The adoption of network-centric data sharing in Air Traffic Management

1. Introduction

Aviation systems are generating an increasing amount of data, with estimates of annual global aircraft data production reaching 98 million terabytes by the year 2026 (Maire et al., 2017). The proliferation of data gathering devices, sensors and the vastly improved data storage and communication technology is a major opportunity for improving aviation's performance. The emerging technology of Internet of Things (IoT) has led to more intelligent transportation. One example is the flight operational improvements developed in Air Traffic Flow Management (ATFM), which interlink airlines, airports and relevant Air Navigation Service Providers (ANSPs). Much of the data, however remain within the control and possession of the individual stakeholders.

Some of the evident possibilities include optimized aircraft separation and elimination of "highways in the sky"; real-time airborne fleet adjustment in the eventuality of weather phenomena; congestion prediction and holding pattern elimination through optimized flight regimes and/or departure slot modulation to deliver aircraft at the real-time landing capacity of the arrival airport (Ayhan et al., 2013). Sharing of weather data across the network, sourced from the traditional weather data providers; from real-time airborne aircraft-sourced data, or taken from crowd-sourced ground installations can improve the accuracy of weather models integrated in the Air Traffic Management ecosystem. Such an open sourced approach to data sharing can allow third parties to tap into this information and provide performance-optimized solutions like those developed by SHIFT Aviation Consultants or tools like SkyFusion developed by Harris Corporation in collaboration with the International Air Transport Association (IATA) to close the communication gap between the main stakeholders in the ATM industry.

The Federal Aviation Administration (FAA), in collaboration with the International Civil Aviation Organization (ICAO) have developed the System Wide Information Management concept (SWIM) which is being incorporated into both the Next Generation Air Transportation System (NextGen) and Single European Sky ATM Research (SESAR). The goal of the concept is to provide a platform for open sharing of all information between operators, airports, ANSPs and meteorology services. The SWIM protocol provides a framework by which any actor can develop solutions using a standardized database of parameters commonly understandable to all subscribers.

Despite its 20 years of existence, the implementation of this concept is only slowly gathering pace. Two main factors are expected to be the major drivers of this development: Availability and penetration of the required level of technology within the airborne fleet and ground infrastructure; and the willingness and possibility of actors to share their operational data with potential competitors.

A number of scholars have researched the sharing of information. Gal-Or (1985) researched information sharing in oligopolies, Li (2002) focused on horizontal completion, whereas Lee, So and Tang (2000) focused on data sharing two-level supply chain. There area of transportation and especially Air Traffic Management (ATM) remains under-researched.

The study aims to assess the adoption of SWIM by airlines, airports and air traffic management in Ireland, and to identify their drivers to invest in more streamlined communication as well as to identify any reasons why adoption is slower than expected. The potential of real-time data exchange in the aviation industry reaches all aspects and stakeholders, from optimisation of the entire passenger experience from booking through arrival, to improvement of the global weather model and the overall carbon footprint of aviation. This study focuses on the ATM benefits drawn from advances in digital communication between the various stakeholders, an area that is under researched.

2. System Wide Information Management (SWIM)

Researchers identified the need for more robust data communication for the industry to be able to follow the ever-increasing need for managing the airborne fleet (Smith, 1999). IATA (2017) supports the assertion that air traffic management "needs urgent reform to cut delays, costs and emissions". The slow evolution in ATM systems is mainly justified by the regulator's inclination towards safety over innovation (Kelvey, 2018). The current infrastructure, and its capabilities and limitations, are well understood and robust procedures have been developed to overcome the known limitations. Replacing the infrastructure with a modern, data driven solution requires substantial research to ensure improved performance and safety levels can be achieved on all four pillars of air traffic management – Communications, Navigation, Surveillance and Automation.

It became evident that the future of Air Traffic Management lies in generating real-time awareness and provide a platform for real-time data exchange between all stakeholders in the air traffic management equation. It is in this understanding that overarching projects such as SESAR JU (SESAR Joint Undertaking) and FAA NextGen have been initiated to tackle the question of congestion and to deliver future-proof ATM solutions.

The key to keeping up with the increased aircraft movements, is the availability of an agile and scalable solution for data sharing. Traditional information exchanges within Air Traffic Management are built around dedicated point-to-point information systems, often developed individually and specific to the needs of the information sharing partners (Meserole and Moore, 2007). As the volume and complexity of the global air traffic system increases, so does the complexity of the point to point infrastructure, with the need for multiplication of interfaces and agreements between an ever-increasing pool of stakeholders.

Figure 2 illustrate the point-to-point network of a single operations, and the overall ATM system and demonstrates the inherent complexity of integrating many operations in such a network.

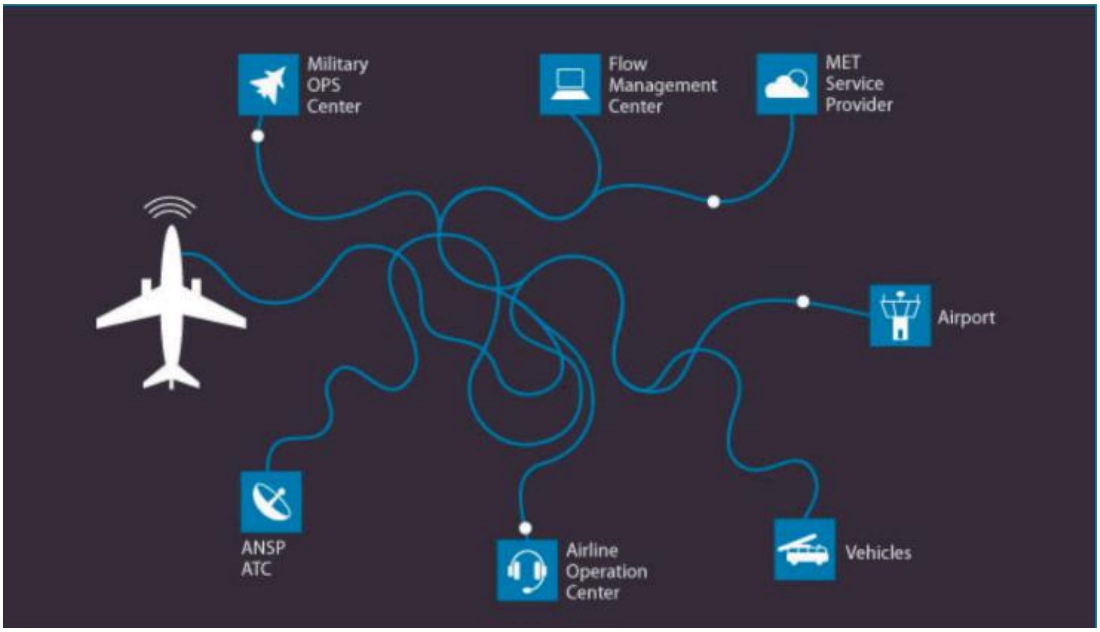

Figure 1: Communications Network of a single operator (Source: SESAR, 2016a)

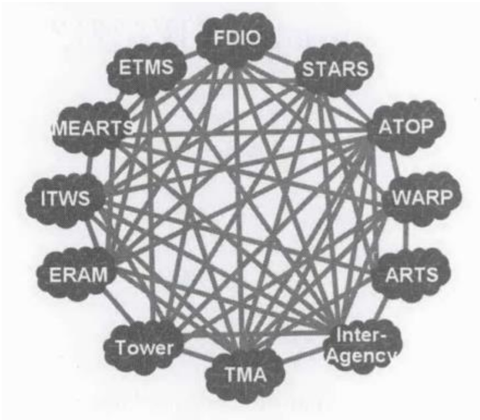

Figure 2: Traditional ATM Network (Source: Meserole et al., 2007)

To successfully meet the future demand and complexity of the air traffic ecosystem, a network-centric operations model was proposed in the form of SWIM – The System Wide Information Management concept (Bowen, 2014). The concept is actively being promoted to improve information sharing within ATM services both for the NextGen and for SESAR (Prabhu and Simons, 2009). Laskowski (2017) identifies SWIM as the key enabler to the success of SESAR.

In a study of the US National Airspace System (NAS), Glickman (2006) identified 5 key shortfalls to the current data-sharing capabilities in air traffic management. These are outlined in Table 1.

Shortfall	**Root Cause**
Applications cost too much to develop, deploy, test and support	Existing point-to-point implementations do not interface well with new applications
The NAS is not an agile air traffic system	Data is hard-wired between different facilities. A single failure cannot be reconfigured easily.
Data Sharing in the NAS is labour-intensive	Data sharing is often paper-based or based on manual re-entry or re-integration.

Real-Time access to data is lacking	Data required to improve Air Traffic Management is not transmitted in real-time
Tools to support a performance-based system are lacking	The available real-time data is not sufficient to support performance-based navigation

Table 1: Shortfalls of Data Sharing in NAS (Source: Glickman, 2006)

It is arguable that Glickman (2006) catered the shortfalls of the current NAS to the solution put forward by SWIM, but in his seminal paper on the business case for SWIM, he identifies how the concept provides a platform for overcoming each of the mentioned shortcomings of current ATM. SESAR also refers to the same shortcomings in identifying a lack of interoperability, standardization, availability and management of data within the network (Cruellas and Roelants, 2013).

Through a survey within the stakeholder community, SESAR identified five strategic business needs for the future of air traffic management (Cruellas and Roelants, 2013). Table 2 summarizes these needs, which lay the foundation for coping with the increase in demand for international air travel. Those are continuity of service, safety of operations, predictability of the air traffic flow, efficiency of flight profiles, access for all airspace users and cost effectiveness.

Business Need	**Description**
Traffic Synchronisation	Aims at reducing tactical Air Traffic Control (ATC) interventions and improving predictability within the network. Through this, aircraft can fly closer to their optimum trajectories, optimizing overall air traffic flow.
Airport Integration and Throughput	Integration of airports in the overall ATM system. Integration will provide ATM with full visibility on airport situation at all times, and airports with the required tools to optimize movements to improve overall system efficiency.
4D Trajectory Management	Continuous exchange of trajectory information between all ATM actors allows optimization of the overall airspace capacity. Tactical interventions can be calculated from gate-to-gate rather than within a specific sector improving the overall effect on the network.
Collaborative Network Capacity Management	Enhanced network management through dynamic collaboration with all relevant actors' planning aspects, including airlines, airports, ANSP's and the network manager
Conflict Management	Use of automation to reduce the controller workload in resolving conflicts

Table 2: Strategic business needs for SWIM implementation (Source: Cruellas and Roelants, 2013).

To meet those business needs, an increased level of ATM automation is required which in term requires the adoption of efficient end-user applications which exploit the power of shared information (Cruellas and Roelants, 2013). Implementing SWIM and realising the benefits requires the adoption of a paradigm change in aviation. Traditional reliance on static, published data and strict adherence to procedures developed to overcome the limitations introduced by these resources needs to be overcome in favour of what will eventually become a platform of services promoting mutual exchange of real-time information (Dubet, 2017).

SWIM promises to deliver a centralized, secure and standardized information sharing platform to which any stakeholder can subscribe (Meserole and Moore, 2007). The concept significantly reduces the number of interfaces required; one producer can use a single interface to deliver data to a wide range of consumers. According to the EU ATM Masterplan, SWIM is a key enabler for stakeholders, and identifies the 4 primary stakeholders in ATM: a) the network manager – for Europe, this is EUROCONTROL, who are the instigator behind SWIM, b) the ANSP, c) the Airport Users and d) the Airspace users. In commercial aviation, the latter are the airlines, in reality, however, this includes military operations interfering with ATM and all of the users who can affect the network.

The SWIM Technical Infrastructure (SWIM TI) deployment is phased in four profiles as illustrated in Table 3 and answers the various needs in terms of data sensitivity, availability and currency.

SWIM TI	**Connection type**	**Typical Use Case**
Yellow Profile	High availability, non-real time, low QoS needs	Business to Business information sharing: Messaging, Security, Supervision, High Availability, Policy Enforcement, Recording and Data Validation
Blue Profile	High availability, real-time	Flight Object information: Real-time interaction between flight operations and ATC, supports Aircraft to Aircraft Communication
Purple Profile	High latency, non-real time, high Quality of Service (QoS) needs	Secure air-ground messaging in areas where connections might be intermittent but QoS is vital
Green Profile	Civil-military data	Military data that cannot be adequately supported by existing profiles.

Table 3: SWIM Profiles

Most of the current applications in SWIM are using the Yellow SWIM TI Profile, which is adequate for purposes such as flight plan exchange and updates, D-NOTAM (Digital Notice to Airmen) or CDM (Collaborative Decision Making) where real-time data exchange is not required, but bandwidth and availability are primordial.

In many ways, Yellow SWIM TI can be considered as standardized replacement for the myriad of existing point-to-point interfaces in air traffic management as illustrated in Figure 2. Deployment of the Blue SWIM TI Profile is still under development and is only expected to be fully operational in 2025 (eATM, 2018). This profile will deliver the greatest impact on ATM solutions as it will enable real-time exchange capability, allowing the aircraft, which until now are mostly consumers of the data, to become producers thanks to the “flight object”. This opens the true potential of the data-sharing paradigm, with for example, Free Flight, 4D trajectory management and trajectory-based operations are reliant on a true high bandwidth, real-time exchange of flight information (Enea and Porretta, 2012).

Once fully operational and available in commercial off-the-shelf (COTS) solutions, SWIM will be a key enabler for Air Traffic Controllers and Regulators to gain insight in the overall use of airspace. General aviation will gain access to SWIM through the deliverables of the Aircraft Access to SWIM (FAA, 2013) and Swim Air-Ground (EUROCONTROL, 2018b) projects, which have been wholly incorporated in the SWIM concept. These projects, which combine the reliability of SWIM TI Purple and real-time nature of SWIM TI Blue envisage seamless integration of the currently unmanaged fleet of General Aviation and Drones as well as airport surface operations (Correas and Apaza, 2016) into the SWIM network, allowing optimization of airspace management for all users (Boeing, 2016; Moallemi et al., 2014; Ahrens et al., 2011).

2.1 Data Exchanges in Air Traffic Management

To assess the impact of a shared data resource on the performance of air traffic management, it is vital to assess the status in terms of what data is currently being exchanged and how. Controlled and safe air travel relies on different types of information required by any of the involved stakeholders:

A. **Aeronautical information** is published as an Aeronautical Information Publication (AIP) on a 28 day cycle, by the local Aeronautical Information Service (AIS) and is mandated by ICAO Annex 15 to be delivered using the most expeditious means available, preferably electronically using web services. It contains information related to the network, including functionalities available in the area, aeronautical charts for e.g. airports and navigation aids etc… (ICAO, 2015). Noteworthy changes to these data in the form of Notice to Airmen (NOTAM) are published more frequently, in the case of the IAA, daily.
B. **Flight Information** is a combination of information services defined by ICAO Doc 444, and is exchanged in the form of voice communications or Air Traffic Service messages, which are exchanged using Aircraft Fixed Telecommunication Network (AFTN). Flight Information includes all immediate updates to air crew and if often, either flight plans, published by the airlines before departure through bespoke interfaces and shared by the ANSP with the network manager, or location information.
C. **Airport Information**, published by the AIS, either as part of the AIP, or separately.
D. **Weather Information** is provided by the local Meteorological services in the form of reports, forecasts and charts which are periodically issued.
E. **Surveillance information**, sourced from various surveillance systems, such as radar scanning, transponder data, Automatic Dependent Surveillance – Broadcast (ADS-B), etc.
F. **Air traffic flow information**, and
G. **Capacity and demand information** are assembled by the network manager and ANSP’s based on the information above and are used to balance the network and provide traffic flow management services.

Today, many of these exchanges are not available in real time, so often strict adherence to procedures is vital to ensure the entire ATM ecosystem is relying on the same data and overcome the challenge of periodic publication. An example is adherence to the Aeronautical Information Regulation And Control (AIRAC) Cycle for delivery of the Aeronautical Information Publication. Non-adherence to this 28 day cycle can result in safety and cost issues, with monitoring across Europe indicating that for every cycle, three significant non-adherence events occur on average (EUROCONTROL, 2018a).

In the SWIM framework, all available data is structured using a universal data model, the ATM Information Reference Model (AIRM), which allows clear identification and understanding of the available data. SWIM categorizes ATM data in 3 major models: Aeronautical Information eXchange Model (AIXM), Flight Information eXchange Model (FIXM) and Weather Information eXchange Model (WXXM) for Weather Information. An additional Aerodrome Mapping eXchange Model (AMXM) was developed to allow for detailed airport mapping data to be modelled and overlaid with AIXM data using the existing SWIM standards. Mapping Table 4 indicated the allocation of the abovementioned data types in the SWIM AIRM Framework. The AIRM model is constructed so that there is no overlap between the different data models, but the models dovetail together to ensure complete coverage of ATM exchanges.

SWIM Model	**A**	**B**	**C**	**D**	**E**	**F**	**G**
AIXM	✈		✈			✈	✈
FIXM		✈			✈	✈	
WXXM				✈			
AMXM			✈				

Table 4: Allocation of data under SWIM

Noteworthy is the nature of wireless data communications today, where SWIM contains a security layer in all profiles, which means that the data communication is encrypted; today's messaging service, Aircraft Communications Addressing and Reporting System (ACARS), which is primarily used to communicate between the aircraft and its airline operations centre, is a non-encrypted exchange format which makes the exchange of flight and aeronautical information prone to corruption. Recently, Datalink capabilities such as Controller to Pilot Data Link Communications (CPDLC) have extended ACARS messaging to include ATC. This vulnerability emphasizes the need for pilots to strictly adhere to verification procedures, although proposals have been made to secure the communications link (Gurtov et al., 2018).

2.2 SWIM Adoption and Stakeholder involvement

The need for an improvement in air traffic communications is clear, but any such technological advancement can only be effectively implemented if all involved stakeholders are willing to participate. It is therefore vital to assess stakeholder appetite and assess the available means of gaining traction within each of the stakeholders.

Due to the regulated nature of the aviation industry, market forces cannot fully exploit to the economic advantages that can be derived from further development of the industry, this is acknowledged by Amaeshi and Crane (2006) who stipulate that stakeholder engagement is one of the keys to achieving sustainable aviation.

Achieving stakeholder engagement in a multi-national environment can be challenging, and collaboration often stem out of economic benefit positions (Gringinger et al, 2012). The positive impact on efficiency and global ecology promised by route optimization, through development of shorter routes, eradication of holding pattern and thus a reduction in overall emissions could be used to achieve buy-in from local actors to meet global emissions targets. It is therefore unsurprising that the SESAR JU, which is driving this collaboration has ecological footprint and efficiency targets (SESAR, 2015).

Regulation is also a key driver for the implementation of new technology and SWIM enabled applications. The European Commission has mandated the implementation of the most essential parts of the European ATM Master Plan to the member states (SESAR, 2018) and explicitly for Ireland. A few key developments are therefore mandated, such as the implementation Departure Management (DMAN), Electronic Flight Strips (EFS) and the adoption of the SWIM-compliant Network Manager Business to Business (NM B2B) Web Services to replace the 70 year old AFTN used for messaging (SESAR, 2017).

Despite the apparent benefits, the uptake of the concept within the industry is slow. Eyselbergs (2016) identified that one of the main contributors to the lacklustre attitude of industry stakeholders is the lack of clear and palpable benefits to the concept. The SWIM Registry (SESAR, 2016b) lists hundreds of SWIM enabled applications, many of which are fully developed. First party applications (i.e. from direct ATM stakeholders) are far-and-between. Eyselbergs (2016) refers to the availability of subsidies and lack of Return on Investment requirements, rather than a genuine business need, as a driver for the development of such third party applications. He also argues that the need for third party agencies to become relevant in an industry driven by major institutions drives the internal investment in these applications.

Achieving buy-in from all stakeholders who will directly benefit from data sharing might appear an evident feat at first glance, but whereas everyone appears to be keen on accessing the data, appetite to sharing the data is not as self-evident, as identified by Laskowski (2017).

As SWIM will also benefit the larger community – some investments may be required from one stakeholder who will not immediately benefit from the development. Arrow (1972) argued that the "public good" argument was a potential barrier to innovation as those parts of the innovation that become public good can no longer remain a private property of the innovator. Falk (2007) indeed identified a direct link between the amount of Research and Development (R&D) investment made by innovators and the availability of public funding – regardless of the direct benefit to the innovator. Subsidies can therefore be argued a pre-requisite to improve uptake of the innovation within the SWIM framework.

It is interesting to discover that challenges related to a shift to network-centric data sharing for Air Traffic Management in 2018 still closely resemble those identified by the US Department of Defence (DoD) in a 15 year old memo on the same subject (CIO (DoD), 2003). In this memo, the key challenges listed included the need to promote a cultural change to encourage data sharing – which Laskowski (2017) still identifies as a challenge in 2017; financial support for implementation – SWIM deployment in Europe is still heavily driven by EU subsidy and mandate as cost-benefit evidence is lacking; Transformation of legacy systems and promotion of meta-data use – Many stakeholders still use point-to-point infrastructures using bespoke data formats; and finally the implementation of security and data governance structures that provide transparency and streamlined, synchronized data processes – this is the very backbone of SWIM.

3. Methodology

As the nature of this study is to identify the potential barriers to wider implementation of the SWIM concept in air traffic management, an exploratory study was deemed most appropriate for this. Saunders (2011) and Robson (2002) claim that an exploratory study is very useful to clarify the underlying uncertainly to a problems origin. Therefore, this research is structured in three distinct phases; a) an exploratory study, b) a series of semi-structured interviews, and c) a case study exploring the implementation of the SWIM concept in an Irish setting. In defining the research framework, the nature of the problem statement was deemed unsuitable to a quantitative approach. No detailed assessment of the specific barriers that could be sampled through a survey resulted from the literature study, and the research population that could actionably be targeted was too small to derive any valid statistical value from such an attempt.

The exploratory study was conducted through a set of unstructured, but guided interviews with innovation centres in the aviation industry, notably Lufthansa Technics and Airbus. This study was relevant to confirming the validity of the underlying research question. It also served to identify emerging themes to improve the focus of the qualitative research. Again, this approach is supported by Robson (2002), who indicates that the purpose of the enquiry might well change over time as the exploratory research progresses.

Further literature research was performed using the newly gained insight from the exploratory study on the challenges of data sharing for the various stakeholders in the industry. The exploratory study population was chosen within the Aviation R&D and 14 senior experts were contacted within Airbus, Boeing, a major Maintenance, Repair and Overhaul (MRO) company, and COOPANS, a research entity of the Irish Aviation Authority (IAA) looking at cross-border cooperation within the air navigation services.

The themes derived from the exploratory study, together with the results from the literature study were used to formulate the core questions for the next phase. Focussing more on the network-centric nature of the concept at hand, a semi-structured interview-based survey was conducted with 46 experts representing operational stakeholders in ATC. To facilitate the process and to allow participants to gather internal feedback on the subject matter prior to the interview, the core questions were provided to the interviewees well before the interview was conducted. This also allowed some participants who could not participate in an interview to provide written input by directly answering the core questions.

The selected population was sourced from within the airline, ANSP and airport domain and includes pilots, base captains, operations managers, technology and development specialists and air traffic controllers. The organizations targeted were notably the Irish Aviation Authority, which acts as the local ANSP, Dublin Airport, Birmingham Airport, Aer Lingus, Ryanair, Lufthansa, American Airlines and Stobart Air. This population is not necessarily involved with the development of the concepts, but is either involved with, or impacted by the development of real-world data-sharing projects.

Concurrent to the semi-structured interviews, an implementation case study was conducted on the status of Airport Collaborative Decision Making (A-CDM) for Dublin Airport. Considerable overlap exists between the qualitative research on SWIM and the Dublin Airport Case study, as many of the respondents would be interested in the data sharing projects whilst equally being involved in the implementation of A-CDM in Dublin. This was a direct consequence of the population choice for the study.

As a commonly used strategy for qualitative studies, a thematic data analysis approach was used. Thematic analysis allows information classification and investigation of recurring patterns in the conversational data gathered (Boyatzis, 1998). The interview transcripts were analysed individually, and key segments of the interview were coded, allowing for disassembly of the results and identification of recurring themes (*Table 5*). Subsequently, the themes segments were re-assessed, and attributes were assigned. The entire coding is categorized as either A-CDM or SWIM depending on the relevance of the comment. Some comments are assigned to both categories as they are mutually relevant. Identification of the themes and attributes was performed organically, and new themes and attributes were created as the analysis progressed.

SWIM	A-CDM
Current Status	Status of A-CDM
Future Status	Barriers to success
Barriers to implementation	Drivers of change
Drivers of change	
Data Analysis	

Table 5: SWIM and A-CDM Themes

Duplicate data-points, which appeared in the same rational argument, were either combined or removed – depending on whether the duplication contained further “soft” information. However, duplicates were not removed, when a respondent provided these data-points multiple times in separate arguments. This choice was made to allow for identification of emphasis within the respondent. When all interviews were codified, the results were reassembled and commonality in the various opinions and objections were analysed.

Finally, all respondents were informed of the voluntary nature of the study and are explicitly requested not to divulge any confidential information should they wish to take part in the survey. The respondents were informed of their possibility to withdraw from the study should they wish to do so at the beginning of every interview.

For reasons of anonymity, the respondents’ names and companies have not been recorded, and the transcripts are identified as follows: XXYZ – TYPE – TITLE. Herein, XX represents the respondent’s organisation type: AL for airline, AN for ANSP and AP for Airport. X and Y are the counters for respectively the organisation type and respondent. TYPE represents the recording type and TITLE is a generic position of the respondent within their organization.

4. Analysis and Discussion of Findings

4.1 Exploratory study

The initial literature review illustrated the true potential of information sharing in aviation, with benefits reaching all aspects of the industry. This section presents the findings of this exploratory study, used to develop the further research and to focus the literature review as well as to identify issues with the questions asked. Two main areas of improvement were identified from this study – optimization of aircraft maintenance operations, and optimization of aircraft navigation performance.

Maintenance operations are found to be specific to the manufacturer and interfaces are bespoke. There are some proprietary programmes under development with the MRO to integrate operations across the different main Original Equipment Manufacturers (OEMs) but overall the message is that the OEM will tend to keep the detailed performance data proprietary to optimize their aircraft design, whilst the MRO who might not be able to access all gathered data will attempt to optimize across a fleet of aircraft and perform predictive maintenance monitoring where possible.

The results have revealed a commercial strategy. Many larger players, including OEMs, Airlines and MROs are in the process of develop their own eco-system which they intend to sell off as a service. As such there is little to no evidence of a convergence to a centralized platform such as the SWIM platform, as it reduces each actor's stake at the overall operation. Thus, maintenance operations were excluded from the scope of the research.

For the remainder of the study, focus was therefore placed on Air Traffic Management improvements which can be achieved through extensive and open sharing of data. There are substantial investments both in Europe and in the United States to draw benefits from Air Traffic data sharing. Noteworthy one of the interviewees stated that airlines, and mainly low-cost carriers, who focus purely on their flight operations, are much more willing to participate in data sharing activities.

4.2 Semi-structured interviews

This section will present the results of the primary research, conducted through interviews and questionnaires with the respondent within the primary stakeholders of air traffic management. First the general response statistics are presented, after which the results for each category are presented and analysed per theme. The overall research yielded 125 excerpts which were categorized for their relevance to either the adoption of network-centric data sharing. The study generated 411 data points for analysis.

The analysis of SWIM questions relates to the existing status of data exchanges in place and the feedback received towards any future evolutions that are planned or being implemented. The commentary of the respondents is then analysed with regards to the position which each respondent took on implementing network-centric data sharing capabilities and the benefits and drawback they perceived. The data were categorised in 5 themes; a) current status of data exchange, b) future status of data exchange, c) data analysis, d) barriers to implementation, and e) drivers of change

4.2.1 Current status of data exchange

All three stakeholder groups were represented in the sample and 25 data points were analysed. Six respondents commented on the current status of data exchanges in their operation. With regards to external data exchange, i.e. exchange of data with stakeholders outside of the respondent organisation, the access by third parties not directly involved in the exchange was analysed. *Table 6* presents the overall results, indicating that most widely available data exchange is related to flight information with ground and air traffic control through ACARS and ADS-B broadcasting which is indeed widely available on commercial platforms (e.g. flight radar 24).

	Internal	**External**
Data Access Shared	N/A	Flight Information, Aeronautical Information, Controller Pilot DataLink Communication (CPDLC) data Meteorology Service (MET) Information
Data Access not Shared	Flight Information, Flight Data Monitoring (FDM), Data, MET Information	FDM Data, Maintenance Data, Dispatch Information

Table 6: Data exchanges results

This short analysis provides two further, unsurprising insight in the types and nature of the existing exchanges. Firstly, there is no internal data, which is either dumped at the gate, or sent wirelessly over bespoke connections, which is accessible to third parties. Secondly, FDM data get used by the organisation and shared with partners which whom a data sharing agreement exists, but are not available to or shared with other parties.

Noteworthy is that one Airline respondent mentioned that sometimes clearance data which was received from ATC, was not systematically shared with their dispatcher leading to inconsistencies in the operation. On the other hand, ANSP respondents commented on the existing collaboration projects such COOPANS, where ATC system definitions are aligned between various countries in Europe, and the XMAN (Cross-Border Arrival Management) integration for London Heathrow where the Irish ANSP provides information to NATS (UK ANSP) so as to improve arrival management.

4.2.2 Future status of data exchange

One airline respondent highlighted the lack of current capabilities of their systems, and a need for a positive business case for investing in extensive data communication capabilities, despite the apparent benefit to operations.

Further positive feedback on the development of SWIM-compliant data communication exchanges were the ANSP and Airport, with respondents indicating benefits to ground operations thanks to the integration of communications with ground handlers into their centralized operations management and arrivals management, allowing them to gain better insight in the airport surface and stand requirements. The airport respondent provided some further insight in the impending upgrades their communications system, with the upgrade of the AFTN as a first step towards implementing SWIM.

No relevant information can be derived from this theme apart from a highlight that the airport and ANSP appear more ready to adopt the change than the airline.

4.2.3 Data analysis

All and only airline respondents commented on data analysis and the purposes of such data analysis. All but one respondent mentioned that data gathering and analysis of FDM data presents significant issues for the airlines due to union pressure or strict data gathering agreements. The airlines are looking for means to improve their operational efficiency by studying fleet performance, but data gathered internally can often not be analysed due to privacy concerns for the pilots.

Data analysis can be performed only in the context of safety review and statistical analysis, within the boundaries of the data gathering agreement and provided that no pilot can be identified. The results are nonetheless significant as the respondents were unanimous in their motivation to access and analyse data. Finally, as discovered in the exploratory study, third parties are also interested in analysing this data as a service.

4.2.4 Barriers to implementation

Seven respondents provided insight on the barriers to implementation of data sharing activities, the data consisted of 32 excerpts, 20 of which were provided by Airline respondents. A recurring concern in the airline respondent answers is the **difficulty to negotiate agreements with the pilots’ trade unions** to allow data gathering, with all airline respondents highlighting this concern (9 out of 20 airline responses concerned data privacy and union pressure).

“Our data gathering agreement does not allow us to do that” – AL11

“But we do not have an agreement with our trade union in that respect” – AL12

“Pilots can show concern about some data like that” – AL31

“Unions will always protect the pilots – messages can now not be analysed” – AL21

The concerns primarily involved FDM data, which, from the analysis of current data exchange was indeed never shared externally. Flight Data Monitoring data which is an inherent and required part of the Safety Management System, is however not part of the data exchanged within the SWIM framework, which primarily looks at the exchanges relevant to air traffic control. The results are nonetheless significant as they indicate that despite the questionnaire specifically asking for insight into SWIM-enabled data sharing, and respondents were asked whether they were aware of the concept prior to the interview taking place. As such these feedback points indicate that there is a lack of understanding with the airlines of what the remit of SWIM is. Union pressure could therefore prove to be a challenge when airlines move towards a SWIM-compliant communication model.

Cost, and the lack of a positive business case evidence, was the second main response. Respondents commented on the drive towards lower cost of operations, with airlines expecting to see lower charges on air traffic management services which places constraints on the ANSP resources:

“Most ANSP’s have been undergoing a lot of cost cutting over the last number of years. There is a demand from the Airlines to keep unit Charges down. Implementing a SWIM concept is a complex task with risks” – AN12

Concerns on the cost model were also raised by airline respondents, with all actors agreeing that the theory makes sense, but there is quite a bit of scepticism in the responses on whether the promises on paper would transpire in operational benefits.

“Who is going to pay the cost of sharing the data?” – AL21

“The business cases are all fine on paper – we have ANSP corporate people with slides talking about savings, and we can demonstrate that we are getting none of that. Our experience is that such initiatives that are pushed by the ANSP are dubious in terms of actual benefits.” – AL31

“That’s the theory, the vision – in the end it will all depend on whether it makes economic sense” – AP11

Unsurprisingly, the cost of implementation was also a driver, with respondents commenting on the need to upgrade their ground and airborne systems to fix a problem that does not exist today – they can quite effectively communicate and operate with the existing technology. One respondent highlighted the **maturity of the concept** with concerns on data validity and cyber security as a potential blocking point to stakeholders as the technology moves from well understood and proved satellite and radio technology to an internet-based protocol.

Finally, three respondents commented on the **natural resistance to change**, either from a safety perspective because the existing systems have a proven safety record, or from an operational perspective, where the current systems have an inherent inaccuracy which operators tend to exploit.

4.2.5 Drivers of change

Despite the evident push-back in terms of cost and confidence in the concept, 18 excerpts were recorded in favour of data sharing, for all but one of the respondents. Most of the commentary was anecdotal, illustrating the respondents' acknowledgement of the value of data sharing, with two recurring themes, clarity of communication and transparency.

Clarity of communications (3): Sharing information through data, despite initial pushback from e.g. pilots regarding extra workload to log into data link, improves the quality of data communications.

> *"Once the messages arrive it does improve the communication quality – this is a change over the last few years when pilots were more inclined to stick with the original voice exchanges" – AL21*

With the move from voice to Data link (e.g. CPDLC), and the move to data sharing between ANSP and the airline operations centre, pilot respondents confirm that the right, unambiguous information arrives with them in a timelier fashion. For example, confirmation from the dispatcher on the feasibility of a proposed new flight plan arrives immediately after the flight plan is received because the dispatcher was informed along with the flight crew.

Transparency (4): through more extensive data sharing, all actors can get a better view on the overall picture, pilots get better insight in the reasons for some Flow Management requests, whilst their operations centre can become more aware of the upcoming constraints in the network. One airline respondent commented on a project run by Boeing related to automatic turbulence reporting, providing the network with visibility on live turbulence reports from participating airlines. The ANSP commented on the ability to get a better overall view of the network, even beyond the reach of their own responsibility. For this, some pilot projects were mentioned such as the COOPANS collaboration effort between the IAA and Sweden, Denmark, Austria and Croatia; and the involvement of the IAA in London Heathrow's (LHR) XMAN, which provides allows arrival management at LHR to extend beyond the boundary of UK ATC. The information shared by the IAA in this collaboration is not based on the SWIM architecture, but on OLDI (On-line Data Interchanges). NATS on their side, providing the acquired data as a SWIM service to other SWIM compliant ANSPs.

The ability to be **more agile** and to quickly and economically integrate new functionality and new stakeholders was mentioned by one airline, the ANSP and the airport respondent. Where the ANSP is already working on integrating SWIM in pilot projects, the Airport commented that they already adopted a central enterprise bus solution in 2009 and therefore there is a level of motivation to extend functionality and integrate new stakeholders such as ground handlers. **Obsolescence** of technology was also mentioned as a driver for change as the current enterprise service bus operated by the airport does not have the capabilities needed to fully integrate the airport operations, and some technology such as the 70 year old AFTN technology used for flight information messaging.

Overall, the majority of positive feedback related to the concept came from the ANSP and Airport, which is not truly surprising as the amount investment made, and the initial benefits gained are higher for these actors. Two airline respondents suggested that **regulation** would be required to make the airlines invest in the required infrastructure to support SWIM.

4.3 Case study: Airport Collaborative Decision Making (A-CDM) for Dublin Airport

4.3.1 A-CDM overview

To address the real-life implementation of a SWIM-enabled solution, the local application of one of the five strategic business needs identified by SESAR (Cruellas and Roelants, 2013) is studied in this section, the Airport Collaborative Decision Making (A-CDM). In this section, the A-CDM is explained. Moreover, the considerations for A-CDM in Dublin are investigated through an interview-based survey held with respondents within the ANSP, Airlines and the Airport, the main pertinent stakeholders. This first part covers any feedback received from the respondents with regards to the status of A-CDM at Dublin Airport. The second part elaborates on the barriers to its success and motivation to change are assessed for the different stakeholders.

The A-CDM concept is an operational process aiming to enhance the efficiency and turnaround, to increase capacity at participating airports with high traffic movements by reducing delays, improve punctuality of events and optimise resources. It is a tool that allows for real time sharing of operational data and information between the stakeholders using an airport, thus creating "common situational awareness" (EUROCONTROL, 2016).

The concept, which has been fully implemented in 28 airports in Europe, primarily aims to improve the predictability of the of the air traffic network by providing the Network Manager (EUROCONTROL) with accurate Target Take-Off Times (Huet et al., 2016) and therefore allows for optimal Air Traffic Flow Management and capacity balancing. A-CDM requires organisational culture changes, handling of sensitive data, procedural changes and understanding of all A-CDM partners (DAA, 2017).

The concept relies on improved messaging between the airport, airlines, ground service providers, ANSP, and the network manager, ensuring improved awareness for all these stakeholders. Managing the multi-stakeholder environment of an airport is an extremely complicated task (Murphy and Efthymiou, 2017). The benefits are not limited to the remit of the airport, as the entire network will reap the rewards. Locally, the airport and airlines will benefit from improved efficiency of stand allocation, improved aircraft sequencing and shorter taxi times yielding fuel economy, and improved availability of ground handling services. Thanks to the visibility of all departures in the network, capacity balancing of the network becomes more streamlined, with reduced flow management required and a proven improvement in Air Traffic Flow Management induced delays (Huet et al., 2016).

Information sharing is however only a part of the equation as adherence to the provided timestamps is a pre-requisite to the success. Correct sequencing of the aircraft can only happen if ground handlers, and airlines can ensure that the moment at which they claim the aircraft is ready for pushback is correct, otherwise unnecessary delays are introduced and the benefit in turn-around quickly erodes (Martin et al., 2018)

A-CDM is currently being trialled in Dublin, with block testing with some of the airlines to check on how the concept can benefit the operations and how it can be extended to 24/7 operations. In 2009, Dublin airport invested an enterprise service bus, which was a key enabler for growth at that time and which in 2011 was connected to the airport operations. As such, the airport was well prepared for a project involving improved and increased communication between the airport and airlines as primary stakeholders to departure management.

Airport respondents commented mainly on the operational experience of A-CDM, with both respondents highlighting the lack of consistency in A-CDM implementation for the various airports in Europe with both Dublin and Heathrow managing departures through a different timestamp (Target Startup Approval Time instead of Target Off Block Time) than the rest of the airports, which was a mention-worthy inconsistency. The main comment for both respondents was the lack of a key enabler for effortless A-CDM operations, no screens are available indicating the relevant timestamp to the flight crew. Operational timeliness is primordial to the success of A-CDM, this was confirmed by one of the respondents. Both airline respondents confirmed that despite some communication existing between the ATC and the airline operations centre, brokered by Dublin airport, there is still a lot of room for confusion and need for voice communication between both cockpit and operations, and between operations and ATC. This jeopardising the potential for airlines to strictly adhere to the timestamps delivered by ATC. Both airline and airport commented that the screen was expected to be available in 2019.

The airport respondent confirmed that Dublin airport has completed the development and has the systems in place to deploy A-CDM. Once A-CDM is fully implemented from a concept perspective, the airport will include ground handling in their A-CDM implementation, and they will communicate on departures and gather flight plans through a SWIM-compliant data exchange in the future when the ANSP is also able to provide and accept such information.

4.3.2 Barriers to the success of A-CDM

All respondents were asked about their opinion of A-CDM and what they see as barriers to the success of A-CDM in Dublin. Because the implementation of A-CDM is mandated by the regulator for larger airports, and objection to the implementation is not a considered measure.

The main target of A-CDM is to promote predictability to the overall air traffic network. The primary beneficiary of A-CDM is agreed to be the Network Manager (EUROCONTROL) for whom the concept provides visibility of accurate departure information from all airports, and allows network capacity balancing through governance of departure timestamps by the various ATC centres. One of the key features of A-CDM, which enabling the optimization of the network is the airport's **ability to re-sequence** aircraft on ATC request. Dublin however has a primarily single taxiway infrastructure, which means that no re-sequencing is possible for aircraft that have been pushed back from the stand. This was highlighted as a major concern by two airline respondents.

The results do indicate that there is a substantial **cultural** issue with A-CDM, with all respondents claiming that the main beneficiary of A-CDM is one of the other stakeholders. The airport respondent accepts that they are playing a vital role in deploying A-CDM but see the main beneficiary with the airline and the Network manager.

"There are a lot of benefits, the airport doesn't necessarily benefit from it but the airlines certainly do" – AP11

"… also the environmental impact [less taxiing] and the benefits to the network manager" – AP11

Whilst the airlines see A-CDM as a means for the airport and ATC to deny responsibility for delays, and the ANSP argues airlines prefer to claim on time departure and blame congestion for any delays.

"it is better to sit in a long line of taxiing aircraft because you can claim an on-time departure and blame the ATC and Airport for congestion on the ground" – AN11

"ANSP and Airport can deny their responsibility for their issues of congestion" – AL31

Additionally, there is an aspect of **cost** with A-CDM, much linked to the cultural challenge, because the airline respondents argue that there is a lack of burden sharing between the operators, who are mandated (through REGULATION (EC) No 261/2004) to operate on a strict time-schedule. Airlines can be delayed by A-CDM and incur penalties due to compensation, whereas there is no motivation for the other stakeholders to do anything about that, although the ANSP provides some commentary against this, arguing that the airports have a clear incentive to get aircraft away from the stands.

"We have an operational imperative to run on schedule. There is a subsequent flight planned and the EU commission will force us to pay out for delays for passengers" – AL31

"CDM back-plans from your scheduled take-of time to find the ideal pushback time - it could happen that you end up delaying your target take off time" – AL12

"There is no burden sharing with the other stakeholders, so they have no motivation to change or to address the impact on the airline" – AL31

"If you need to stay on stand for 20 minutes, the airports themselves do not want that because of stand capacity constraints" – AN11

A final finding is a palpable sense of lack of maturity of the concept, with both airlines and the ANSP providing interesting insights. On the ANSP side, concerns were voiced on the validity of the A-CDM model mandate, because only airports exceeding 77K movements are required (and subsidized) to implement A-CDM, whereas the aviation industry has gradually moved away from larger airport hubs, towards a point-to-point network, with airlines flying to smaller airports that do not necessarily make that threshold. In Ireland for example, only Dublin appears to be required to implement A-CDM, whilst the traffic from Irish airports to London is at least as frequent from those airports combined as it is from Dublin. As such, predictability in the network is challenged as the traffic emanating from those smaller airports needs to be integrated into the capacity of the controlled airspace as well.

"A-CDM and SWIM ignore the smaller airports. The system was thought up using the old fashion way where the national carriers are flying between the hubs, it does not allow for the new point to point routes from secondary airports which also have to go through the same airspace." – AN11

An airline respondent voiced their concern on the compatibility of the concept with the operational reality of air traffic, especially for Low Cost operators, or those flying multiple short-haul routes daily. These operations often have very short turn-around time capabilities, which are ignored by A-CDM, causing unwarranted delays

"If I have multiple departures in a day [and] there is flow control being applied...[aircraft] carrying a one hour delayed slot. I will not update my flight plan, because I know ... I can turn the aircraft around in time for its Calculated Take Off Time (CTOT). A-CDM does not account for that, which is a common practice throughout the industry." – AL31

4.3.3 Drivers of change

Commentary supporting the motivation to change was mainly received from the airport and ANSP respondents, providing mostly feedback on the overall improvements to the network. With a total of 7 relevant excerpts.

Two airline respondents did comment, coyly, that there is a benefit in such that there is a fuel burn advantage when A-CDM is successfully implemented. A-CDM has the potential to significantly reduce taxi times by sequencing aircraft optimally. These respondents did go on to state that the main reason why it is being done is the **EU mandate**.

One ANSP emphasized the benefits of **network predictability** and the effect on capacity optimization of timely information with regards to departures, and accurate departure times. Finally, as none of the respondent fully accepted that they are the true beneficiaries of A-CDM implementation, it is therefore not surprising that the main motivator for its implementation is that the change is required by EU mandate and the availability of funding.

5. Conclusions

The potential of data sharing in aviation is substantial. SWIM provides access to real-time, relevant aeronautical, flight, and weather information so users enabling them to respond faster and more accurately. SWIM also contributes to global interoperability and standardisation by providing commonly understood quality information delivered to the right people at the right time.

Air Traffic Management is an inherently difficult concept to change because of the severe safety implications of change. Implementation of SWIM appears to be staged, with the network manager driving the process, followed by the ANSP. The system is developed to improve messaging compatibility in an environment where many bespoke interfaces already exist. From a network point of view the further down the chain from network manager to airline, the less different interfaces are required. It therefore makes sense that the implementation of SWIM has progressed to a higher level of adoption within the ANSP, then followed by the airport. At this stage, there is no genuine incentive yet for airlines to implement the change, as the necessary messaging capability, which will allow the network to benefit from data production at aircraft level will only become a reality with the arrival of the Blue SWIM TI profile.

While the literature review highlighted a need for all stakeholders to participate and invest for the SWIM concept to be successful, the general feedback was that such collaboration does not exist at the moment. Airline respondents expressed scepticism towards the real benefits of data sharing, arguing on the basis of historic failures that there is no benefit, as current infrastructure is sufficient. In reality however, SWIM is already being deployed within the network manager and the ANSP's, and airlines are already reaping the rewards of improved Air Traffic Flow Management thanks to for example the implementation of A-CDM in 38 airports in Europe. It can also be argued that the further the development of SWIM progresses within the network, with more ANSP's sharing collaboration, and airports joining A-CDM, the smaller the perceived impact will be of an eventual adoption of the concept in Dublin, because much of the improvement will already be gained from other operations.

Where the literature identified solution readiness with key functionality missing to fully exploit the benefits, the primary research indicated further issues with concept maturity, especially for A-CDM with both airlines and the ANSP highlighting that the realities of airline operations are not taken into account, and that the concept is at least for now, not fit for purpose.

The emphasis from airline respondents on the difficulties encountered with data sharing related to FMD data was not something that was expected from the literature. This finding also shed some light on the ability of airlines to negotiate the further development of data sharing capabilities in general, as for every change in data gathering and sharing activity, the pilot unions are likely to join the table, looking for clear indications that they can protect their members.

The cost of implementation, and the need for a positive business case to justify the investment identified in the literature was echoed by the respondents, will all stakeholders agreeing that the costs are substantial and are one of the main barriers to overcome. Furthermore, the primary research yielded some interesting insight in the motivations and for some actors the lack thereof to invest in data sharing capabilities to support, for example the A-CDM concept at Dublin Airport. The key finding is that none of the respondents truly feel that they are the beneficiaries of such an investment and hence, the motivation to invest lies on the development of a "greater good", a distant future where everyone, eventually, will benefit.

6. Recommendations

In order to move forward with the adoption of SWIM, the change must be regulated through a mandate. Command and Control regulations can be effective in situations where some of the parties do not see the long-term benefit of the scheme. Providing financial incentives and disincentives to guide the behaviour of regulated entities will not work as the regulated entities will provide information that will not be useful or will not be delivered on-time. This practice was implemented in Single European Sky with poor results (Efthymiou and Papatheodorou, 2018). In combination with the mandate, an effective stakeholder management will be required to gain buy-in from all participants. All the participants need to understand how SWIM benefits them and how the scheme will improve the overall performance of the network.

Furthermore, many developments do exist for the SWIM framework, primarily in the domain of third party stakeholders attempting to gain relevance in the air traffic services industry, for which SWIM is a formidable enabler. Further investigation on how these third-party applications might prove to be drivers for the future adoption of SWIM among the primary actors could yield some interesting results.

One of the biggest constrains of SWIM is the cost of investment and investments in Research and Development in the area of airspace harmonisation, technological innovations and especially Internet of Things need to be made. The European Commission through Horizon 2020 and European Structural and Investment Fund programs needs to allocate funding for innovative solutions and technological advances. An additional measure could be the subsidisation of technology adoption for airlines, airports and ANSPs.

In conclusion, global data sharing can drastically improve the overall safety and efficiency of aviation by improving and enforcing the global safety culture for the former and by improving operational efficiency. Further study of such concepts will certainly be required and touch on one key finding within this study as well as the sensitivity and privacy of data.

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Table 7 abbreviations and terminology

ATM	Air Traffic Management (ATM)
SWIM	System Wide Information Management
ACARS	Aircraft Communications Addressing and Reporting System
A-CDM	Airport Collaborative Decision Making
ADS-B	Automatic Dependent Surveillance - Broadcast
AFTN	Aircraft Fixed Telecommunication Network
AIP	Aeronautical Information Publication
AIRAC	Aeronautical Information Regulation And Control
AIRM	ATM Information Reference Model
AIS	Aeronautical Information Service
AIXM	Aeronautical Information eXchange Model
AMXM	Aerodrome Mapping eXchange Model
ANSP	Air Navigation Services Provider
ATC	Air Traffic Control
ATFM	Air Traffic Flow Management
CDM	Collaborative Decision Making
COTS	Commercial off-the-shelf
CPDLC	Controller to Pilot Data Link Communications
CTOT	Calculated Take Off Time
DAA	*previously* Dublin Airport Authority
DMAN	Departure Management
DoD	Department of Defence
EFS	Electronic Flight Strips
EU	European Union
FAA	Federal Aviation Administration
FDM	Flight Data Monitoring
FIXM	Flight Information eXchange Model
IAA	Irish Aviation Authority
IATA	International Air Transport Association
ICAO	International Civil Aviation Organization
IoT	Internet of Things
LHR	London Heathrow
MET	Meteorology Service
MRO	Maintenance, Repair and Overhaul (facility)
NAS	National Airspace System
NATS	National Air Traffic Services
NextGen	Next Generation Air Transportation System
NM B2B	Network Manager Business to Business
NOTAM (D-)	Notice to Airmen (Digital-)
OEM	Original Equipment Manufacturer
OLDI	On-line Data Interchange
QoS	Quality of Service
SESAR	Single European Sky ATM Research
WXXM	Weather Information eXchange Model
XMAN	Cross Border Arrival Manager