Supporting the sky
Computer mediated co-operation to fly aircraft

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Abstract. To fly aircraft many people from various organizations have to co-operate. The justifiable strict safety requirements have led to very strict allocation of responsibilities and corresponding separation of tasks. Over the years every party has developed its own proprietary system. The resulting patchwork of systems exhibits a slow response to the current market-driven changes at increasingly unaffordable costs. In the general domain service-driven network-centric solutions are used. To assess the feasibility of these solutions for air transport a prototype for air transport has been realized.
For the prototype a multi national consortium has been established. Our project experience yields some lessons learned about computer support to facilitate such co-operation.

1 Introduction

Flying commercial air transport involves the cooperation of many people from various organizations. Actors include airlines, charter operators, airports, passenger security, air traffic management, ground handling, meteorological offices, aircraft maintenance, etc. For each actor there may be a large number of organizations fulfilling this activity. To illustrate the significant number of organizations involved, IATA already represents 270 airlines and IACA another 36 with many airlines not affiliated. For airports ACI bundles 554 organizations from 169 countries operating over 1500 commercial airports. The current commercial fleet consists of 21551 jet aircraft plus 13025 turbo-prop aircraft. The 41 European Civil Aviation Conference (ECAC) member states each operate their own air traffic control organizations.

The various accidents in the early history of air transport, combined with the continued high profile of current air transport mishaps, make ensuring the current high levels of safety a prime concern for the survival of a viable air transport industry. To ensure these safety levels, the various sectors of the industry each have implemented self-improving safety systems. Due to historic reasons the systems of e.g. pilots, air traffic management, passenger security, airport operations and aircraft maintenance are independent. Most of these systems are national, based on very generic international treaties, sometimes complemented by European regulations and enforced by national legislation with their national interpretations. Each actor has a dedicated system, optimized to support its activities. The result is a patchwork of proprietary procedures and systems.

Over the decades air transport has shown significant long-term growth, despite its

Kesseler E. (2004).
Supporting the sky Computer mediated co-operation to fly aircraft.
In *Proceedings of the 1st International Workshop on Computer Supported Activity Coordination*, pages 51-60
DOI: 10.5220/0002676900510060

cyclical nature. Each party deals individually with the various bottlenecks as they manifested themselves, leading to ever more dedicated and locally optimized solutions. The current patchwork of systems already can not cope with the current levels of traffic for the high-density parts of the European airspace and major airports.

The many improvement ideas are all based on every actor being able to access and share all relevant information. This allows optimization taking the constraints of other actors into account. Table 1 lists the major integrated air traffic management concepts of the last decade. When a concept has several phases, all have been included in Table 1, separated by slashes. The time-to-market, typically around a decade, indicates the beginning of a transition period. Full deployment usually takes another decade. Even in the fiercely competitive telecom industry deployment takes four to ten years for infrastructure items, but for new services can come down to a few months [9]. With the notable exception of EUROCONTROL's short-term CDM Airports, none of these concepts have been implemented.

Table 1 Overview air traffic management concepts

Concept plus originator	**Year**	**Time-to-market (years)**	**# of services**	**# services implemented in 2004**
ATLAS-SUATMS EU	1993	12-17	5	None
Gate-to-gate EUROCONTROL	1997	8/13/18	8/6/4	None
Free flight US	1998	4/7	5/3	None
DAG-TM FAA	1999	6	15	None
COOPATS EUROCONTROL	2001	9/14	11/3	None
CDM Airports EUROCONTROL	2002	3	13	12

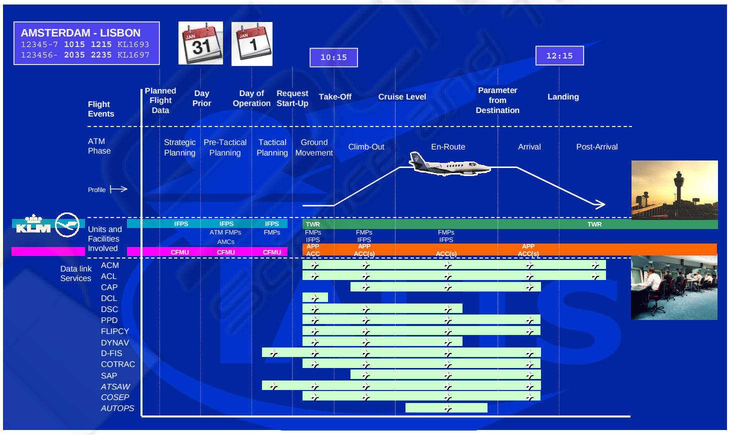

Fig. 1. Air transport services concept

Fig. 1 depicts the kind of concepts being considered, using EUROCONTROL's Co-operative Air Transport Services (COOPATS) [4] as an example. Some services related to flight planning by the airline start well before the preparation of the actual flight. The required services change during the execution of the flight.

General domain information technology can integrate the systems of the various stakeholders involved into a network-centric system-of-systems, a virtual enterprise. Such co-operation improves the combined performance of all stakeholders involved. In various other domains, which lack air transport's safety concerns, such improvements have already been achieved. The Total Information Sharing for Pilot Situational Awareness Enhanced by Intelligent Systems (TALIS) project [1], realizes a prototype of such a network-centric architecture.

Fig. 2. Conceptual overview of the TALIS network-centric architecture

. The completed prototype, consisting of the middleware and two sample applications, demonstrates the technical feasibility of this network-centric approach. Fig. 2 provides a conceptual overview of the prototype.

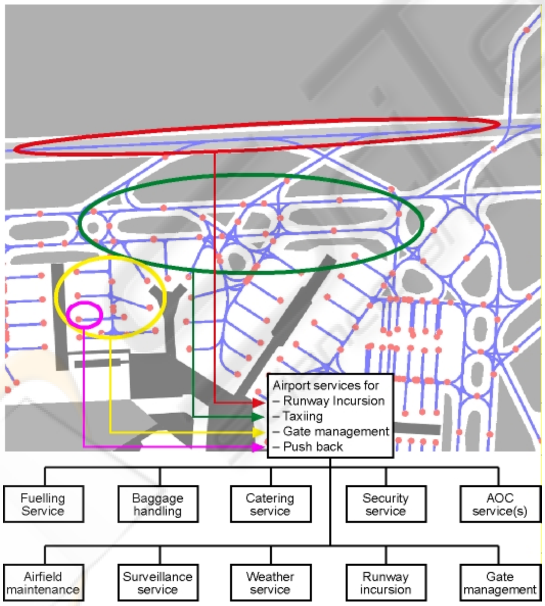

Fig. 3. Pilot-oriented sample service

The network-centric architecture supports services for all flight phases. Fig. 3 demonstrates the integration of various actors at the airport. The pilot-oriented sample service illustrates the kind of optimisation that the prototype aims to support.

Also at an airport the pilot information-needs are flight-phase dependent. A coordinated pushback service will allow the pilot to improve the reliability of on-time pushback. For this the pilot needs amalgamated information from, e.g., fuelling services, baggage-handling services, catering services, security services and Airline Operations Center (AOC) about transfer passengers. This pushback service optimizes utilization of the taxiway linking the various gates and prevents aircraft from blocking each other or ending up in the wrong take-off order. Subsequently taxiing-services guide the aircraft to the correct runway, optimized for the other airfield traffic, its departure timeslot and taking possibly adverse weather or airfield maintenance restrictions into account. Finally, runway incursion services, using surveillance services, improve the safety during take-off.

Fig. 4 shows how the prototyped network-centric architecture builds upon various Commercial off-the-Shelf (COTS) components, which in turn support various hardware platforms, from small mobile wireless equipment (Java Micro Edition, J2ME) to standard PC-based hardware with standard communication (Java Enterprise Edition, J2EE). The TALIS services, which enable the actual co-operation between the users, will run on top of the prototyped architecture. Once a service is connected to the network-centric architecture, all other services in the network can connect to it, either to provide input or use the result.

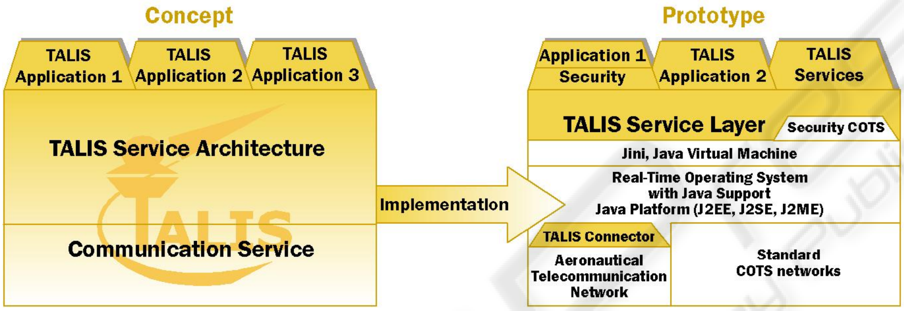

Fig. 4. TALIS architecture overview

The TALIS prototype consists of four parts:

- The federated architecture (FAR) to implement the network-centric idea. The FAR is denoted as TALIS service architecture in Fig. 2;
- Two application services to demonstrate the capabilities of the prototype infrastructure. The first service (MET) provides pilots with in-flight weather updates. Current weather information allows pilots to optimize their flight, demonstrating tangible benefits, like shorter flights and fuel reduction to pilots and airlines;
- Traffic Information Services (TIS), to provide the pilot with in-flight airport information like runway-in-use, visibility etc. This service reduces voice congestion on scarce frequencies and reduces pilot workload during a busy flight phase.

During realization of the prototype, the activities to provide a portable demonstration platform for dissemination purposes were formalized into the fourth part called the Verification Platform (VPR).

Fig. 5 shows the realization of the airborne part of the MET application. To improve pilot acceptability, the display layout closely resembles other cockpit displays. The left column of buttons lists available airports based on current aircraft position. The text box at the bottom provides meteorological information for the selected airport in the compact format pilots are familiar with. To illustrate the independence of the actors and their systems, the airport is referred to as EHAM by pilots, Amsterdam by passengers, AMS on luggage labels, Schiphol for local passengers and the meteorological office and AAS for the gate handler.

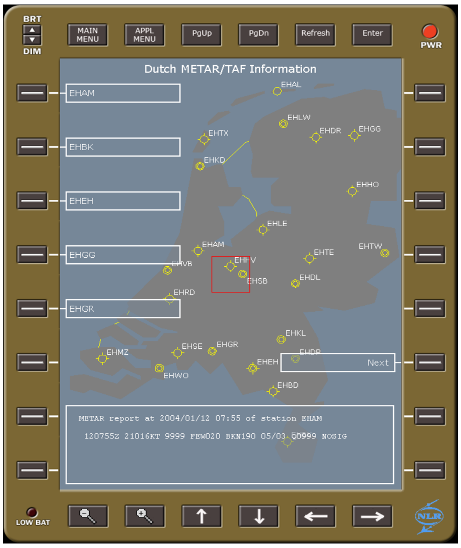

Fig. 5 TALIS workbench MET application, airborne side

The next section provides the users' response from every type of actor. The subsequent section analyses the computer-supported process of the multi-national consortium that realized the prototype.

2 User response

To assess whether the air transport community is open to network-driven services, for at least two organizations of each type of actor presentations/demonstrations were given, followed by interviews. To prevent a national bias, a total of 13 actors from six European countries have been consulted. All recognize the problem and acknowledge the need to optimize their co-operation using computer based information exchange.

As a monopolistic service by nature, air traffic management service providers have no problem with providing their information. They express a reactive attitude: their customers, i.e. the airlines, have to ask for it first. As a new system for an air traffic management center typically takes at least a decade to realize, their time-to-market is in multiple years.

The current challenge for airports is to keep the data obtained from the various actors consistent and base them on uniformly defined moments in the aircraft turn around processes. Services based on these data are not yet within their time horizon. Being closer to the customer their time-to-market is several months to year(s).

The regulator's role is to approve those operational applications that could infringe the safety. They express interest in the new technology but will only take actions once a product is being submitted for certification. In the European Union the regulatory scene is changing due to evolution from National regulators and Joint Aviation Authorities to the European Aviation Safety agency (EASA) at European Union level, temporarily reducing their available effort for new technologies. Unfortunately the various proposed services need different types of certification [6].

Conventional airlines, due to the harsh economic realities after September 11, 2001 need a business case per application. Their time-to-market is years, except when a competitor gets there first. Competition derived concerns limits their willingness to share information considered sensitive.

Following their US examples, low cost carriers are becoming very successful in Europe as well. Using the Internet to sell the majority of their tickets, they are used to network-driven services. They want to restrict the required capabilities to data exchange to ease certification. Their time-to-market is a few months at most with a similar short return-on-investment. Potential next steps are flexible depending on continuously monitored consumer changes and experience gained.

To conclude the advantages of a service-driven network centric concept are recognized by all actors. Facing the harsh economic realties, and not used to innovation beyond a single user community, no one is willing to take the first step. Consequently for the first service the time-to-market should be a couple of months, with a very affordable investment. This implies that it can not be a certifiable service. Fortunately many ideas for such non-certifiable services are available. An impeccable user interface will be key for user acceptance.

3 Process experience

This section assesses the co-operation between the consortium members realizing the prototype. The conclusions will be based on metrics, which are derived using the goal-question-metric paradigm of [2] that served us well in some previous analysis.

3.1 Project organization

The consortium comprises five carefully selected partners from four different European countries, supplemented by a European institute, which formed the project-specific consortium. Each partner effectively has a veto right. The main disciplines and corresponding contributions of each partner are:

- Deployment of one application of which it provided the detailed specification;
- The airborne part, which it provided, and certification issues, which were studied;
- The infrastructure, which it specified and verified, and certification issues, which were studied;
- Deployment of the other application, which it realized, and the infrastructure. This activity is combined with consortium management;
- Deployment of both applications, which it realized.

At project start the objectives and the network-centric concept were sufficiently mature. The details of the two pilot applications were to be determined. In the air transport industry the waterfall model is the standard for safety-critical software development and compatible with the mandatory airborne DO-178B [8] certification. To accommodate the requirement for a drastically reduced time-to-market, the USDP paradigm was chosen, even though none of the partners had experience with it.

The change request administration depicted in Fig. 6 shows some remarkable facts:

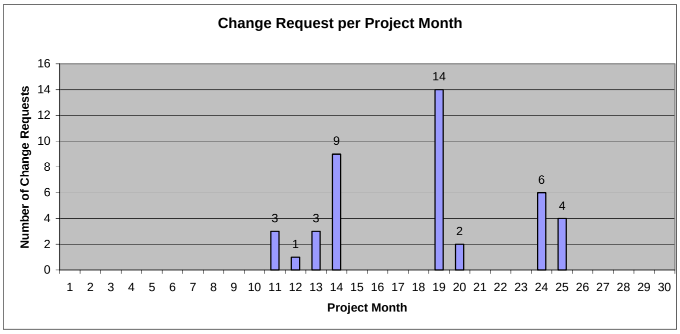

Fig. 6. Change request during project

- All changes relate to the specifications of the four components, none were submitted to other process artifacts, including software. As the completion of build 1 kept shifting, most code was only submitted to the project repository shortly before project completion. The change administration before that date was the responsibility of the developing partner and hence is invisible in the Fig. 6;
- One team member submitted 30 changes to downscale his TIS component. These changes explain the peaks at month 19 and month 25 and part of the peak at month 11-13. This preceded the client reviews in month 15 and 26;
- Another member submitted 10 changes to clarify and downscale his application, which explains the remaining part of the month 11-14 peak;
- The remaining four changes clarified some requirements. The additional change with respect to Table 2 relates to a withdrawn and resubmitted change.

The USDP process assumes a spiral model with several deliveries and subsequent adaptations of the requirements based on user feedback on the partial delivery. The change administration reflects that the project maintained the single iteration waterfall process familiar to all partners. The time-to-market and adaptability advantages of the spiral model were not realized. Breaking down the requirements into smaller ones could have helped.

3.2 Requirements and design phase

Table 2 provides some data about the realization of the prototype.

Table 2 Overview TALIS prototype realization

	FAR	**MET**	**TIS**	**VPR**
# requirements build 1/2/3	22/7/7	54/14/-	10/13/8	15/2/3
# identified requirements	66	118	108	26
# requirements test/inspect	2/34	68/-	31/-	20/-
# rejected requirements	3	34	3	1
# pages	90	85	97	80
# review comments (high/medium/low)	23/29/1	12/-/-	20/-/-	36/8/-
# approved/rejected changes	4/5	2/-	27/3	-/-
Analysis (man month)	22	9	18	5
Implementation (man month)	100	41	39	1
K Lines of Code	32.2	17.6	18.9	COTS
# of classes	106	65	75	COTS

From Table 2 and some project information the following can be derived:

- Up to now, 1.5 month prior to the project end, build 1 has not been completed. Many hard requirements have been postponed to future builds;
- The first row provides the numbered requirements. The second row lists the amount of identifiable requirements based on current wording. The requirements could have been phrased in smaller, separately identifiable units to ease incremental implementation and testing;
- FAR uses inspection as verification method where test could have been used more often;
- The many rejected MET requirements reflect the user belonging to one organization and the analyst and the designer belonging to another. Communication and elucidation was done by discussing the detailed requirements;
- The document volume combines the requirements and the UML use cases;
- The number of review comments per page of specification is low, indicating friendly reviewing, as e.g. [5] found 1.1 comment per requirements page of which they rated 45% as critical;
- The many approved TIS changes reflect severe downscaling of this application;
- The VPR consists only of COTS, which requires a limited installation effort;
- Project management including quality assurance accounted to an additional 15% of the total project budget. However this figure reflects the reality of the maximum acceptable to the customer (the European Union). The remaining management is included in each partners' budget, in our case an approximate 10%. Such figures are in line with our other international projects.

3.3 Project communication

Traditionally in multi-national projects face-to-face meetings are held regularly to align the views, the partner's ambitions and to guide the project. For this purpose 46 meetings were planned, evenly split between the sites of the partners. In order for one partner to save costs, frequent formal teleconferences and even more frequent e-mail (averaging 230 per month between the 10 technical team members) replaced meetings. Fig. 7 depicts the actual communication pattern to date, mid month 29. The analysis of Fig. 7 combined with some project process information yields:

- The teleconferences tended to focus on project management issues in stead of on technical issues;
- Maybe a technology to simultaneously share graphical information, used a/o to express the requirements and the design, could improve this. Five levels of co-operation from communicative to concerted are recognized in [3]. The project needs the latter to achieve the required flexibility in service definition and time-to-market. For concerted cooperation group support technologies are needed [3]. These could have been used at affordable costs;
- For one sticky management issue a videoconference has been held between two partners in month 23. Due to the additional face-to-face contact this proved to be efficient and cost-effective. Still this facility has not been used since;

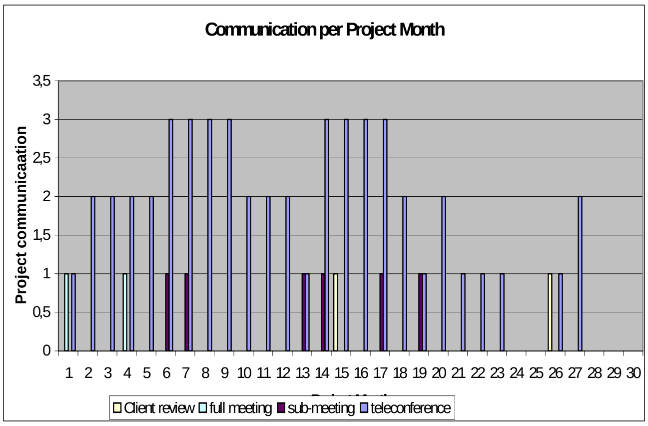

Fig. 7. Project communication means used

- The first build kept shifting, depriving the project team from feedback to shape the next build. Limiting the first build would support the USDP micro deliveries and comply with a short time-to-market;

As an aside in month 26 a much smaller application mimicking an electronic flight bag taxiing application was realized using 1.5 man month. In the last few days, many small upgrades were implemented, including user comments from actors like pilots. This application was realized within one partner, with people literally walking into each other's office. This prototype generated ideas for a second prototype that was realized from scratch. It contains more additional electronic flight bag capabilities and network-centric capabilities. It took a mere additional 2.5 man month. These two activities demonstrate the feasibility of the USDP approach for air transport and its value in obtaining user feedback. This success supports the view of [7] that a virtual team requires information rich media like face-to-face meetings to achieve its goals.

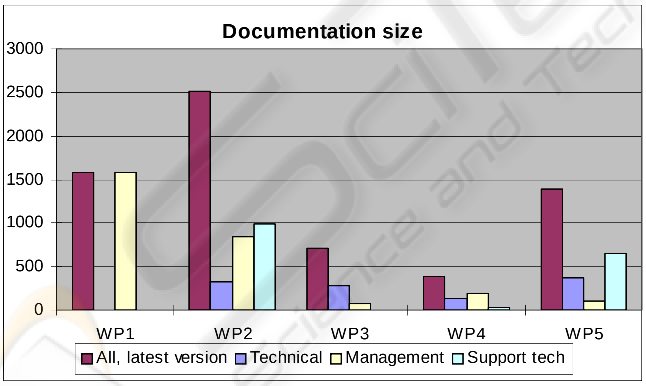

Fig. 8. Most recent document version size per work package

The size of the most recent version of the documentation is depicted in Fig. 8. The most recent version comprised 57% of all documentation in the configuration-controlled archive. Previous versions of the same documents make up for the other 43%. Fig. 8 combined with the previous information leads to the following observations:

- Only 17% of all documentation is a technical deliverable. Note that as testing is not completed yet, the usually sizable test report documentation is excluded;
- Consortium level management documentation (WP1) amounts to 24% of the total using 15% of the effort;
- The certification study (WP5) produced 21% of the documentation using 11% of the effort;

- WP2, WP3 and WP4 work package management and quality assurance of contributed 27 % to the documentation using 10% of the effort;
- The remaining 11% are primarily white papers. The electronic management style and the resulting lack of face-to-face discussions lead to most technical exchange being performed by exchanging white papers. Only the final result becomes a technical deliverable.

4 Conclusions

The various air transport actors have confirmed the need for computer assisted cooperation. Our COTS based prototype is acknowledged as a feasible solution. A final validation needs actual deployment, for which the first service needs careful selection and an impeccable user interface.

The distributed consortium achieved its goal. Our cooperation shows that for a traditional waterfall implementation model electronic communication can replace nearly all meetings, even for a newly formed, dedicated consortium. To achieve the intended fast response to market driven changes a spiral model is required which assumes a closer co-operation. Affordable computer-support like group support facilities might facilitate the required co-operation in stead of the proven method of a multitude of face-to-face meetings. The one case of video conferencing achieved its objectives as effectively as a traditional meeting.

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