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Integrating navigation and communication systems for innovative services

by

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Abstract

In air transport, safety rightly is a prime concern. This has led to safe proprietary solutions but a conservative approach to innovation. Forecasted traffic growth, economic pressure and passenger preferences require more responsiveness. Both new air traffic management concepts, Eurocontrol's COOPATS and FAA's DAG-TM, are based on extensive information sharing between all parties concerned. The Total Information Sharing for Pilot Situational Awareness Enhanced by Intelligent Systems (TALIS) project has chosen to use COTS based Internet technology to provide the enabling data sharing. This open solution also allows for easy integration with non-traditional actors like airports, passenger services etc. The planned 2½year realisation time for the TALIS prototype versus the decades typical for the industry and the relatively minor investment, of which already half is allocated to applications, testify to the success of the approach.

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(20 pages in total)

1 Introduction

Air transport is a safety conscious industry. Its good safety records testify to the success in this area. The downside of this success is the industry's conservative approach to innovation. Economic pressure will force it to be become more competitive and hence more responsive to other user needs. This paper describes an approach to use the Internet based service paradigm in which services are provided to customers. These services are based on, or use, other services. In this way communication services and navigation services can be integrated to provide innovative services to satisfy user needs in a timely fashion.

The first section will provide some background or a high level view of the current practise in air transport. The second section argues why innovation is needed. Subsequently section 3 describes the two major user-driven new Air Traffic Management (ATM) concepts, Eurocontrol's Co-operative Air Traffic Services (COOPATS) and FAA's Distributed Air-Ground Traffic Management (DAG-TM). Section 4 elaborates the Total Information Sharing for Pilot Situational Awareness Enhanced by Intelligent Systems (TALIS) services approach, illustrated by an en-route example and an airport one. The TALIS solution is elaborated in section 5, including its underlying Internet technology. Finally section 6 discusses some safety issues before the conclusion summarises this paper.

2 Background

Air transport technology is heavily influenced by safety concerns. Air transport's safety record justifies this approach. As in any industry concerned with safety, proven technology is favoured above innovative solutions. Compared with the general market, the volume, both for aircraft avionics and for ground systems is relative minor. This reinforces a slow evolution of the technology deployed and a very limited use of commercial off-the-shelf (COTS) products. Nevertheless the evolution tends to be technology driven in stead of user driven due to the complex aeronautical issues involved. Typical implementation times for new technologies are measured in decades, as illustrated by certified GPS approaches in the navigation domain (versus massive GPS use in the general domain, cars and the maritime domain), and the still incumbent Aeronautical Telecommunication Network (ATN) versus massive use of mobile communication in the general domain. The COOPATS document [1] provides a vivid example of these long implementation times by contemplating the use of data link technologies, which it mentions started in the early 1970's.

3 Need for change

Air transport is expected to grow in the long term, despite the temporal downturns like the one after the September 11, 2001 attacks, see [2]. It is a widely held view [1], [3], that this expected traffic volume can only be accommodated by a paradigm shift away from the current concepts and ways of working. Rising delays reinforce the business need for more responsiveness of the air transport system to user needs instead of the current practise of innovation based on technological opportunities. Cost concerns imply that an effort should be made to harness the power of COTS to concentrate the resources on air transport specific problems. Some observations on the relevance of COTS for ATM are provided in [4].

Apart form these high level incentives for change, other factors reinforce this need for more responsiveness. Based on the finding that weather related accidents have the highest fatality rate, [5] studied the use of data linked weather update for general aviation pilots Conclusions include that on-board intelligence is needed to transform weather information to a usable service supporting the pilot. Also the important but not well understood issue of the Human Machine Interface (HMI) makes updates of any initial service and its supporting software likely, reinforcing the need for responsive user-driven services.

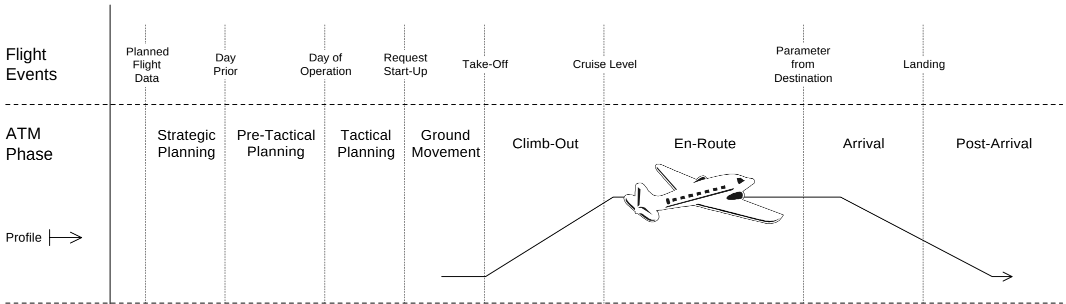
4 User driven concepts

Currently a number of air-ground integration operational concepts are being conceived. These range from short term improvements based on ADS-B and Controller/Pilot Data Link Communications (CPDLC), through Airborne Separation Assurance System (ASAS) to the long term vision of Co-operative ATS (COOPATS) of Eurocontrol for the European Civil Aviation Conference (ECAC) area or Distributed Air-Ground Traffic Management (DAG-TM) of NASA for the USA. These concepts are based on integrating the air-side and the ground-side comprising amongst others integration of the navigation capabilities with the communication systems. These communication systems are an enabling technology, just now being deployed in the air transport domain. The need for flexibility and more responsiveness of the air transport information technology systems will be illustrated by the following cursory description of COOPATS and DAG-TM.

4.1 COOPATS concept

The COOPATS concept is defined in [1] as “a concept of Air Traffic Management (ATM) that enhances the productivity and safety of Air Traffic Services by optimising the involvement of (air traffic) controllers, aircrew and airline operators through integrated Data Communications and improved forms of surveillance and automation”. The high level objective of Co-operative ATS is to support controllers, pilots and all potential ATM users, in all phases of flight, up to enabling autonomous flight operations in Free Flight Airspace by progressively implementing fully seamless communications, data exchange, situational awareness and automation capabilities. The Co-operative ATS concept is based on the human centred automation paradigm, as a consequence of the responsibilities defined by ICAO in [6]. It identifies the following concept goals:

- Fully seamless communication between air traffic controllers and pilots,
- Fully seamless data exchange capabilities between all involved ground systems and aircraft,
- Optimal provision of flight information data in real time, for use by aircrew and any other involved parties, such as meteorological centres.



	Strategic Planning	Pre-Tactical Planning	Tactical Planning	Ground Movement	Climb-Out	En-Route	Arrival	Post-Arrival
Units and Facilities Involved	IFPS CFMU	IFPS CFMU ATM FMPs AMCs	IFPS CFMU FMPs	TWR APP ACC IFPS FMPs	APP ACC(s) IFPS FMPs	ACC(s) IFPS FMPs	ACC(s) APP	TWR
Data link Services: ACM				Q	Q	Q	Q	Q
ACL				Q	Q	Q	Q	Q
CAP					Q	Q	Q	
DCL				Q				
DSC				Q	Q	Q		
PPD				Q	Q	Q	Q	
FLIPCY				Q	Q	Q	Q	
DYNAV				Q	Q	Q		
D-FIS			Q	Q	Q	Q	Q	
COTRAC				Q	Q	Q	Q	
SAP					Q	Q	Q	
ATSAW			Q	Q	Q	Q	Q	
COSEP				Q	Q	Q	Q	
AUTOPS						Q		

Figure 1 Envisaged Co-operative ATS services

The key principle is improved situational awareness for both pilot and controller, enabled by data link technologies. ATM will become increasingly dependent upon the efficiency and quality of supporting processes and services such as System-wide Information Management (SWIM), Aeronautical Information Services (AIS) and aviation meteorological services (MET). For planning purposes, Co-operative ATS is divided into two concept levels, level 1 for evolution up till 2008 / 2010 and level 2 for realisation between 2007 and 2015. Figure 1 provides an overview of the data link services per flight phase. The bottom three services, in

Italics, relate to level 2 services. Note that the Co-operative ATS concepts naturally uses the word services and the notion that advanced services build upon more primitive services.

Co-operative ATS assumes the ATM system evolves in a gradual and interactive way towards its final form. Consequently Co-operative ATS implies a mechanism for continuous change of the software and applications which implement these services.

4.2 DAG-TM concept

The Distributed Air-Ground Traffic Management (DAG-TM) concept is defined in [7] as “a concept in which flight deck crews, air traffic service providers and aeronautical operational control personnel use distributed decision making to enable user preferences and increase system capacity, while meeting air traffic management constraints. DAG-TM will be accomplished with a human centred operational paradigm enabled by procedural and technological innovations. These innovations include automation aids, information sharing, communication, navigation and surveillance (CNS) air traffic management technologies”. The fundamental objective of DAG-TM is to minimise static restrictions i.e. the users can plan and operate according to their preferences (as the rule) with ATM deviations only when inevitable (by exception). The DAG-TM concept will be implemented using a spiral development approach, as known from the information technology [8]. The DAG-TM concept, as described in [3], is referred to as the gate-to-gate concept. Taking the user needs and individual return-of-investment decisions into account, it assumes a mixed fleet equipage for the additional DAG-TM capabilities. The centrepiece of the DAG-TM concepts is distributed decision making between the three parties involved

- The flight deck, operated by the flight crew,
- The aeronautical operational control centre, operated by the flight planners and flight dispatchers,
- The air traffic service provider, including air traffic controllers and traffic flow managers.

This is depicted in figure 2.

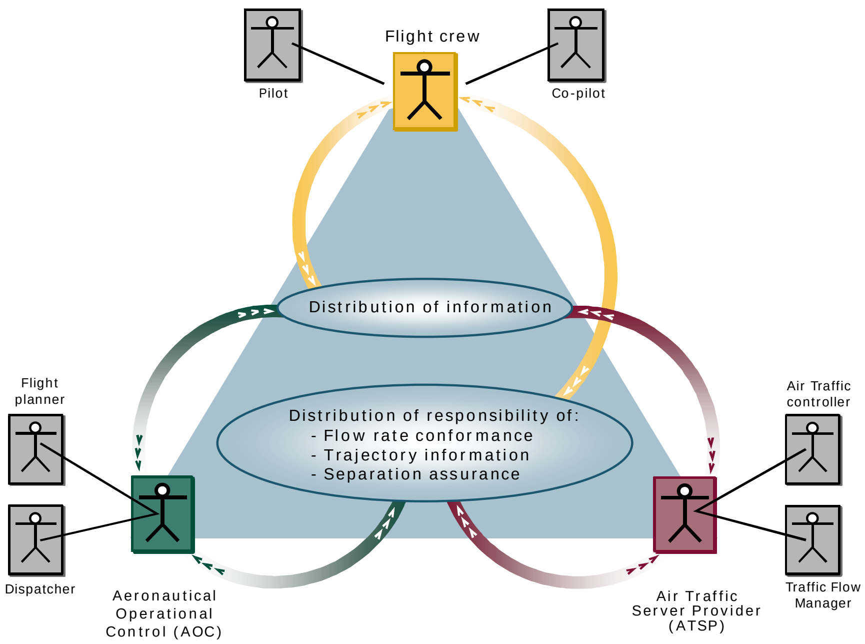


Figure 2 DAG-TM concept triad

The flight deck plus the aeronautical operational control centre together constitute the DAG-TM users. The DAG-TM concept is based on extensive information sharing and subsequent distributed decision-making responsibility by all three parties. To exchange information the 4–D trajectory is considered fundamental. Table 1 provides the fundamental gate-to-gate concept plus the 14 derived DAG-TM concept elements and their provided services.

Table 1 DAG-TM concept elements and provided services

DAG-TM concept element	**provided services**
1. Gate-to-gate	Information access / exchange for enhanced decision support
2. Pre-flight planning	NAS constraint considerations for schedule / flight optimisation
3. Surface departure	Intelligent routing for efficient pushback times and taxi
4. Terminal departure	Free manoeuvring for user-preferred departures
5. Terminal departure	Trajectory negotiation user-preferred departures
6. En route (departure, cruise, arrival)	Free manoeuvring for • user-preferred Separation assurance • user-preferred local traffic flow management conformance
7. En route (departure, cruise, arrival)	Trajectory negotiation • user-preferred Separation assurance • user-preferred local traffic flow management conformance
8. En route (departure, cruise, arrival)	Collaboration for mitigating local traffic flow management restrictions due to weather, Special Use Airspace and complexity
9. En route / Terminal arrival	Collaboration for user-preferred arrival metering
10. Terminal arrival	Free manoeuvring for weather avoidance
11. Terminal arrival	Trajectory negotiation for weather avoidance
12. Terminal arrival	Self spacing for merging and in-trail separation
13. Terminal arrival	Trajectory exchange for merging and in-trail separation
14. Terminal arrival	Airborne conflict detection and resolution for closely spaced approaches
15. Surface arrival	Intelligent routing for efficient active-runway crossing and taxi

The DAG-TM concept is based on decision support tools. The determination of the required information exchange is one of the foremost research issues to determine its feasibility. The information sharing and the improved situational awareness aim to increase both safety and capacity. For the arrival phase, the Estimated Time of Arrival (ETA) will be replaced by a Desired Time of Arrival (DTA). This will allow the users to either accept some delays using their preferred route or to avoid congested airspace and arrive earlier (e.g. using another runway with increased taxiing time). This mimics car drivers, which might take the shortest but congested route or take a longer not congested route.

The DAG-TM concept states information sharing and distributed decision making as fundamental enablers. As research continues, current ideas evolve and new ideas are expected to arise necessitating new procedures and algorithms. A software characteristic is that even stable products evolve over time, so the DAG-TM concept comprising evolving ideas and relying heavily on software implicitly needs a mechanism to cost-effectively and swiftly disseminate new software or software updates to the existing fleet i.e. it needs a flexible communication infrastructure.

5 TALIS services approach

The aforementioned need for change results in user driven concepts enabled by a way to share information. Based on this, the Total Information Sharing for Pilot Situational Awareness Enhanced by Intelligent Systems (TALIS) project is being executed. Its objective is to provide an architecture that supports a layered services concept. To achieve this, the architecture builds upon (or uses in Internet parlance) navigation and communication services to provide more advanced services like ADS-B (Automatic Dependant Surveillance) and Traffic Information Services (TIS). By using general hardware and software components i.e. COTS technology and Internet based solutions, the time-to-market of the services can be reduced drastically. Uplinking new data, or even new software, facilitates a swift deployment of new or updated services, also for aircraft with legacy avionics. This is a big advantage when new requirements arise, as is currently the case for security. Figure 3 depicts this layered services concept. Viewing the Flight Management System (FMS) in an analogue way, the FMS provides the capability (service) to navigate from any designated point to any point, based on ground beacons plus the aircraft’s Inertial Navigation System (INS) combined with local processing capabilities or intelligence, the supporting or lower level services.

TALIS aims to be an enabler for the Co-operative ATS and DAG-TM concepts as well as for many other services, including non-ATM services like aeronautical operational control and passenger services. The next two services describe two sample services, both from the ATM domain, the first being realised in the TALIS project and the second being considered for implementation. Both services focus primarily on pilot users.

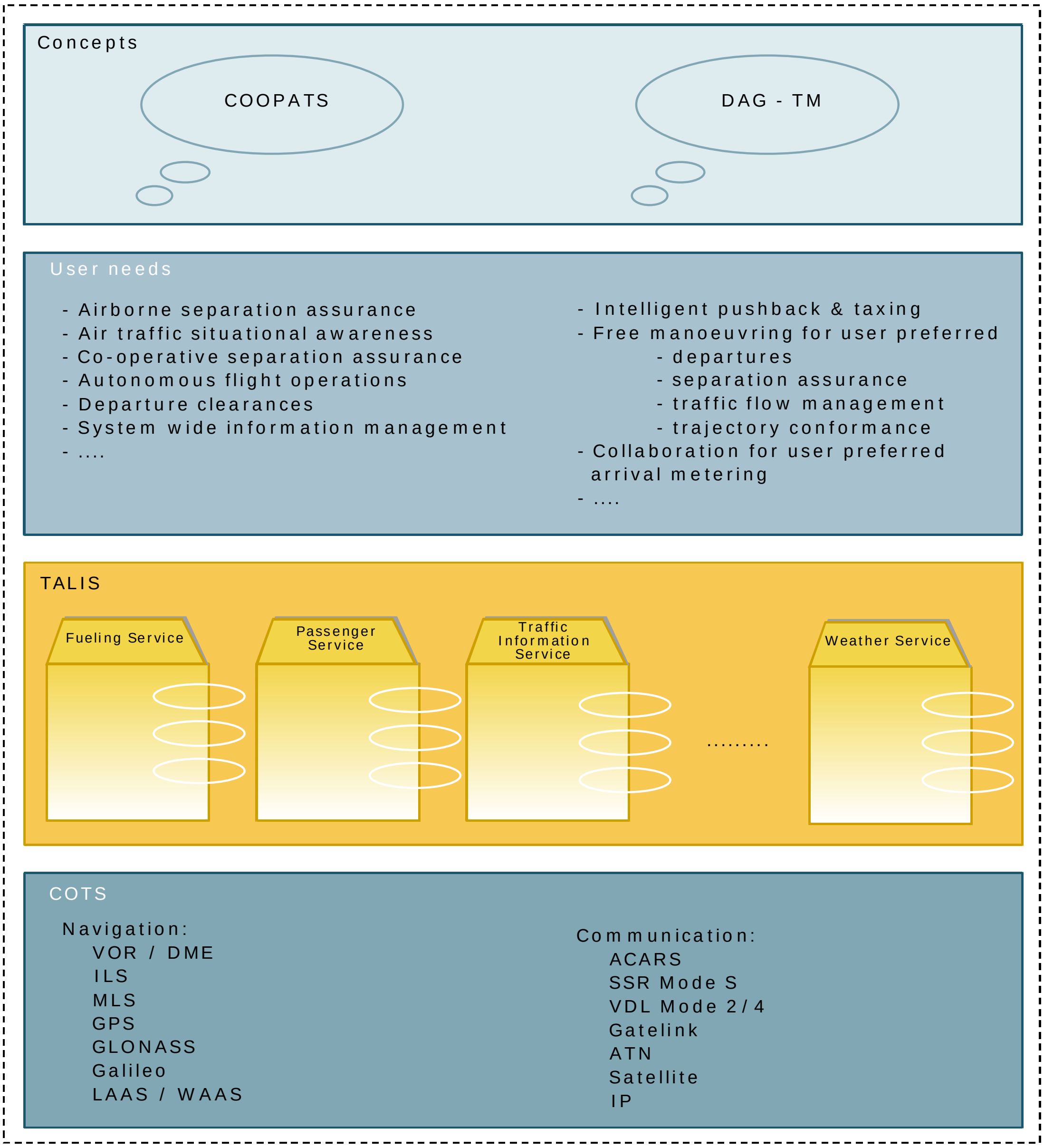


Figure 3 TALIS layered services concept

5.1 En-route example services

Some en-route services with their TALIS support are illustrated in figure 4 using the Airborne Separation Assurance System (ASAS) concept. Depending on the navigation and communication services available, a different level of ASAS service can be supplied. When no radar is available, ASAS will be Automatic Dependent Surveillance Broadcast (ADS-B) based and provides protection for equipped aircraft only. Where radar and ATN are available, the aircraft in the immediate surrounding of the own ship can be uplinked providing protection to all aircraft. In the approach phase, when radar, ATN and Traffic Information Service-Broadcast

(TIS-B) are available, these services will allow station keeping. Figure 4 illustrates these context dependant services. TALIS is currently working on the Traffic Information Service part.

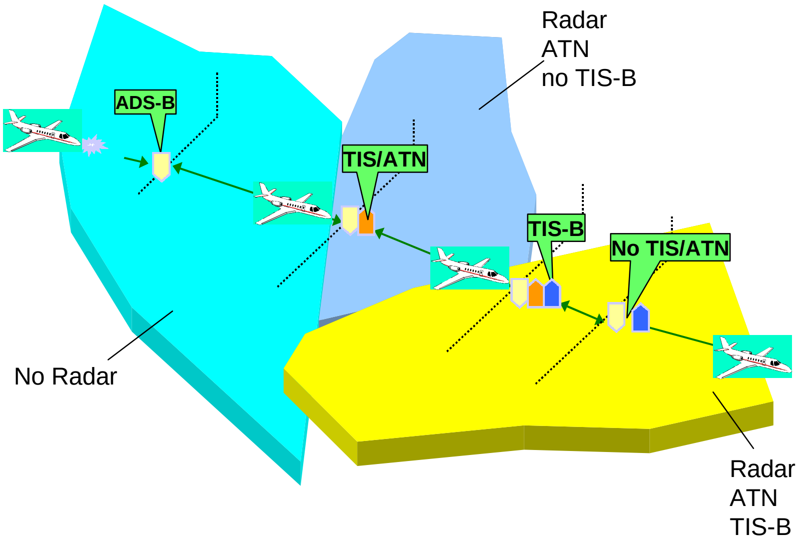


Figure 4 TALIS en-route context dependant services

5.2 Airport example services

On an airport the pilot has different information needs, depending on the flight phase. Figure 5 provides some sample services. The co-ordinated pushback service will allow the pilot to improve the reliability of on-time pushback taking information of all relevant parties into account. The pilot needs amalgamated information from fuelling services, baggage-handling services, catering services, security services, gate personnel, AOC for information on connecting passengers etc. This co-ordinated pushback service optimises usage of the taxi-way linking the various gates and prevents two aircraft from blocking each other or ending up in the wrong take-off order. Subsequently taxi-services [9] guide the aircraft to the correct runway, optimised for the other airfield traffic. Finally runway incursion services improve the safety during take-off. For arriving aircraft taxi services can guide the aircraft and the ground handling vehicles to the (re)allocated gates. These services illustrate the power of integrating navigation and communication capabilities based on updateable software.

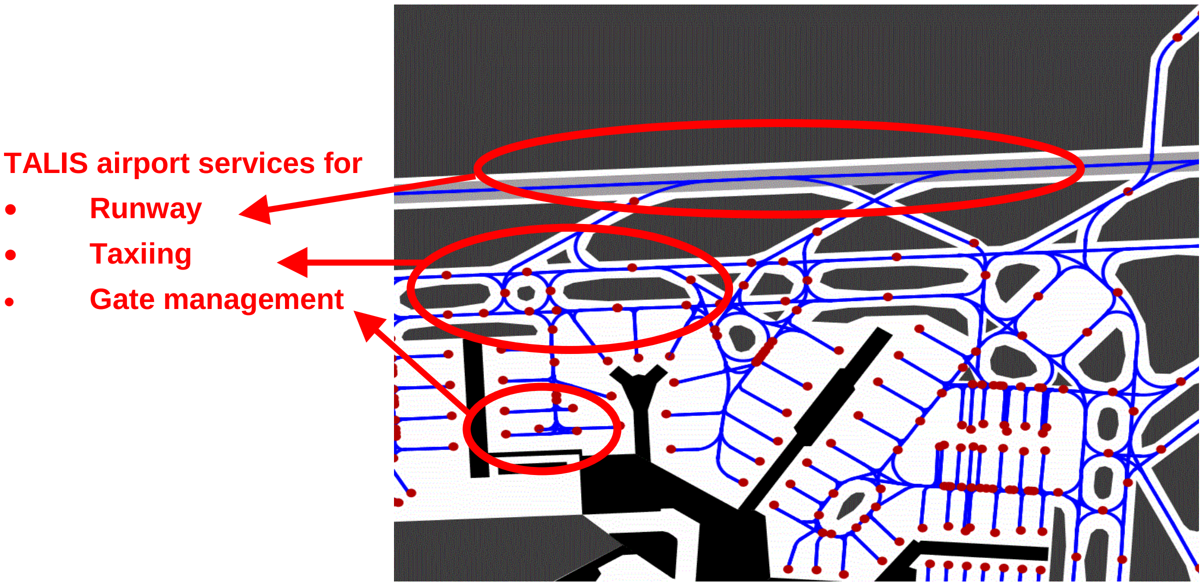


Figure 5 Example TALIS airport services

6 TALIS solution

Summarising, some important requirements for the TALIS solution will be to

- Support a variety of applications, the mix of which will evolve over time, for a diverse set of users,
- Support a mix of hardware and software platforms, both on-board the aircraft and for the various ground systems involved,
- Be responsive to evolving user requirements,
- Be able to accommodate the safety and security concerns of some of the envisaged applications.

To accomplish this, TALIS has chosen to harness the power of COTS tools by choosing Java™ technology. As Java™ is being used in a.o. many Internet applications a lot of work is being done on Java™ technology, resulting in investments which are much larger then possible for dedicated air transport solutions. The general usage of Java™ also implies that TALIS can be used for other applications then air traffic management alone, like Aeronautical Operational Control (AOC), passenger information and even for security services. This will improve the return-on-investment, or increase passenger service and hence the competitiveness of the airline. For a solution which interfaces with so many independent parties as TALIS, it is important that the solution is vendor independent i.e. open. Open solutions provide a level playing field for all competitors, prevent monopolies, foster innovation by competition and tend to generate standard solutions that are easier to integrate in a business organisation. Java™ complies with this requirement.

Note that independently of this work, in the automotive transport industry a similar approach of Internet based service provision is being aimed at [10]. Interestingly both security services and a number of charged passenger services are being envisaged, like tourist information, weather/news/stock and location based information. A car is even referred to as a Java^{TM} browser on wheels. In another independent work stream for military pilots, [11] investigates the concept of on-board intelligence combined with a network connection and supporting ground services. It seems the time is set for this type of network-centric solutions.

Figure 6, TALIS concept

Figure 6 depicts the general philosophy of the TALIS solution. A standard infrastructure will be provided, which will connect all relevant actors, or people performing functions. On top of this infrastructure applications (or services) will be provided, which support the person(s) involved. By using the TALIS infrastructure these applications will be easier to develop than in the current business practise. An advantage of the shared infrastructure is that applications can interact, allowing for more advanced services or even entirely new innovative services to be offered building upon existing services. The TALIS architecture consists of TALIS applications complemented by TALIS services. The application provides the services to the user e.g. a weather update to the pilot. The corresponding TALIS service will be a meteorological service, probably ground based, which can provide the requested weather. As is common in the Internet, many applications will also provide services to other applications. This is depicted in the TALIS application and TALIS services boxes in figure 7. The mapping of the TALIS architecture to the COTS based implementation is shown in figure 7.

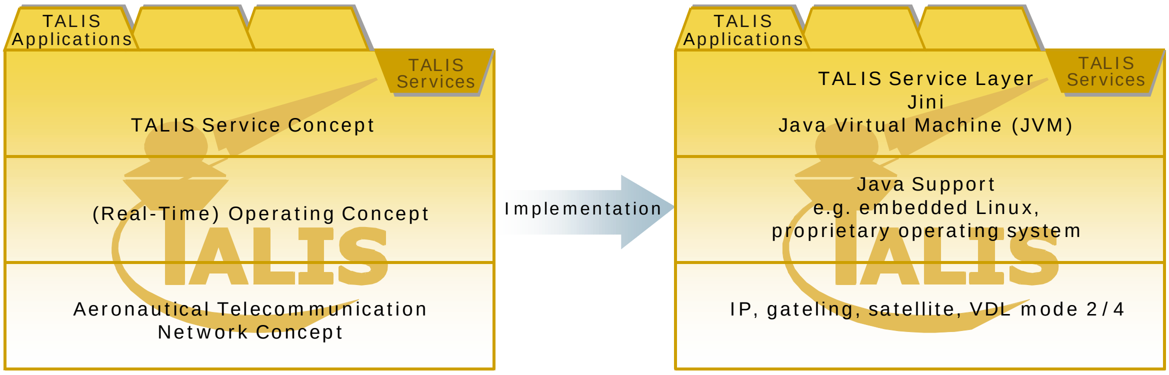


Figure 7 TALIS architecture and implementation

The TALIS service concept layer hides all network and operating system implementation specific details from the TALIS application developer. By using Java™ TALIS will be able to dynamically detect new services, and servers. Java™ has been designed to run unmodified on any computer platform where a Java™ Virtual Machine (JVM) is available. The Java™ compiler translates the TALIS application in Java™ to intermediate Java™ byte codes. The Java™ Virtual Machine then executes these Java™ byte codes. Depending on the type of application, the amount of functions required from the JVM may vary and consequently several Java™ Virtual Machines are available, from the full J2EE (Java™ 2 platform Enterprise Edition) to the smallest J2ME (Java™ 2 Platform Micro Edition). To illustrate the power of COTS, in March 2002 the standard Java™ 2 platform software was already downloaded over one million times. Also, due to the recent security concerns, work is being done to include some security features into Java™. This is possible for COTS products that are in common use. For air transport specific products the cost of such additions would be prohibitive and the realisation time, even for a limited implementation, would be far longer.

Jini network technology is an open architecture that enables developers to create network-centric services. Jini technology is designed to build adaptive networks that are scalable and can evolve. These are the characteristics needed by TALIS. As can be seen from figure7, TALIS will need to add a specific interface for communication over the Aeronautical Telecommunication Network. Due to the substantial deployment of Java, it is expected that it will be easy to add wireless, portable and wearable devices when they will become available in the future, as all of these will be COTS products. This architecture will allow the air transport actors to concentrate on providing added value by exploiting new technologies, as they become available.

The use of the chosen COTS technologies pays off for TALIS. A study of airborne certification issues and project management plus consortium management account for nearly one third of the TALIS effort. Of the remaining effort, half is spend on the two demonstration applications, a meteorological update service and Traffic Information Service. The other half is spend on technical issues related to the TALIS federated architecture, the common infrastructure.

7 Certification issues

Air transport could benefit from a number of services, which can be provided by the TALIS infrastructure. Some of these services are not critical, like passenger information services, but many of these services incur a safety concern in case the TALIS infrastructure would fail. Consequently there is a requirement to certify TALIS services and the supporting TALIS infrastructure. Due to historic reasons, for the airborne part of TALIS DO-178B [12] is available, but for the ground part no standard is mandated yet. In the US DO-278 / ED-109 [13], the ground equivalent of DO-178B, has just been completed. For the European Civil Aviation Conference (ECAC) area Eurocontrol is busy with an European standard. This European standard is based on combining elements of DO-178B, IEC 61508 [14] and addresses both safety concerns as well as quality issues. For the latter the Capability Maturity Model (CMM) [15] is used. All of these standards classify applications depending on the hazardous consequences software failure can incur for system behaviour. This information is obtained from Functional Hazard Analysis (FHA) plus (Preliminary) System Safety Assessment (P)SSA. The number of software classes, the definition of these classes and the required assurance for each class differ for each standard. DO-178B has levels A till E, IEC 61508 has Safety Integrity Levels SIL 1 to SIL 4, DO-278 has assurance levels AL1 to AL6 and European standard will probably have 6 assurance levels.

The TALIS approach will be to study the safety and certification issues starting with applications with low safety classification levels. This practical approach is chosen as no FHA or (P)SSA for any data link application is known, which has been accepted by a certifying authority. When the FHA and (P)SSA classify a new TALIS application to a higher class, the certification activities of the relevant services of the TALIS federated architecture could be extended to higher levels, if feasible. This approach is based on the experience that considerable effort can be saved by applying the costly safety critical development process only to those parts that really need them and by partitioning the application according to its safety critical functions

[16]. Like many other languages, certification concerns will lead to the definition of a safe subset of the language complemented by programming standards limiting the use of some other unavoidable constructs. In the Open Group work on Java™ and DO-178B is being discussed [17].

It is expected that some TALIS applications will require some form of real time behaviour. Those applications will need a real time operating system kernel to support those services. Again the COTS paradigm can be exploited. The Real Time Java™ (RTJ) working group recently completed the definition of a hard real-time version of Java™ [18], on which already some comment is available [19]. Due to the communication delays incurred by the ATN, it is expected that for TALIS currently soft real-time will suffice. The real time Java™ working group also addresses related DO-178B certification issues.

8 Conclusions

1. Both new ATM concepts, Eurocontrol's COOPATS and FAA's DAG-TM, are based on information sharing. They implicitly assume many applications which will evolve over time. A more responsive ATM necessitates a reduced time-to-market for new applications. The current proprietary solutions can not cope with this.
2. The TALIS approach is based on layered services. This approach is extensively used in other domains and hence validated.
3. TALIS uses proven Commercial of the Shelf (COTS) Java™ technology, thereby capitalising on a lot of effort and allowing for easier integration of future updated capabilities.
4. The layered open TALIS architecture
   - allows for easy adaptation of innovative services, innovative technologies and innovative solutions
   - reduces time-to-market in accordance with user / operational needs
   - benefits fully from COTS solution(s) which have proven itself
   - eases integration with other business applications of the actors involved
   - fosters competition
   - promotes innovation
5. TALIS will address some safety / certifiability aspects, starting with expected classification levels for the initial applications.
6. The resulting air transport system will be more responsive to user needs while maintaining its good safety record.

Acronyms and abbreviations

ACARS	Aircraft Communication Addressing and Reporting System
ACC	Area Control Centre
ACL	ATC Clearance and Information (Service)
ACM	ATC Communications Management (Service)
ADS-B	Automatic Dependant Surveillance – Broadcast
AIS	Aeronautical Information Services
AL	Assurance level
AMC	Airspace Management Cell
AOC	Aeronautical Operational Control
APP	Approach Control (Service) (Unit)
ATC	Air Traffic Control
ATSAW	Air Traffic Situation(al) Awareness
ATSP	Air Traffic Server Provider
ASAS	Airborne Separation Assurance System
ATM	Air Traffic Management
ATN	Aeronautical Telecommunication Network
ATS	Air Traffic Services
AUTOPS	Autonomous Flight Operations
CFMU	Central Flow Management Unit
CMM	Capability Maturity Model
CNS	communication, navigation and surveillance
COOPATS	Co-operative ATS (Air Traffic Services)
COSEP	Co-operative Separation Assurance
COTRAC	Common Trajectory Co-ordination (Service)
COTS	commercial off-the-shelf
CPDLC	Controller/Pilot Data Link Communications
DAG-TM	Distributed Air-Ground Traffic Management
DCL	Departure Clearance (Service)
DSC	Downstream Clearances (Service)
DFIS	Digital Flight Information (Services)
DME	Distance Measuring Equipment
DTA	Desired Time of Arrival
DYNAV	Dynamic Route Availability (Service)
ECAC	European Civil Aviation Conference
ETA	Estimated Time of Arrival
FHA	Functional Hazard Analysis
FLIPCY	Flight Plan Consistency (Service)
FMP	Flight Management Position
FMS	Flight Management System
GPS	Global Positioning System
HMI	Human Machine Interface
IFPS	Initial Flight Plan Processing System
ILS	Instrument Landing System
INS	Inertial Navigation System
IP	Internet Protocol
J2EE	Java^{tm} 2 platform Enterprise Edition
J2ME	Java^{tm} 2 Platform Micro Edition
JVM	Java^{tm} Virtual Machine

LAAS	Local Area Augmentation System
MLS	Microwave Landing System
NAS	US National Airspace System
PPD	Pilot Preferences Downlink (Service)
PSSA	Preliminary System Safety Assessment
RTJ	Real Time Java[tm]
SAP	System Access Parameters (Service)
SIL	Safety Integrity Level
SSA	System Safety Assessment
SSR	Secondary Surveillance Radar
SWIM	System-wide Information Management
TALIS	Total Information Sharing for Pilot Situational Awareness Enhanced by Intelligent Systems
TIS-B	Traffic Information Services-Broadcast
TWR	Tower Control Service (Unit)
VDL	VHF Data Link
VOR	VHF Omni-Directional Radio Range
WAAS	Wide Area Augmentation System

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