1}^{t2} f1(\mathrm{I\ S1, S2})\mathrm{dt} = \int_{t\ at\ I\ low}^{t\ at\ I\ high} f2(\mathrm{AV, AT, F, D})\mathrm{dt} \quad (3)$$

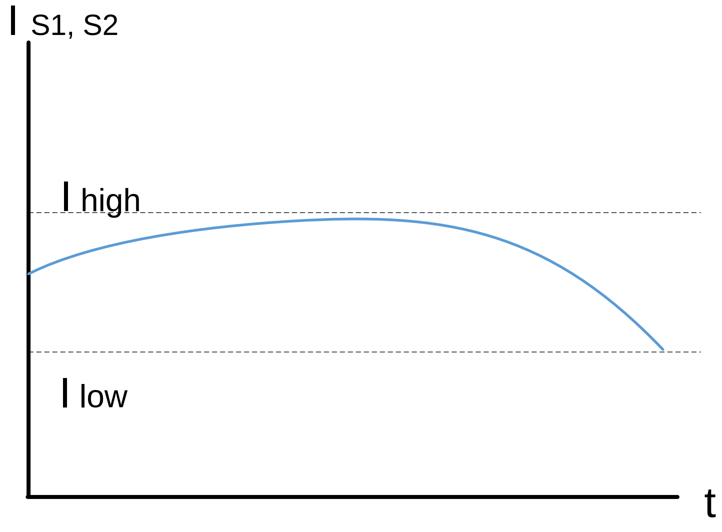


Figure 3: Empirical model for the variation of System Interoperability over time.

The interoperability would typically vary over time due to factors such as avionics technology upgrades (AV), ATM technology upgrades (AT), system failures (F) and system degradation (D). It should be maintained between required interoperability levels between I (High) and lower level I (Low), by maintaining the factors at a controlled level. The upper and lower levels of interoperability must be defined at system design stage.

The proposed new model is specific to CNS/ATM system interoperability measurement, unlike other models currently available. It focuses on the special factors that contribute towards the interoperability between two systems as described above, and considers the requirement for a real time interoperability measurement in order to maintain a level of interoperability that is required to assure the safe operation of the CNS/ATM systems.5. Conclusions and future research

This research investigated the interoperability requirements for CNS/ATM airborne and ground systems. When considering the system architecture, the main constituents of the CNS/ATM system that require interoperability are data, system (electronic hardware and software) and the HMI. The total interoperability requirements of two given systems were presented as the summation of the individual interoperability measures between the key constituents of the two systems. Since interoperability varies over time due to factors of avionics technology upgrades, ATM technology upgrades, system failures and system degradation, an upper level and lower level must be defined at system design stage.

This interoperability assessment model can be further developed taking into consideration various levels of interoperability requirements within systems. For example, sub-systems of the aircraft require to be interoperable, in order to deliver a resulting interoperability with the ground systems. Similarly, interoperability between sub-systems of ATM should also be considered in the assessment process. The i-score model can be optimised to be used for interoperability measurement between several sub-systems of a system.

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