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Validation Comparative Analysis Report

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NLR

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Executive Summary

In EMMA2, it was shown again that the quality of the discussed services, especially the higher services, which include several planning, guidance and alerting tools, depends on the quality of the available surveillance information. Some issues with ADS-B Out led to the conclusion that it is not yet suitable for A-SMGCS purposes.

Furthermore, it could be shown that it is difficult to look at the benefits of different A-SMGCS components in isolation, in particular on the ground side. The planning, monitoring and control chain from gate to runway and vice versa should be seen as a coherent series of tasks that need to be supported by a coherent set of A-SMGCS components.

In EMMA2, different test sites with different system implementations looked at that series of tasks which led to results that are either very much dependent on a certain implementation of a tool, integration issues between different A-SMGCS components, or fine tuning activities for airport peculiarities. In the beginning, some of the trials showed that the systems tested did not reach the required maturity for the environment in which they were used, which led to very detailed comments by controllers. While these comments led to improvements of the specific tool in question and operational feasibility could be shown in another validation cycle, the results could not indicate whether expected performance targets for the overall concept could be reached. The system components would need to be validated again regarding their performance after each new development cycle in order to get to more conclusive results on an overall concept level. Iterative processes like this are rather complex and need to be investigated in the future.

Still, controller and pilot comments made it possible to come to subjective results so that most validation exercises could at least show feasibility of concept and systems even if performance gains could not always be expressed in absolute terms. In order to bring the services further and obtain more objective results, future projects should build on these results and further validate the operational concept focusing on the role of air traffic controllers and their working environment and further elaborating task distribution between pilots and controllers. Innovative approaches to these topics are suggested to become part of SESAR activities, as SESAR will lead the development approaches in Europe in coming years.

Looking at the airborne side, the situation regarding tools and interoperability heavily depends on the capabilities of the ground systems. The IMM, which integrates different functionalities in a single interface, seems to be rather advanced in development. Tools for guidance and control are integrated to such an extent that delegation of certain tasks from the controller to the cockpit might be considered a possible topic for further research.

The TAXI-CPDLC service, which must be an integral part of both ground and airborne working environments, was tested in EMMA2 with promising results. While refinements are still necessary in the proposed solutions for data input on both the controller and pilot positions, the result regarding workload and situational awareness on both the airborne and the ground side were encouraging, at least for start-up, push-back, taxi clearances and handover procedures.

As an important part of its safety assessment, EMMA2 showed that human factors and safety studies can be performed in combination with real-time simulations. Results will help to assess critical operational situations. In order to get the complete picture, full-scale human and hardware-in the-loop real-time simulations will need to be performed on flexible simulation platforms that allow assessing the complete hardware solution for the chosen A-SMGCS set. Eventually, on-site shadow-mode trials must prepare implementation of the complete solution of high-level A-SMGCS components.

In the future, EMMA2 results should drive further standardisation activities in ICAO and EUROCAE working groups and should be considered in related EUROCONTROL and SESAR activities. Relevant recommendations, also regarding the process of validating A-SMGCS, are part of the EMMA2 Recommendations Report (Ref. [22]).

More details on the specific results and conclusions are provided in Chapter 6 of this document.

Table of Contents

1 Introduction

This document is deliverable 2-D6.7.1 of the EMMA Part 2 (EMMA2) Project (Ref. [8]) and is entitled ‘Validation Comparative Analysis Report’. The introduction describes the context of this document within the EMMA2 Project and within Work Package 7 (Validation Analysis and Recommendations) of Sub-Project 6 (Validation). Furthermore, the document purpose and scope are presented.

1.1 Document Context

This document represents the output of Work Package 6.7.1 (Analysis) of the EMMA2 project and gives a compilation and an analysis of the validation results.

1.1.1 EMMA2 Project Background

Air transport demand in Europe, despite world-economic upheaval and related negative air traffic growth rates in 2009, is expected to continue to grow from 2010 onwards, albeit with a more moderate pace (cf. Ref. [1] and Ref. [2]). Today there still is a need to respond to these public demands, especially when looking at the long-term expectancy, while maintaining a high level of safety in air traffic operations.

In order to answer to the demands and cope with the consequences of growing air traffic in the future, the ATM 2000+ Strategy (Ref. [4]), defined a number of major strategic objectives and named directions for change. Among the new concepts for a structural revision of the ATM processes are ‘Advanced Surface Movement Guidance and Control Systems’ (A-SMGCS). A-SMGCS is described as one of the most promising elements for achieving the necessary paradigm shift towards the year 2012 and beyond as airports are seen as the future bottlenecks of air transport.

The ‘European Airport Movement Management by A-SMGCS’ (EMMA) integrated project is set within the Sixth Framework Program of the European Commission (Directorate General for Energy and Transport) and looks at A-SMGCS as a holistic approach for changes in airport operations. It builds on the experiences of earlier projects such as ‘Operational Benefit Evaluation by Testing A-SMGCS’ (BETA). With BETA (Ref. [25]) new technologies for data extraction, digitising, data fusion, data link and multilateration became available. Although A-SMGCS progressed from a demonstration status to a full operational system, the complete proof of benefit of A-SMGCS was missing. Therefore, EMMA is supposed to set the standards for A-SMGCS systems and their operational usage, safety and interoperability while also focussing at the benefit expectation in Europe.

In order to achieve this ambitious goal, EMMA was subdivided into two project phases. The first phase of EMMA, which ran from 2003 until 2006, mainly looked at different implementations of lower level A-SMGCS at a number of European airports as an initial step for enhancing safety and efficiency on the ground. In particular, additional surveillance services (Level I) and an automated control service for detecting potentially dangerous conflicts on runways and in restricted areas (Level II) were investigated.

The second phase of the EMMA project, running from 2006 to 2009, focuses on the development and validation of a higher-level A-SMGCS operational concept. This means that in addition to the services investigated in the first phase of EMMA, higher-level functions and services, as described in Ref. [5], are developed and validated. The higher-level services allow for the sharing of traffic situation awareness among pilots and drivers on the airport, the introduction of an automated routing function and the up-link of a validated route planning to pilots and drivers.

1.1.2 EMMA2 and SESAR

The Single European Sky (SES) initiative was launched by the European Commission in 2004. It established a political framework for actions in Europe to unlock sustainable and viable growth in air transport. In order to support the SES legislation and for modernisation of the European air traffic control infrastructure, the Single European Sky ATM Research Programme (SESAR) was launched. SESAR aims at developing the new generation air traffic management system capable of ensuring the safety and fluidity of air transport worldwide over the next 30 years. It involves all actors in European aviation in defining, committing to and implementing a pan-European ATM system.

A-SMGCS is a major cornerstone of investigations on future airport operations and as such the topic also found its way into the SESAR ATM Target Concept and Master Plan (Ref. [26] and Ref. [27]). The results and recommendations of the EMMA project, and in particular EMMA2, therefore represent an important contribution to SESAR and should indicate what research efforts are needed in the future to bring A-SMGCS closer to deployment.

1.1.3 Sub-Project 6 Background

Validation of different A-SMGCS implementations and experimental systems is carried out in Sub-Project 6 of the EMMA2 Project. EMMA2 aims at conducting an overall validation of A-SMGCS in accordance with the European Operational Concept Validation Methodology (E-OCVM). This methodology (Ref. [3]) has been developed by EUROCONTROL together with the European Commission and several European ATM research institutes in recent years and currently is the only broadly accepted framework for ATM concept validation.

Validation exercises of the EMMA2 functionality identified in the A-SMGCS Services, Procedures, and Operational Requirements (SPOR) document (see Ref. [9]) are performed on three ground sites (Prague-Ruzyně, Toulouse-Blagnac and Milan Malpensa airports) and different airborne platforms which are collectively referred to as the airborne site. Additional validation exercises are carried out in research simulators. The validation process at each site is based on a corresponding site test plan. In order to assure maximum compliance with the E-OCVM and consistency of the site test plans a validation strategy has been developed in WP6.1 consisting of a Validation Plan and a Generic Experimental and Test Plan (cf. Ref. [14] and [15]). The major objective of both documents is to provide the sites with a framework and guidelines for developing the different site Validation Test Plans.

The results of this validation phase will also provide inputs to future A-SMCGS concepts, architectures and designs that result from other projects. It should confront all stakeholders in A-SMCGS with the question whether they are going to implement the right A-SMGCS system, procedure or concept. Moreover, SP6 investigates whether the chosen A-SMCGS systems, procedures and concepts fulfil the demands (for example, in terms of acceptability, workload, feasibility, and safety of operations) of the different operator roles involved in A-SMGCS. The combination of these characteristics is expected to permit A-SMCGS overall validation to cope with any constructive evolution in ATM.

It should be noted that EMMA and EMMA2 were based on assumptions and requirements described in the ICAO A-SMGCS Manual (Ref. [24]). The assumptions and requirements in the manual were seen as a proposal or a starting point. Still many of the guidelines will have to be validated.

1.1.4 Work Package 6.7 Context

The objective of WP6.7 is to conclude the work carried out in EMMA2. This is achieved by making a compilation of all validation results, analysing the measurements and data, summarising overall results and lessons learnt, and presenting recommendations on the basis of the analysed results. The work is split into three sub work packages, called WP6.7.1 Analysis, WP6.7.2 Recommendations, and WP6.7.3 Review.

In a first step, a compilation of all validation results generated at the test sites and in the simulators will be produced, and the measurements and other data will be analysed with respect to the described concepts (Ref. [9]) and the operational and technical requirements (Ref. [9], [10] and [11]). The analysis work is concluded with writing a report of the mentioned activities including an overall summary and a description of lessons learnt.

The second step revisits the validation results, the comparative analyses, and the lessons learnt during the integrated project. It derives recommendations from this information, which are laid down in a public report. Recommendations are outlined considering at least the following aspects:

- Standardisation, general rules, certification,
- Implementation,
- User benefits,
- Industry, and
- European policy on A-SMGCS

Finally, both analysis and recommendation reports are reviewed by industry partners and by EUROCONTROL.

1.2 Document Purpose

The purpose of this document is to present a compilation of the results of the validation activities carried out within the EMMA2 integrated project and perform an analysis with respect to the concepts and operational requirements described in the EMMA2 SPOR (Ref. [9]) and the technical requirements for both ground and air (Ref. [10] and [11]). The document is concluded with a summary section to give an overview of the results and compare them whenever possible. Lessons learnt are included in the document.

The analysis document will serve as input to WP6.7.2, in which recommendations for standardisation, certification, implementation, user benefits, industry, and European policy are derived from the consolidated EMMA2 results.

The analysis document will represent the executive summary of all validation activities carried out in the EMMA2 integrated project.

1.3 Document Scope

The document starts with a table for quick and easy reference, so that there is a clear link between a certain test site, the validated services, the validation platform and technique used, and the respective chapter in this document (Chapter 2).

In general, this document has been structured in accordance with the EMMA2 SPOR document (Ref. [9]) and it separates the validated A-SMGCS services into air traffic controller (Chapter 3), flight crew (Chapter 4), and vehicle driver services (Chapter 5). Within each of these service categories A-SMGCS is divided into surveillance, control, routing and planning, and guidance services.

Results are then presented for each of the test sites that validated the service under consideration, which allows for comparing the results and analysing them in a more coherent way.

In order to give a better overview of the manifold results, Chapter 6 will summarise them, highlight the most outstanding issues in comparing and analysing them and present the lessons learnt in conclusion. Thus, the document serves as input for the EMMA2 recommendations (Ref. [22]).

2 Concise Overview of EMMA2 Validation Activities

In order to facilitate reading and for quick an easy reference, the table below lists all EMMA2 validation activities per site, including the A-SMGCS components tested, the validation platform and technique used, and the appropriate reference to sections in this document where results can be found.

Validation Site	Validation Platform	Validation Technique	A-SMGCS Component	Relevant Chapter
Paris CDG	DSNA Athis Mons Tower Simulator	Human-in-the-loop Real-time Simulations (RTS1)	SCA (A-RSN)	3.2.2.2
	DSNA Athis Mons Tower Simulator	Human-in-the-loop Real-time Simulations (RTS2)	DMAN (Interoperability)	3.3.2
			EFS	3.2.1
Prague Ruzyně	DLR Tower Simulator	Tool refinement and early feedback (RTS1)	Departure Management	3.3.2
			EFS	3.2.1
	DLR Tower Simulator	Full-scale Human-in-the-loop Real-time Simulations (RTS2)	Departure Management	3.3.2
			EFS	3.2.1
			Route Planning	3.3.1
			TAXI-CPDLC	3.2.3
			Taxi Route Conformance Monitoring	3.2.2.1
	Prague On-site Platform	Shadow-mode Trials (OST)	Departure Management	3.3.2
			EFS	3.2.1
			Route Planning	3.3.1
			TAXI-CPDLC	3.2.3
			TIS-B	3.1.1
Toulouse Blagnac	Toulouse On-site Platform	Shadow-mode Trials (OST)	Taxi Route Conformance Monitoring	3.2.2.1
			TAXI-CPDLC[1]	3.2.3
			DMAN Interoperability	3.3.2

[1] Ground CPDLC Clearances

Validation Site	Validation Platform	Validation Technique	A-SMGCS Component	Relevant Chapter
		Field Trials	Vehicle Moving Map	5.1
			Delegation using TIS-B	3.1.1
Milan Malpensa	SICTA/SELEX Tower Simulator at ENAV Experimental Centre, Rome	Small-scale Human-in-the-loop Real-time Simulations (RTS1a)	EFS	3.2.1
	SICTA/SELEX Tower Simulator at SICTA facility, Naples	Small-scale Human-in-the-loop Real-time Simulations (RTS1b)	EFS	3.2.1
			Route Planning	3.3.1
			SCA	3.2.2.2
	NARSIM-Tower at NLR, Amsterdam	Full-scale Human-in-the-loop Real-time Simulations for Safety Assessment (RTS2)	EFS	3.2.1
			SCA	3.2.2.2
	Malpensa On-site Platform	Shadow-mode Trials (OST)	EFS	3.2.1
			Route Planning	3.3.1
			1090 ES ADS-B out	3.1.1
			TAXI-CPDLC[2]	3.2.3
			TIS-B	3.1.1
Airborne	DLR Flight Simulator	Full-scale Human-in-the-loop Real-time Simulations	Ground Traffic Display	4.3
			TAXI-CPDLC	4.5
	TUD Flight Simulator	Human-in-the-loop Real-time Simulations	Ground-Air Database Upload	4.7
			Surface Movement Alerting	1.1
			Traffic Conflict Detection	4.4
	Prague Field Trial	Field Trials	TAXI-CPDLC	4.5

[2] Mainly technical tests

Validation Site	Validation Platform	Validation Technique	A-SMGCS Component	Relevant Chapter
	Platforms (ATTAS Test Aircraft, TUD Van and FAV Piper Archer Test Aircraft)		Ground Traffic Display	4.3
			Surface Movement Alerting	1.1
			Traffic Conflict Detection	4.4
	Airbus A320 Cockpit Integration Simulator	Tool refinement and early feedback	TAXI-CPDLC[1]	4.5
	Airbus A320 Cockpit Integration Simulator and TATM Ground Station linked via real ATN	Human-in-the-loop Real-time Simulations	TAXI-CPDLC[1]	4.5
	THALES Avionics Flight Simulator	Tool refinement and early feedback	Moving Map and Ground Traffic Display[3]	4.1, 4.3
			Head-up Display	4.6

Table 2-1: Overview of EMMA2 Validation Activities

[3] Integrated Moving Map with display of ground traffic

3 Results and Analysis for Services to ATC Controllers

3.1 Surveillance

The A-SMGCS surveillance service is expected to gather and merge all relevant information automatically, discard any discrepancies between information from various sources and generate a complete and consistent image of the traffic situation.

The EMMA project looked mainly at the combination of SMR and MLAT and the display of radar and associated label information on a Traffic Situation Display (TSD). This was part of the assessment of lower-level A-SMGCS. In EMMA2, ADS-B and TIS-B trials were performed.

3.1.1 Testing of Technical Enablers (ADS-B and TIS-B)

Prague On-site Platform Results

ADS-B Out receiving equipment and TIS-B transmission equipment were integrated into the EMMA2 test-bed and tested at Prague Ruzyně airport between August and November 2008. The implementation of both services was based on Mode S 1090 MHz Extended Squitter (ES) technology.

ADS-B

1090 MHz ADS-B Out transmissions from aircraft and vehicles were successfully received and decoded by the MLAT/ADS-B ground system.

The general requirements for aircraft ADS-B Out interoperability with the A-SMGCS ground system were met and it was possible to correctly and unambiguously identify the sources of the transmissions. The "accuracy" and "timeliness" performance requirements of A-SMGCS were not fully met by ADS-B.

The latest Mode S transponders on aircraft meet the requirements of RTCA document DO-260A Minimum Operational Performance Standards (MOPS) for 1090 MHz ADS-B. However, these standards do not specifically address A-SMGCS requirements.
A transponder that meets DO-260A requirements is able to transmit a parameter called the Navigation Accuracy Category of position (NACp), which provides the receiving system with an indication of the accuracy of the on-board measurement (as a number from 1 to 10). To meet A-SMGCS accuracy requirements the NACp must always have the value 10 (Re < 8 m). This normally means that the measurement has been made using differentially corrected satellite navigation means. Currently, only a few aircraft are continuously sending reliable position data with NACp = 10.
Many aircraft are equipped with older Mode S transponder equipment that does not transmit the NACp parameter, and they carry navigation equipment which does not comply with the A-SMGCS position accuracy requirements.

Another, more serious, drawback with current transponder technology on aircraft is the latency of the information. The on-board "time of position measurement" is not transmitted using the 1090 MHz ES technology, as this message format does not comprise the respective data item. Usually, the 1090ES ADS-B ground (receiving) station provides a time stamp that indicates the reception time of the ES ADS-B message by the ground station. This time stamp is included in the ASTERIX messages sent from the ADS-B ground station to the Sensor Data Fusion (SDF) unit of the A-SMGCS, but due to transmission and processing times it may be up to two seconds later than the time of measurement on-board the aircraft. This latency is also not constant, but varies continuously and unpredictably. For stationary or slow-moving traffic, this latency is not significant, but for fast-moving or rapidly turning mobiles large position and/or direction errors will be apparent to the end-user. For example, with 3

seconds end-to-end latency, an aircraft moving at 50 kts (25 m/s) may have an along-track position error of 75 m when presented on the ATCO's (radar) traffic situation display.
It should also be obvious that ADS-B technology will always have higher latency than MLAT, SMR and other ground-based (non-dependent) technologies because the ADS-B data link chain has several extra processing steps.

It can be concluded that aircraft ADS-B can only be used for A-SMGCS when the respective standards and requirements exist, and all ADS-B equipment and the integration strictly follow the standards and requirements, and when the data quality is according to the A-SMGCS requirements. Currently, this is not achievable, not only because ADS-B is in a relatively early state of implementation, but also because avionic equipment providers and airlines are as yet mostly unaware of the A-SMGCS requirements.
For these reasons, ADS-B Out transmissions received from aircraft were suppressed for the operational on-site tests at Prague airport.

For vehicles, the situation was somewhat better. Vehicles using the movement area at Prague airport are fitted with portable Mode S Squitter Beacons that transmit each vehicle's position and identity using low-latency 1090ES ADS-B technology. The Squitter Beacon transmits standard 1090 MHz extended squitters with downlink format DF18. Two types of messages are used: the "Surface Position" message and the "Aircraft Identification and Type" message. The "Surface Position" message conveys information about the position of a vehicle, i.e. latitude and longitude, movement and direction. The "Aircraft Identification and Type Message" contains information about the ADS-B Emitter Category and identification, which encodes the callsign of the vehicle.

Tests were carried out in the Czech Republic to determine the most suitable antenna type, its mounting on the vehicle, and the optimum transmitter power. Based on this testing, the following recommendations are made for the use of portable squitter beacons:

- The Mode S 1090 MHz ES technology is recommended because it is globally used for the transmission of ADS-B information and it is therefore compatible with MLAT systems already in use at airports.
- The Mode S Extended Squitter DF18 message is recommended for transmission because it is designed specifically for non-transponder devices. Two messages should be transmitted: the "Surface Position" message and the "Aircraft Identification and Type" message.
- A compact antenna that is designed to work well on a metallic roof is recommended for the 1090 MHz transmissions.
- The antenna can be mounted anywhere on the roof of a vehicle, but the best omni-directional performance is achieved when the antenna is mounted on the middle of the roof.
- The minimum required radiated power has been estimated at 10 W. However, in order to ensure a reasonable margin whilst minimizing the impact on 1090 MHz spectrum usage, a value of 18 W is considered optimal for this type of beacon.

TIS-B

TIS-B is a service to pilots and vehicle drivers, not to air traffic controllers. This section addresses only the ground station part of the TIS-B service.

The TIS-B System provided for the EMMA2 test-bed at Prague airport operated in accordance with RTCA MOPS document DO-260A.
The TIS-B Server operated in full surveillance mode whereby all targets within the Traffic Information Volume (TIV) were broadcast, including those that were sending 1090ES ADS-B reports.
The general requirements for TIS-B transmission interoperability with on-board systems were fully met, with the exception of the radio frequency (RF) coverage volume and message latency requirements, which were deliberately degraded for safety reasons.

The RF coverage volume was determined by RF field simulation analysis. The analysis showed that, due to the antenna characteristic and the antenna location, not all areas of the TIV could be covered. Coverage was only provided for the northern half of the Prague airport movement area, which was the main area used for the EMMA2 on-site trials. This was done deliberately in order to avoid any possible interference with the MSSR in the southern part of the aerodrome.

The theoretical mean transit delay (latency) of TIS-B messages passing through the SDF, the TIS-B Server and the TIS-B Ground Station (including the local area network) is well below 0.25 sec. However, the TIS-B update period was set to 2 seconds in order to reduce the RF field load and avoid possible interference with other systems. This led to a mean transit delay of 0.5 sec in relation to the track reports generated by the MLAT/ADS-B system.

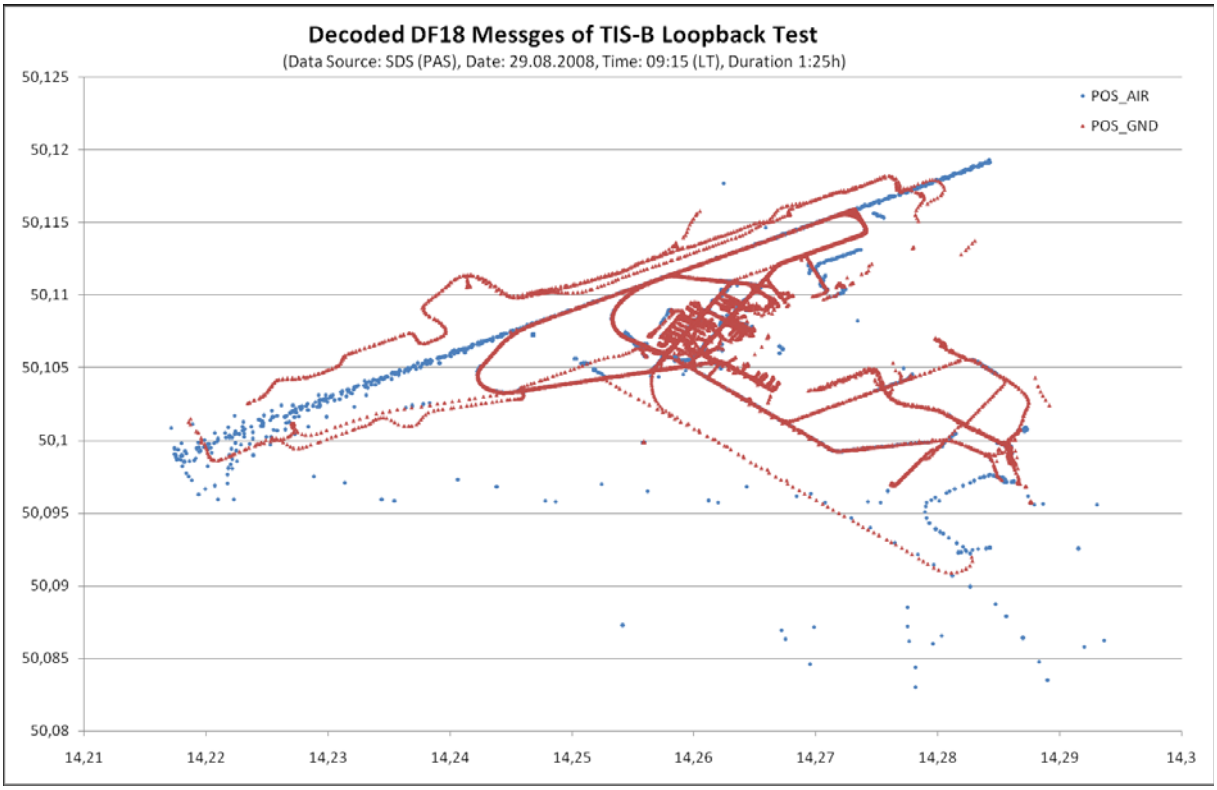

Figure 3-1: Plot showing Target Position Reports received during TIS-B Loop-back Test

The preliminary safety assessment of the TIS-B ground system at Prague identified a hazard that could result in malfunction of the operational A-SMGCS. In its current version, the operational MLAT system is not able to distinguish between ADS-B and TIS-B messages (i.e. DF18, CF0-1: ADS-B and DF18, CF2-5: TIS-B). This is because the MLAT system was designed to meet the requirements of DO-260, which does not include TIS-B requirements; it was procured before DO-260A was published. If no mitigation is applied, the TIS-B transmission may interfere with the operational MLAT system in two ways:

- Jumping Targets: Targets may be detected by the MLAT system not only at their actual positions, but also at the position of the TIS-B transmitting antenna.
- Looping Target Information: Targets detected by the MLAT system may be processed by the SDF, transmitted by the TIS-B system, and then again received by the MLAT system, causing a continuous loop.

A work-around solution was implemented at Prague so that TIS-B trials could take place without interference with the operational A-SMGCS.

From a plot of the target position reports transmitted and received during a TIS-B loop-back test at Prague Ruzyně airport on 29-Aug-2008 it could be concluded that the 1090ES TIS-B ground system technology reached a high level of maturity (see Figure 3-1).

Malpensa On-site Platform Results

The ADS-B out and TIS-B services were available in Malpensa during On-Site Trials (OST). The Milan Malpensa (MXP) on-site surveillance function was provided by the Multi-Sensor data Fusion (MSF) integrating the following contributions:

- Local Primary Surveillance Radar (PSR):
  - Surface Movement Radar (SMR-A), covering the whole manoeuvring area
  - Surface Movement Radar (SMR-B), covering the whole manoeuvring area
- Multilateration (MLAT), covering the whole movement area (manoeuvring area + apron)
- ADS-B out, covering the whole movement area
- Multi-radar tracking flow coming from ACC in Linate
- APP PSR
- APP Secondary Surveillance Radar (SSR)

During Shadow Mode (SM) trials, the ADS-B out contribution was filtered as it emerged, in the testing phase, that the precision of the onboard equipment of some aircraft is insufficient for A-SMGCS purposes. As a result of these findings, it was considered appropriate to disregard the ADS-B contribution so as to avoid contaminating the stability of the tracks.

Figure 3-2: DLR ATTAS Test Aircraft (D-ADAM)

The MXP TIS-B service was tested during the ATTAS trials (see Figure 3-2). The MXP TIS-B system was capable of working in gap filler mode (i.e. transmitting only information on non ADS-B equipped traffic) as well as transmitting the complete traffic scenario. From a technical point of view, the service worked well and a reliable traffic picture was available in the ATTAS Ground Traffic Display

Function. From an operational point of view, although TIS-B is mainly a service to flight crew, ATCOs demonstrated interest into this service. According to their feedback, the main benefits are expected to be provided particularly in reduced visibility conditions, where the major difficulties for both ATCO and flight crew arise and, as a consequence, aerodrome performances decrease. TIS-B and ADS-B systems together with the Ground Traffic Display Function provide pilots with the complete surrounding traffic scenario. This could significantly enhance pilot situational awareness and support pilots in the ground movements to avoid collisions with other traffic.

Toulouse On-site Platform Results

ADS-B was tested in Toulouse during the first phase of EMMA as part of an assessment of lower-level A-SMGCS. In the framework of the EMMA2 project, TIS-B trials were performed in Toulouse Blagnac in October and November 2008. In order to assess possible delegation using TIS-B, ATCOs participated to the technical verification of the installation (vehicle and/or aircraft equipped). Conclusions are summarised in the following.

The surveillance function of A-SMGCS brings a high level of situation awareness to ATCOs. However, pilots do not benefit directly from such an improvement and will keep on taxiing very slowly in low visibility conditions as long as they are not fully aware of their position and of surrounding traffic. By introducing TIS-B technology, pilots could have the same level of information about local traffic as ATCOs and thus share a common understanding of the situation.

A goal of the EMMA2 trials was to implement TIS-B at Toulouse Blagnac in order to test its technical feasibility and to discuss TIS-B operational use with ATCOs. The idea was to see how much control ATCOs would delegate with TIS-B.

The overall conclusion is that:
1. ATCOs consider TIS-B as a very interesting tool for pilots and, in return, as a tool increasing their own safety perception.
2. ATCOs would use it without any change in current procedures for conditional clearances (follow, behind etc.) provided that they can share the same information: aircraft position, callsign (aircraft identification) and aircraft type.
3. Currently, ATCOs would not rely on such a technology (MLAT and TIS-B) for ground separation in low visibility.

ATCOs do not trust the surveillance information itself for separation, i.e. spacing needs to be ensured by control working methods and by pilots. However, ATCOs think that TIS-B could increase airport throughput due to a better confidence of pilots. Finally:

4. ATCOs estimate that the sharing of information with pilots should not particularly increase their workload (with disturbing questions from pilot). To the contrary, they expected that their workload would be reduced in LVP.

3.2 Control

ICAO defines control as the ‘application of measures to prevent collisions, runway incursions and to ensure safe, expeditious, and efficient movement’. Within A-SMGCS, the control function is understood as the assistance provided by the system to implement the planned traffic flow and to support the tactical operations.

Consequently, EMMA2 defined the following main A-SMGCS control elements:
- Conflict prediction, detection, and alerting function

- Conflict resolution function
- Support to controller-pilot communication via voice and data link
- Support for transfer of control and co-ordination within the tower and with adjacent centres

In more detail, the following control system components were proposed in the EMMA2 SPOR (see also Ref. [9]) for a fully-fledged A-SMGCS:

- Conflict prediction, detection, and alerting considering surveillance conflict information, route and clearance conformance information, and clearance consistency information
- Conflict resolution (not part of EMMA2 but expected as a final control implementation step)
- Point-to-point data link applications (DLIC, CPDLC)
- Integrated controller HMI with EFS enabling TAXI-CPDLC (and TOC/AOC)
- Integrated onboard HMI enabling TAXI-CPDLC

Thus, the major components that were assessed in EMMA2 were EFS, conflict alerting tools and TAXI-CPDLC.

3.2.1 Electronic Flight Strips (EFS)

Toulouse On-site Platform Results

Two electronic flight strip systems (EFS) were installed at the Toulouse test site. One system provided a display of operational flight plans enhanced with departure sequence information received from the DMAN and the other system was integrated with the A-SMGCS to exchange traffic information and additional routing and clearance data necessary for the D-TAXI and the Conformance Monitoring functions.
Thus, the latter system provided the D-TAXI HMI, and the EFS server managed ATN CPDLC message exchanges with the on-board system.

The existing core function of the EFS has not been evaluated in EMMA2. Only EFS enhancements for DMAN and D-TAXI were assessed. The corresponding results are reported directly under the concerned functions (see Chapters 3.2.3 and 3.3.2).

Prague On-site Platform and DLR Tower Simulator Results

After several iterative evaluation cycles with EFS for the Prague test site, that took place throughout the EMMA2 timeframe, ATCOs rated the EFS platform as useful and felt that the EFS was ready for operational implementation. During the trials the EFS platform could prove that its HMI design fits the ATCO needs, that it is able to carry other A-SMGCS services, such as DMAN, TAXI-CPDLC, routing, and alerting, and that it is reliable, intuitive and interactive. It does not impair a comfortable workload level, and the displayed clearance status and current flight plan increase the controllers' situational awareness (cf. detailed results in Ref. [17]).

With respect to cost benefit, it was pointed out that EFS would also save costs for printing out paper strips. Currently, at Prague Tower, more than 1000 strips are printed out each day, which would correspond to an annual sum in excess of 40,000 EUR that could be saved by electronic strips.

Malpensa On-site Platform and SITCA/SELEX and NARSIM Tower Simulator Results

The EFS function was available during all MXP validation activities. The focus of the A-SMGCS HMI assessment was put on Operational Feasibility (OF) aspects, which have been assessed both in RTS1 (two sessions a and b) and RTS2 exercises and On-site trials. In addition, early feedback was collected on Operational Improvements (OI) related to situational awareness (in both RTS1 sessions and OST) and to workload (in RTS1b).

According to the feedback collected and taking into account that the ATCOs were not used to working with the new HMI, which radically changes their way of working, controllers had an overall good impression of the new HMI. They considered it consistent with their way of working, compliant with their needs and easy to use.

Figure 3-3: Malpensa Air Traffic Controllers during RTS1

Nonetheless, several remarks and suggestions came out of the analysis of the data collected during the exercises. Below the main considerations are reported:

- General and HMI
  - The EFS HMI must support the possibility to undo any action undertaken by the ATCO on the strip.
  - The A-SMGCS HMI should allow for a reversion to adequate fallback procedures if failures in excess of the operationally significant period occur.
  - Appropriate training should be provided in order to allow the controllers to recognise a failure state in time, i.e. before the failure results in serious operational problems.
  - Support of a checklist to monitor the correct functioning of the all system functionalities could be useful.
  - The A-SMGCS HMI needs further improvements regarding strip management: in some occasions, the HMI made it difficult for the ATCO to find the flight strip he needed when he had to manage more than 18 to 20 flights. A bigger monitor could mitigate the experienced issue.

  - Flight strips were logically grouped in bays according to ATCO needs, but ATCOs required the possibility to easily detect the active flight strip (i.e. the strip that the ATCO is momentarily working on) at any time.
  - Improvement of flight strip sorting in the Electronic Strip Bay (ESB), especially for the Delivery CWP, was required. Sometimes ATCOs had difficulties in detecting a specific flight strip in the bay due to the automatic sorting; controllers would like that the flight strips were sorted according to their own configurable criteria.

- Sectorisation, Transfer of Control, and Co-ordination
  - Electronic handover worked properly and was easy to use, even if it was very different to the handover ATCOs are used to. In the current operational environment involved controllers are aware of the handover as it occurs by physically passing the paper strips; with the electronic handover there is no trigger allowing the receiving controller to be aware that a new flight must be assumed. This means that the time between transferring and assuming a flight could be variable. With the electronic handover some trigger (lights) would be required, so that the next control position is aware of the handover.
  - Differently from the tested system, where there was a restriction at the CWP to only transfer a flight to the previous or next logical sector (e.g. from CDD CWP to GEC CWP, and not from CDD CWP directly to GEC CWP), ATCOs required maximum flexibility for the handover process. Each CWP must be able to transfer EFS to every CWP, without restrictions. This requirement was implemented in a direct feedback loop to developers in the next simulation phases (RTS2).

In each validation phase different measurement tools and techniques were used. They were extensively discussed in the Milan Malpensa A-SMGCS Test Result Report (Ref. [18]):

- Questionnaires:
  - SUS Questionnaire (assessing system usability)
  - Operational Feasibility Questionnaire (checking SPOR operational requirements)
  - SASHA Questionnaire (assessing ATCO perception of situational awareness)
  - NASA TLX Questionnaire (assessing ATCO workload)
- Observations
- Debriefings

Analysing and summarising all the results, it can be stated that:

- ATCOs had an overall good opinion on HMI usability: user-friendly and intuitive (short training in the starting phase is required)
- ATCOs had a positive opinion on situational awareness, specifically in terms of:
  - prediction of traffic evolution
  - planning and organisation of the work
  - usefulness of information provided by the A-SMGCS system
  - perception and understanding of the situation

  This opinion is enhanced by the fact that simulation constraints (no external view in RTS1) had to be taken into account. In particular, the positive controller feedback on their overall situational awareness during the exercises demonstrated that they had a good feeling about the new HMI and especially did not perceive a decrease of situational awareness with respect to the real operational environment. This last analysis highlights the capability of the developed A-SMGCS to compensate abovementioned limitations.
- ATCOs had a positive opinion on workload: they stated that the new HMI did not result in a significant workload increase neither in terms of mental demand, nor physical demand, temporal demand, performance, effort, or frustration.

3.2.2 Conflict Prediction, Detection and Alerting

3.2.2.1 Route Conformance Monitoring

Toulouse On-site Platform Results

In the framework of the EMMA2 project, Route Conformance Monitoring trials were performed in the Toulouse Blagnac test room in October and November 2008 involving one ATCO representing an imaginary GND position. The conformance monitoring tests led to a number of conclusions.

The main conclusion was that the transition to an electronic environment in the tower should allow a strong support to controllers from the introduced systems. In the same way that clearances were used to trigger alerts on runways during the CDG EMMA2 real-time simulations, it was proposed to assess a conformance monitoring system on taxiways in Toulouse-Blagnac. The main idea was that the system monitors an aircraft deviation from its cleared route and warns the controller early enough to prevent complex re-routings.
The system was tested in Toulouse-Blagnac with live traffic data and ATCOs were intentionally selecting wrong routes on the display for inbound and outbound flights.

A key aspect of route conformance monitoring is the HMI. There is a trade-off between the support provided to the ATCO in permanently checking deviations and the additional task required from the ATCO to input a route:

1. Although a generic route was proposed to ATCOs from parking stand to runway threshold (and vice versa) the system was considered unusable as it required too many actions (input and selection) from the ATCO on different screens (EFS and traffic situation display).

Deviation alerts were triggered during the trials. However, the following was concluded:

2. Even though displaying Toulouse airport topology, ATCOs considered the system as not being adapted to their working methods, which were expressed in Ref. [13], especially regarding the use of acknowledgment before re-routing.
3. Very demanding requirements on the HMI made the conformance monitoring system very difficult to assess. The concept was considered insightful by ATCOs but the implementation would need further work and attention.
4. To be usable, especially regarding the alerting service proposed, conformance monitoring should not require more time and energy from the ATCO than a simple radio call.

Prague On-site Platform and DLR Tower Simulator Results

When the system is informed about the cleared taxi route and the current clearance status through EFS inputs and additionally knows the current position of a flight, additional safety nets can be exploited by an A-SMGCS: route deviation alerting and clearance conformance monitoring were the two safety nets that were implemented for the Prague test site.

From a technical point of view these new safety nets functioned satisfactorily. During the trials, alerts were shown to the ATCOs, but the feedback was not taken into account in the final reporting for the Prague test site, as it was obvious that both safety nets would need further tuning and testing in order to minimise nuisance alerts and provide the desired alerts at the right time. This tuning could not be completed in the simulation trials and would need further long-term testing and adjustment.

3.2.2.2 Surface Conflict Alerting System

In EMMA2 two different kinds of Surface Conflict Alerting systems were tested. At the DSNA Athis-Mons tower simulator site for Charles-de-Gaulle Airport (CDG) an Advanced Runway Safety Net (A-RSN) was developed and integrated taking into account control instructions that were entered into

the system through electronic flight strips. In the NARSIM-Tower validation environment for Milan-Malpensa (MXP), a taxiway conflict alerting tool based on a separation bubble algorithm (warnings and alerts are issued when the virtual safety bubbles around two aircraft touch) was implemented on top of the existing runway incursion safety net.
As both approaches differ in both concept and trigger mechanisms for alerts, they cannot be compared directly. Instead, the focus of the analysis will be laid on the comments received by controllers and the recommendations given for further improvement for each of the systems.

DSNA Athis-Mons Tower Simulator Results

At the DSNA Athis-Mons tower simulator test site for CDG, the R&D team succeeded in integrating an Advanced Runway Safety Net (A-RSN) taking into account control instructions in an environment already using a B-RSN based on A-SMGCS Level I information (convergence of trajectories, speed etc.). A week of HITL-RTS showed several improvements brought by an A-RSN:

1. Conflict detection is anticipated through the processing of instructions issued by the controllers and input on the electronic flight strip.

A-SMGCS surveillance provides controllers with reliable and timely information on position and identification of a movement. In order to improve the detection of stop bar crossings, DSNA tried to derive speed information from A-SMGCS surveillance data by computing an average of speed vectors based on several position reports. Speed test areas were then defined around each stop bar to anticipate unauthorised crossing. This test was designed as a pre-alert phase to complement FISSA (a safety net for clearance conformance monitoring) by providing alerts on aircraft approaching stop bars with a high probability of crossing them without authorisation. The result was the following:

2. Anticipation of runway incursions by speed testing around stop bars seems feasible but does not seem to bring a significant safety improvement (43 level 1 alerts out of 666).

Another improvement was made regarding the shape of the Runway Protection Area (RPA). It was noted that the conventional shape of the RPA (a rectangle) does not coincide with existing stop bars. This prevented DSNA from achieving a high level of precision in detection of runway incursions. Therefore, the conventional shape was replaced by a polygon linking stop bars. This led to the following result:

3. The conventional design of the Runway Protection Area (RPA) as a rectangle surrounding the runway was not sufficient for the timely triggering of alerts. The shape of the RPA was defined as a polygon linking stop bars: when one side of the polygon is a stop-bar the next one is the line linking this stop-bar to the next one.

It was also endeavoured to determine whether the use of A-RSN would lead to the introduction of different sets of rules for alerting depending on the operational use of the runway (e.g. mixed mode):

4. RTS1 could not show if the same rules were applicable at CDG when runways are used in doublet (twin parallel runways, one for take-offs, one for landings) or when a runway is used for both take-offs and landings. In RTS1, it was assumed that the same rules would apply in both cases. This assumption was called into question. However, it was not possible to make more assertive statements about it.

The RTS also demonstrated a number of feasibility conditions to install such a tool:

5. The introduction of an A-RSN in a system already including a B-RSN seems feasible and did not raise major issues. Besides, an A-RSN based on clearances only (receiving no surveillance information) does not seem to be operationally feasible, as surveillance data is necessary to determine the distance between the mobiles and their relative position.
6. The control interface shall allow conditional clearances. This was not the case in RTS1. Nuisance alerts were triggered by lack of contextual information and lessened drastically the A-RSN utility and acceptability.

7. The alert display shall display the same information on EFS and TSD at the same time. Every inconsistency leads to a lack of trust in the system. In RTS1, the alert display did not always allow the controllers to easily understand the situation. The following cases were noted:
   - False and nuisance alerts creating doubt
   - Incoherent display on EFS HMI and TSD (i.e. a few seconds of delay between the end of alerts or between the changes of the alert level on both displays)
   - Alert situations involving more than two aircraft
8. A stepwise approach to tune the parameters of an A-RSN seems advisable. Assessing a whole set of alert situations together means to configure and test all the rules at the same time, which makes the evaluation rather difficult. It seems more effective to implement one or two rules at a time (in a priority order locally defined), make them work for some months, and then progressively add other rules. Considering that the most frequent cases of runway incursions are due to movements entering the runway without authorisation, a priority order for Paris Charles-de-Gaulle Airport is proposed below. The list goes from high to low priority, based on a trade-off between frequency of occurrence of the runway incursion and ease of implementation of the alerting rule:
   - Several aircraft authorised or not on the runway protection area:
     - An aircraft cleared to take off with traffic on the runway protection area (ALARM).
     - An aircraft cleared to take off with a movement cleared to line up, cross or taxi ahead (ALARM).
     - An aircraft detected taking off without clearance with a movement cleared to cross, line up or taxi (ALARM).
   - One aircraft not authorised on the runway protection area:
     - A movement entering the runway protection area without clearance (INFO).
     - An aircraft detected taking off without clearance (INFO).
     - An aircraft detected crossing or lining up without clearance (INFO).
   - Landing aircraft with other aircraft on the runway protection area authorised or not (INFO or ALARM according to the distance from threshold).

NARSIM Tower Simulator Results

The Surface Conflict Alert (SCA) is responsible for automatic conflict detection and alerting within the A-SMGCS. SCA will analyse the track data provided by the Multi Sensor Function (MSF) or by the Surface Movement Tracker (SMT) with respect to conflict situations on the manoeuvring area of the airport. SCA is able to detect an alert situation: around each object (aircraft or vehicle), SCA defines a security area called Safety Bubble[4]. A superposition between two or more safety bubbles is identified as a conflict situation. A superposition between a safety bubble and an airport obstacle (stop-bar, OFZ, ILS critical zone and so on) is identified as a conflict situation.
The SCA is configurable in terms of acoustic signalling with independent settings (enabling/disabling) for warnings and alarms (e.g. beep on/off for all alarms, beep on/off for all warnings). For more information on SCA, Ref. [6] should be considered.

In EMMA2 a safety assessment supported by real-time simulations on the NLR NARSIM-Tower platform of a design of an EMMA2 A-SMGCS operation on Milan Malpensa airport was performed as part of RTS2. The primary purpose of the safety assessment of operations at Malpensa Airport, with a Surface Conflict Alerting system (E-SCA), and Electronic Flight Strips (T-EFS) as a technical enabler, was to provide optimal feedback to the operational developers about the safety of the design of an EMMA2 A-SMGCS operation on Milan Malpensa Airport. This design was considered for R&D purposes, and hence the focus was on delivering feedback to the developers, not on completing a safety case for regulatory approval of operations.

[4] It should be noted that for the current A-SMGCS definition it is not possible to provide an accurate estimate of the speed and direction of a movement. Real-world surveillance limitations were not considered in simulation and will therefore have to be tested.

The adopted safety assessment approach was based on an approach which argues that for effective assessment of complex A-SMGCS operations, the domains air traffic services (ATS), aircraft systems and aircraft operations should be considered in an integrated way (see Ref. [12]). The assessment was limited to the safety of aircraft taxiing in the manoeuvring area and the EMMA2 A-SMGCS operation that was specifically designed for the simulation purposes. Hence no conclusions on current operations can be drawn.

As a basis of the risk assessment, a large range of hazards was identified for the considered operation. These hazards reflected conditions, events or circumstances which could induce an accident, either by causing conflicts (root hazards) or by hampering their resolution (resolution hazards). These identified hazards were structured into six conflict scenarios:

I. Conflict involving two taxiing aircraft
II. Conflict involving a taxiing aircraft and a vehicle
III. Conflict involving a taxiing aircraft and an aircraft in take-off
IV. Conflict involving a taxiing aircraft and a landing aircraft
V. Taxiing aircraft affected by jet-blast of other aircraft
VI. Taxiing aircraft affected by veer-off or overrun

The risk of each conflict scenario was assessed based on historical accident data, real-time simulations dedicated to gathering inputs for this safety assessment (see Ref. [20]), operational expert judgement, safety expert judgement, and, for Conflict Scenario III, Monte Carlo simulations using dynamic risk modelling. To be in line with the ICAO A-SMGCS Manual (Ref. [24]), accidents involving fatalities or hull loss were considered in a separate severity class, besides the usual accident severity class. For both classes a target level of safety was derived based on the A-SMGCS Manual.

For the severity class concerning accidents including fatalities and/or a hull loss, a maximum allowable probability of $8*10^{-9}$ A-SMGCS related accidents (fatal/hull loss) was adopted as the target level of safety. This severity class was assessed to be applicable for Conflict Scenario III, IV, and VI. The assessment delivered some confidence that this target level of safety is met by the designed EMMA2 operation. The largest contributors to the uncertainty in the risk assessments were Conflict Scenarios III and IV. For conflict scenario IV conflict situations in which an aircraft lined up for departure on runway 35R while another aircraft was about to land on the runway were the main risk contributor. For conflict scenario III the main risk contributor was the situation in which an aircraft took off from runway 35L, while a taxiing aircraft erroneously entered that same runway. The uncertainty in these latter results was mainly caused by uncertainty about the probability of a runway incursion.

For the severity class ‘accident’ (including non-fatal accidents without hull loss), a maximum allowable probability of $2*10^{-7}$ A-SMGCS related accidents was deduced as the target level of safety. This severity class was assessed to be applicable for Conflict Scenarios I, II, IV, V, and VI. The current safety assessment did not deliver sufficient evidence for stating whether this target level of safety could be met by the designed EMMA2 operation. This uncertainty was particularly related to Conflict Scenario I, in which the main risk contributions were from situations where a pilot misjudged the separation, a pilot did not give way to an aircraft, or a pilot did not hold in time when a leading aircraft stopped taxiing. For the other conflict scenarios, there was confidence that these do not deliver problems in meeting the target level of safety.

The assessed contributions of the new A-SMGCS systems in the above assessments were as follows:

- MLAT/AVMS and T-EFS were assessed to deliver a general small positive effect on the safety of all conflict scenarios.
- E-SCA was assessed to deliver a small positive effect on the safety of Conflict Scenarios III and IV, and no significant effect on the other conflict scenarios.

A main reason of these assessed benefits being limited was that good visibility conditions were assumed, which implies that pilots of the involved aircraft and the air traffic controllers were usually already well capable of detecting and resolving conflicts.

It is stressed that all the above results are subject to preliminary safety requirements and various assumptions on the design and operational use of the new systems. These assumptions refer to aspects such as sufficiency of training for the new systems and fall-back scenarios, and assuring low rates of nuisance alerts for E-SCA and of wrong labels.

Considering that the safety assessment primarily aimed to deliver feedback to the operational developers, no firm conclusion could be drawn about the safety of the EMMA2 operation under investigation. For most conflict scenarios, confidence exists that the adopted target levels of safety can be met, for some there is more uncertainty. A certain level of uncertainty in risk results is inherent to safety assessments of potential future operations; uncertainty may be reduced by the collection of more data. No evidence was identified that the designed EMMA2 operation is unsafe.

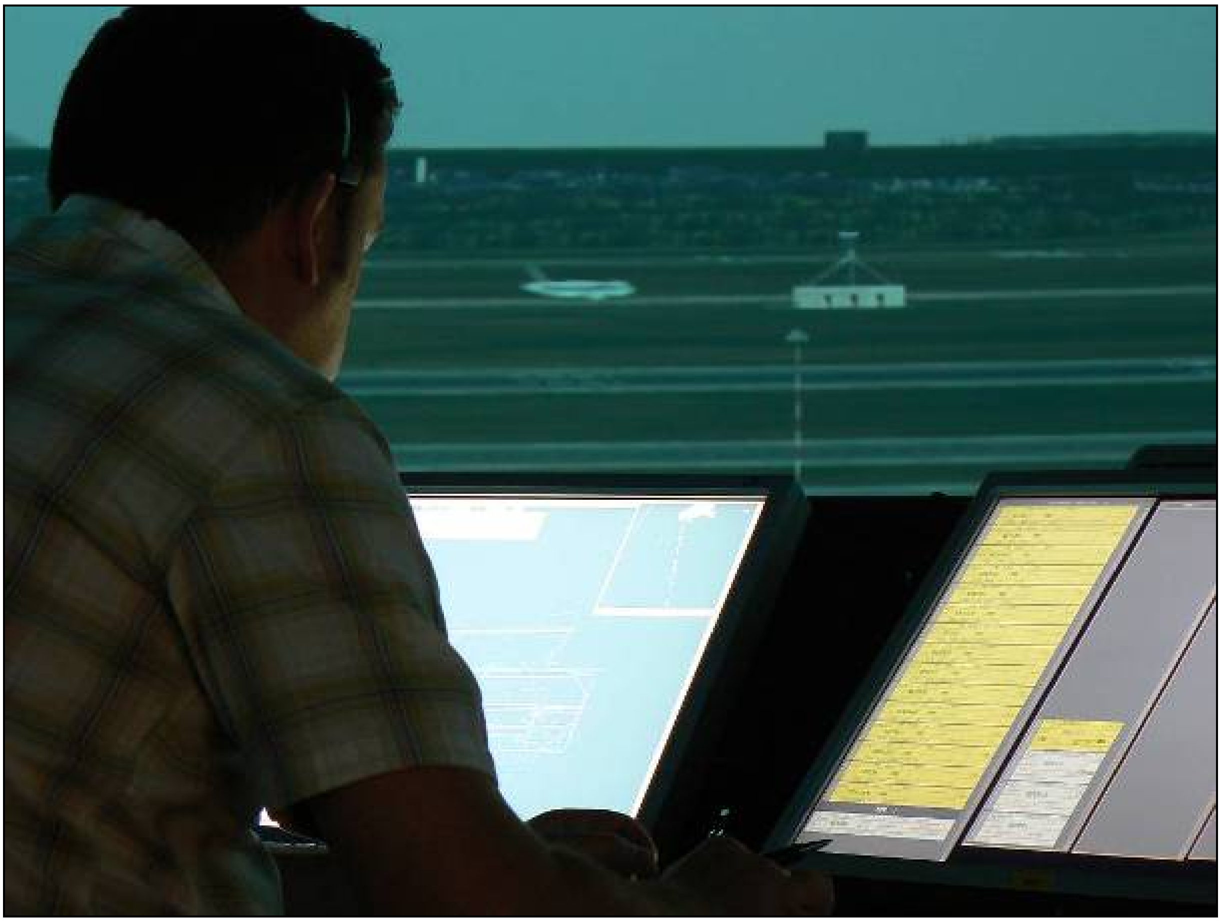

Figure 3-4: NARSIM-Tower Real-time Simulations for Malpensa Safety Assessment at NLR

For the further design of the EMMA2 A-SMGCS operations on Milan Malpensa Airport the various assumptions that were adopted on the design and operational use of the new systems should be verified. Also, it is recommended to explore several further possibilities for optimisation of T-EFS that were identified in Ref. [20]:

- Input devices being sufficiently simple
- Possibility to see the information on the displays in all light levels

- Possibilities to configure the electronic strip display
- Aspects of the electronic flight strip bay
- Strip hand-over
- Possibilities to correct a mistake

To further decrease the risk related to Conflict Scenario I, it is recommended to explore the possibilities of using the crossing conflict detection (CROS) and/or opposite direction conflict detection (ODIR) in good visibility conditions. Both CROS and ODIR are already available in E-SCA, but were not part of the EMMA2 operation under investigation. For other conflict scenarios also possibilities for potential improvement have been suggested.

The further development of the EMMA2 A-SMGCS operations on Milan Malpensa Airport should be accompanied by further safety assessment activities, so that sufficient confidence can be reached that such an operation is safe. The detailed risk modelling applied in Conflict Scenario III delivered more precise insight into the risk related to the conflict scenario than the approach adopted for the other scenarios. Thus, it is recommended to explore the possibilities of such an approach as well for Conflict Scenarios I, involving conflicts between two taxiing aircraft, and IV, involving conflicts between a landing and a taxiing aircraft. In further safety assessment activities, uncertainty may also be decreased by using measured or reported runway incursion data instead of expert opinion.

3.2.3 TAXI-CPDLC

In the context of this document, the TAXI-CPDLC, at first instance, is seen as a control service allowing the controller to issue ground clearances via data link. Since it is also the link to an onboard service to pilots, though, it is hard to analyse the results without considering the consequences for the cockpit. This section will therefore look at the service in an integrated way, considering remarks from both controllers and pilots on ground clearances via datalink. In a later chapter (see Section 4.5), the results purely related to onboard interfaces and operational issues will be reported.

Toulouse On-site Platform Results

As part of EMMA2, trials for giving ground clearances by data link were performed in the Toulouse Blagnac test room in October and November 2008. ATCOs were invited to participate to Airbus cockpit simulations in order to assess the ground and onboard operational concept. Field trials were also performed in the test room with one ATCO managing the Ground Controller (GND) position. The conclusions on the tests for ground clearances by data link are summarised in the following paragraphs.

Toulouse controllers and Airbus test pilots were involved in the trials. Controllers were situated in a test room sending data link taxi clearances through an interface provided by THALES Air Systems. Pilots performed manoeuvres in a cockpit simulator.
The overall feasibility of ground clearances by data link was assessed with the modus operandi proposed in the CPDLC report (cf. Ref. [13]).

After consultation of controllers and pilots the following questions came up:

- If one intends to revert to voice for runway operations like runway crossings, then the route is not displayed on board anymore. How will it be possible to maintain both advantages of the party line effect and of the on-board route display?
- How were controllers able to cope with mixed mode communication (equipped and non-equipped traffic, reversions voice/data link according to strategic/tactical situations)?
- As to the question of information sharing, what did controllers and pilots think about the “expect routing” information?

Simulations and debriefings led to the following conclusions:
At introduction of data link as a means of communication for airports, the disappearance of the party line effect, i.e. the ability to listen in to the complete R/T communication, was first considered as an important shortcoming. The consensus was quickly reached that the party line effect had most of its importance on runways, so that the focus in the EMMA2 trials with DSNA ground controllers was laid on the area from parking stand to runway holding point.
Excluding the runway from the scope of data link, though, quickly raised the issue of runway crossing. The fact that it was not handled by data link was misleading for the pilot who thought he was not allowed to cross.

1. After the trials, the following opinion was shared by both controllers and pilots: provided voice remains the primary means of control, the sending of a data link message for runway crossing and line-up is not expected to raise safety issues. ATCOs would continue giving instructions by voice and would send data link clearances in parallel, so that they are displayed on-board. Since the operation is handled by voice in parallel, no read back would be required by data link. The voice acknowledgement would be sufficient.

At any new system introduction, the transition phase must be assessed. With data link, the mixed mode (voice and data link) might raise a number of issues, among which is the possibility that the transition phase could become a permanent phase if no mandatory CPDLC implementing rule is enacted.

2. In an electronic environment, where ATCOs digitally input most of their instructions, non-equipped aircraft will appear as a constraining factor, since they require voice clearances, while clearances are automatically transmitted when using data link.
3. The priority of voice (tactic) over data link communications (strategic) was assessed and recognised as fundamental. A set of datalink messages and voice instructions is required to notify the change of communication means (such as “RESUME TAXI” and “REVERT TO DATA LINK”).
4. It was also agreed that the choice of the communication means shall not be constrained by procedure but left to the users, for example when there are time constraints.

A clearance by data link needs time to be processed at both ends. While voice communication is direct and applies to the current situation, data link communication was felt as a means to prepare instructions in order to reduce workload peaks on the ground side.

5. Throughput increase through information sharing could be facilitated by the “expect routing” information. A prerequisite for pilots is that they retrieve information that is timely and reliable enough to be accounted for. From an ATCO perspective, this kind of information shall be processed automatically and they shall be left with a means to modify it.

The operational use of such expected routing information was assessed and discussed.

6. An agreement was reached: the “expect routing” information needs to be provided with the departure clearance for outbound flights and when retrieving the ATIS in approach for inbound flights. Clearances would provide refinement along the way. These refinements would be done by voice in a first implementation step, and then by data link exchange when system wide information management is available and when the ground HMI is more mature.

Eventually, in addition to providing the pilots with an unambiguous record of the clearance, an electronic moving map would provide a graphical depiction of the route, information about the current location, and the distance to and direction of the next turn. On the ground, a graphical route display would allow controllers to quickly and more easily read taxi routes and to detect the aircraft location, and a possible deviation:

7. Both pilots and controllers expressed the need for being provided with data link information in both text and graphical format, and they stressed the importance of the quality and efficiency of

both interface and data.

Prague On-site Platform and DLR Tower Simulator Results

In the Prague real-time simulation trials, an experiment was set up including both ATCOs in a tower and pilots in a cockpit environment. The simulation was run with three ATCOs from ANS-CR, a cockpit crew, and five pseudo-pilots. In total six ATCOs and eight commercial pilots were participating. They performed 15 TAXI-CPDLC test runs resulting in more than 350 movements and more than nine hours of testing.

In the simulation trials, controllers worked with a data link equipage rate of 50% of the participating traffic, which was considered a representative future traffic scenario. The Ground Executive Controller (GEC) and the Clearance Delivery Dispatcher (CDD) handled START-UP, PUSHBACK, TAXI-in, TAXI-out, and HANDOVER by data link. The Tower Executive Controller (TEC), who was responsible for the runways, used voice exclusively.

Figure 3-5: EFS with TAXI-CPDLC used at Prague Airport

The ATCO feedback for handling those clearances by TAXI-CPDLC was predominantly positive. The ATCOs indicated that they were provided with an effective human-machine interface that permitted efficient data link communication with the pilots. They also stated that a mix of TAXI-CPDLC and voice communication for different phases of a single flight and a mix of equipped and non-equipped aircraft did not lead to confusion or safety critical communication errors. They also refuted formerly mentioned constraints, that they would be distracted by TAXI-CPDLC from looking outside and that they would be unsettled by too many input requests to operate TAXI-CPDLC (cf. detailed results in Ref. [17]).

During the on-site trials at Prague Airport, the technical and operational feasibility of TAXI-CPDLC were successfully assessed as well. Using the combination of VDL Mode 2 and ATN, clearances could be exchanged between the flying test aircraft, operated by pilots via the CDTI, and the controller working positions, operated by the ATCOs in the control tower.

During the debriefing sessions, interviews were performed with the ATCOs. The following statements reflect a common opinion of all six ATCOs. If there were contrary opinions or assumptions only, it was concluded that further testing would be necessary. The concluding notes mainly address aspects of operational feasibility and proposals for improvement of the new A-SMGCS services.

- In general, TAXI-CPDLC with start-up, pushback, taxi-out and taxi-in, and the silent handover worked fine and, with some exceptions, it was accepted by the ATCOs.
- The handover was initiated via data link by the message “CONTACT LKPR GROUND 121.900” but the initial call with the next control position was done by voice. This procedure was very much appreciated by the ATCOs because it would ensure that voice contact was established and that it could act as backup in case TAXI-CPDLC failed or be used for non-routine communication. The following phraseology was tested and accepted:
  - Pilot: “RUZYNĚ GROUND, DLH621 ON YOUR FREQUENCY”
  - ATC: “DLH621 FOLLOW DATA LINK”
  - Pilot: “FOLLOWING DATA LINK, DLH621”

  This phraseology was seen as safe and unambiguous. However, it was proposed that it could be even shorter when TAXI-CPDLC is in operation and users are more familiar with the new service.
- With outbound traffic the GEC transmitted the complete taxi-out clearance including the clearance limit, which is usually the holding point of a runway to be crossed: “TAXI TO HOLDINGPOINT F RWY 06 VIA TWY P L F HOLD SHORT OF RWY 13 NEXT EXPECT VIA TWY F” or without an intermediate clearance limit, when no additional runway on the way to the departure runway had to be crossed: “TAXI TO HOLDINGPOINT A RWY 24 VIA TWY P L H A”. At the respective handover point, the GEC handed over the flight to TEC by “CONTACT LKPR TOWER 118.100” and the TEC continued control by voice communication only. ATCOs indicated that this procedure worked fine.
- It was stated by an ATCO that a TAXI-CPDLC message for crossing might be an option worth testing. A TAXI-CPDLC crossing clearance would also solve the operational problem that a stop bar on the onboard display would be switched off by an ATC clearance instead of by one of the pilots in accordance to the voice crossing clearance, which is not the correct procedure from an operational point of view.
- Time-critical and safety-critical instructions or clearances like line-up, take-off and landing, or a “hold position” command, should be given by voice for the time being. To finally validate or reject them would need further investigation.
- With inbound traffic, after handover from TEC to GEC, the GEC provided the taxi-in route to the final parking position by TAXI-CPDLC, e.g. “TAXI TO STAND S17 VIA TWY F L P”. This procedure was well accepted by the ATCOs.
- Dealing with a TAXI-CPDLC revised taxi route while taxiing was seen as potentially feasible by the ATCOs, but would need further testing to confirm it. It seemed that this procedure was very much dependent on the actual traffic situation. However, ATCOs were never forced to use TAXI-CPDLC and could revert to voice at any time.
- A pre-requisite for transmitting taxi clearances by data link is that the correct taxi route has been computed and preselected by the routing function or that alternative routes can easily be selected. Manual input of taxi routes would not be acceptable for controllers.

- The pilots' acknowledgement of a data link clearance by "WILCO" or "UNABLE" messages was well appreciated by the ATCOs. "ROGER" or "STAND BY" messages were not tested.
- Instead of receiving a positive logical acknowledgement (LACK) from the system in response to every message, indicating that the message has been successfully delivered to the onboard CDTI, the ATCOs would prefer only to be informed in case of a transmission failure.
- An acoustic signal for incoming TAXI-CPLDC could be helpful to attract attention to an incoming message. Further testing would be necessary to confirm this.

Malpensa On-site Platform Results

The TAXI-CPDLC service was tested in Milan Malpensa during On-site Trials. From the ground side, the service was not object of an operational assessment but only of technical testing to verify the system functionalities.

The service was accessible at the CDD/GEC CWP with its own HMI and was not integrated with the EFS HMI. The TAXI-CPDLC HMI was available in a dedicated window within the controller's Traffic Situation Display (TSD). The tests were performed during ATTAS trials, consisting of three exercises where the DLR test aircraft performed several movements on the airfield (including RWY 35L). During the exercises, ATTAS was always under control of active operational ATCOs, whose instructions/clearances by voice were sent in parallel to the ATTAS pilot by the EMMA2 test bed GEC via data link messages.

During the tests, the TAXI-CPDLC service worked properly and TAXI-CPDLC messages were correctly exchanged with the ATTAS aircraft. The tested service supported controller instructions (e.g. "START-UP" or "TAXI ROUTE" clearances) but did not include operations on the runway, such as "CROSS RWY" or "LINE UP". The set of messages used was taken from the proposal made by DLR for the ATTAS trials in Malpensa and Prague.
At the on-board side, the successful exchange of taxi route messages allowed displaying the cleared taxi route on the ATTAS moving map display.

3.3 Routing / Planning

Contrary to earlier definitions of EUROCONTROL (cf. Ref. [5]), the EMMA2 project defined routing as a dedicated controller service, with the option to uplink routing information as part of the control or guidance function (TAXI-CPDLC).

Thus, EMMA2 makes the following distinction:
- Routing is generation and assignment of a route
- Transmission of a route to flight crews or to vehicle drivers is part of control or guidance

In the ICAO A-SMGCS Manual (Ref. [24]) a route is described as 'a track from a defined starting point to a defined end point on the movement area'. Planning is seen by both ICAO and EMMA2 as a supporting function for all of the primary functions surveillance, control, routing and guidance. However, EMMA2 decided to describe and categorise the supporting planning function as part of the routing primary function in order to avoid inconsistencies with already established terminology and because of the close link between routing and planning functions.

EMMA2 also follows the ICAO recommendations for automation levels of the routing function, acknowledging that more automation requires more planning and other information support (DMAN, CDM). The ICAO A-SMGCS manual considers the sophistication of the way in which a route is assigned to an aircraft or vehicle as an indicator for the level of automation[5]:

- *Manual Routing* is straightforward assignment of a route by the control authority
- *Semi-automatic Routing* adds advisory information for assigning a route to the process
- *Automatic Routing* is achieved when the route is assigned automatically, however, with the option for manual intervention in the event of a failure or at the discretion of the control authority, all under the premise of provision of adequate information

In conclusion, the following routing system components were proposed in the EMMA2 SPOR (see also Ref. [9]) for a full-fledged A-SMGCS:

- Surface Manager (routing server) with local routing algorithms
- Departure Manager

3.3.1 Routing

Malpensa On-site Platform and SICTA/SELEX Tower Simulator Results

For Milan Malpensa, a Route Planning (RP) function was available for both the RTS1b and OST exercises.

The Route Planning (RP) function aims at providing the most suitable taxi route to controllers based on the shortest taxi distance and current constraints that are known to the function. The RP function calculates and proposes to the ATCO the best route complying with input parameters concerning the airport configuration (i.e. closed taxiway, LVP, restricted areas) as well as the following criteria:

- Start point (e.g. the stand/gate for a departure; the runway exit taken by an arriving aircraft)
- End point (e.g. the allocated stand/gate for an arrival; the assigned runway for a departure)
- Intermediate waypoints (e.g. de-icing, temporary parking positions, holding positions)
- Local standard routes
- Local taxi restrictions (closed or restricted-use taxiways, restricted areas)

The default optimal taxi route is automatically proposed for:

- departing flights, when the CDD gives a departure clearance to a flight
- arriving flights, when the TEC gives the landing clearance to an arrival

The proposed taxi-route shown on the EFS as a string (segments sequence) was red until the ATCO accepted it and it became black.
It was possible for the controller to modify the proposed taxi route choosing the preferred route from a list. For more information on RP refer to Ref. [16].

Analysing the collected results, some inconsistencies could be identified. Although ATCOs in both exercises demonstrated great interest in this supporting tool, reactions were more positive in the RTS session. This is probably related to the familiarity of ATCOs with this innovative tool, which for the OST was presented for the first time to operational controllers who were focused on the real operational environment conditions. Tuning issues of the RP to the Milan Malpensa environment (availability of all stands in data base, etc.) were therefore expected to have a stronger impact on these trials.

[5] In fact, there is some contention with the ICAO recommendations. In EMMA it was postulated that there is no difference between a semi-automatic routing and an automatic routing with manual override. In both cases, the computer will propose an optimum taxi route, the controller will confirm (probably by doing nothing) or reject/modify the route, and the approved route will be assigned when the controller (manually via data link or verbally by voice communication) gives the taxi clearance.

However, the ATCOs in both the exercises were very interested in this innovative support function as results from several suggestions/considerations collected during the debriefing sessions that aim to improve the function.

The main considerations are reported below:

- An intensive tuning of RP is required to fully exploit its functionalities. In particular, in order to maximise benefits, the tool:
  - must be dynamic and take into account both planned and real-time evolution of the traffic
  - should react to any non-planned event
  - should be used in combination with other ATC support tools (e.g. DMAN and route conformance monitoring)
- The ATCO decision should always have priority over the RP proposals. This means that the ATCO should always have the possibility to write and then validate a route, even if it is not proposed by the RP (i.e. the route does not belong to the RP database) and if it is not conflict free[6].
- The system must include the undo command for a validated route allowing the ATCO to always change that route and assign a new taxi route.
- Route proposals by the RP should contain no more than 5 taxi-routes, with the standard taxi routes on the top of the list. In accordance with this statement, ATCOs assigned a higher priority to standard taxi routes than to conflict free routes computed by the RP.
- The RP function proposed the whole route for each flight, from stand to assigned runway for departures, and from the runway exit point to the stand or gate for arrivals. In that regard ATCOs preferred receiving only a proposal for the part of the route under their responsibility (e.g. considering an outbound flight departing from RWY 35R, the RP should only propose the part of the taxi route from the stand to the holding point of RWY 35L to the GEC).
- For inbound flights, the trigger for a route proposal by the RP function should be moved from the landing report input, as it was during the trials, to the landing clearance provision. This is due to the fact that after landing the priority for the controller is to give the taxi route instead of entering the landing report.
- As typically the route choice also depends on the aircraft type, the RP algorithm should take into account this parameter in the route calculation process.

The RP function was integrated into the EFS HMI. According to this, for Operational Improvements considerations refer to section 3.2.1.

<u>Prague On-site Platform and DLR Tower Simulator Results</u>

The routing function is an important enabler for other A-SMGCS services, such as TAXI-CPDLC, DMAN, and route conformance monitoring. In Prague, the routing function was based on pre-programmed standard routes. The system would automatically propose from the pre-programmed set of routes an optimal route for each departing or arriving aircraft. In general, it worked quite well, but due to a number of limitations, primarily because not all possible routes had been implemented, it received only partial acceptance by the ATCOs.

Nevertheless, standard taxi routes were proposed for each departure and arrival flight. As long as there was a flight plan with a valid runway exit/entry point and a valid stand identifier, a valid route was presented on the flight strip. In many cases clicking on the route field enabled the choice of one or two valid alternative routes.

[6] Taxi routes are seldom conflict free, since conflicts depend on the speed at which mobiles move along their assigned routes. The routing tool has no control over this parameter. Pilots are responsible for assuring separation by "see and be seen". Controllers provide "give way" advice to prevent conflicts.

This means that most standard taxi routes were available as needed. Problems occurred particularly when routes were needed that were not in the pre-programmed list of standard taxi routes. Alternative routes could not always be offered by the routing function (due to above-mentioned limitations).

3.3.2 Departure Management

Prague On-site Platform and DLR Tower Simulator Results

The DMAN provided the ATCOs with three calculated flight plan data items, which were shown in the electronic flight strips: Target Start-up Approval Time (TSAT), Target Take-off Time (TTOT), and Recommended Time until Next Clearance (RTUC). In addition, the sequence number for each outbound flight, proposed by DMAN, was always displayed in the strip. The ATCOs liked this additional information and indicated that it would help them to perform their control task more efficiently, to avoid excessive queues at the runway holding points, and to shorten the stop times during taxiing. These results could also be confirmed by analysing traffic data.

Nevertheless, the DMAN could only show portions of its expected benefit. To receive the full benefits, the tool would need to be further adapted to the particularities of Prague Airport and its local procedures, but this would require more time for testing. Furthermore, the integration into a CDM environment would enable the DMAN to work with a broader planning horizon, which would of course also improve the DMAN planning output.

ATCOs confirmed with statistical significance (cf. detailed results in Ref. [17]) that:
- DMAN enables them to work more efficiently
- DMAN avoids excessive queues at the runway entry points
- DMAN reduces taxi times

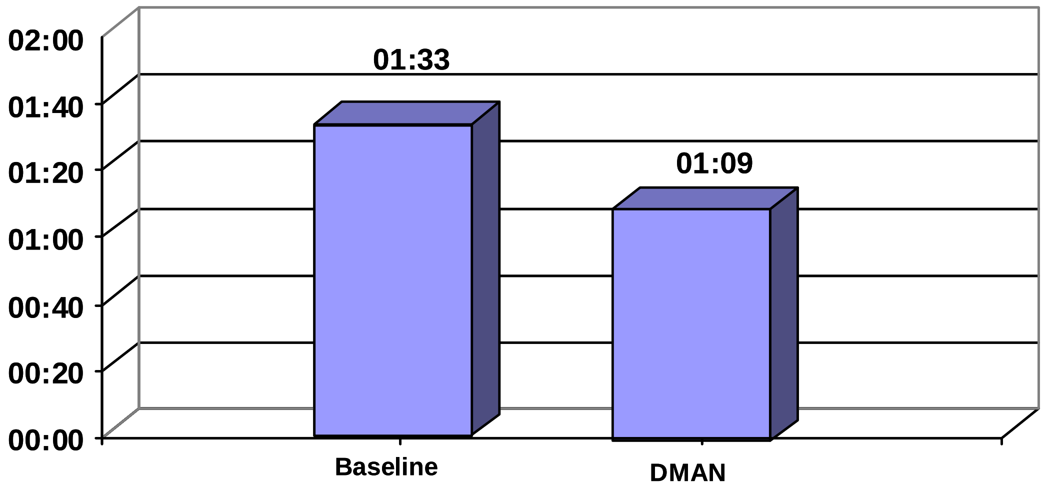

Figure 3-6: Bar Chart for Mean Values of Stop Time during Taxiing (in Minutes)

By support of the DMAN, stop times during taxiing could be reduced significantly, from an average of 1:33 to 1:09 minutes, which corresponds to a 26% reduction of stop times (see Figure 3-6).
The effect of reduced stop times during taxiing was caused by the equalisation of departure peaks through the DMAN planning, which exploited the 15-minute CTOT time window. One of the current problems in managing departure traffic is that, during departure peaks, there are frequently several outbound flights taxiing to the runway at the same time, resulting in an accumulation of aircraft at the

runway entry point. Instead, as long as the stand is not needed by another flight, the DMAN would keep the aircraft at the stand until a free runway slot is predicted. Taking into account this calculated runway slot (TTOT), the DMAN computes a proper Target Start-up Approval Time (TSAT) that is in accordance with the flight plan constraints and the current traffic situation.

The above-mentioned procedure smoothed the outbound peak. This was also reflected in the measurements for the mean departure throughput. As long as the CTOTs are not violated, and arrival stands are not blocked by withheld departures, such a procedure is probably more efficient than pushing departures out in a short period of time, which would result in a high throughput peak but increased stop-and-go traffic throughout the manoeuvring area.

To conclude: it was shown again that the planning of outbound traffic is a very complex process. There are many variables, which have to be considered by a departure manager: some of them are well known in advance; others are difficult to predict or can change suddenly. Additionally, there are local particularities that must be taken into account by departure planning (different runway entry points, standard taxi routes and times, runway dependencies, SID dependencies, etc.). The simulation revealed that there is still room to better adapt the DMAN to the Prague Airport constraints and that such an adaptation would take some time. The integration of a DMAN into a CDM environment is also considered beneficial, as the DMAN would have access to more reliable flight plan information.

DSNA Athis-Mons Tower Simulator Results

In the framework of the EMMA2 project, real-time simulations (RTS2) were performed at the DSNA R&D (Athis-Mons, France) test site in June and October 2008. RTS2 consisted of an evaluation of DMAN interoperability with A-SMGCS and in particular the interoperability of an electronic flight management tool (DIGISCUS) for the Clearance Delivery (CLD) controller with an electronic flight strip system (VigieStrips) for the Ground and Runway controllers.

The DMAN used was a DSNA R&D tool. This DMAN tries to prioritise flights at departure, given their original departure time (TOBT), CFMU slot information (CTOT), static taxiway times and a given runway traffic load to maintain. Given those elements, the DMAN produces an Estimated Off-Block Time (EOBT) mentioned to the CLD controller on the new e-strip system for CLD DIGISCUS.

The objective of the trials was to improve departure traffic management integrating DMAN information to the CLD and ground control tools, for example Managed Off-Block Time (MOBT), slot information and alerts, and to improve DMAN sequencing by providing up-to-date information to the system.

The proposed axes of research were:

- Upgrade the control HMIs to include DMAN information
- Facilitate the circulation of DMAN information between ATCOs

Before assessing the work performed in EMMA2, a key aspect of RTS2 needs to be specified more clearly:

1. The first and important lesson learnt from RTS2 is to re-establish (if need be) the importance of the CDM paradigm in airport planning. RTS2 took place in a non-CDM environment, i.e. there was no exchange simulated between ATC and simulated airlines (or pilots) and the airport manager. This led to the use of the Proposed Off-Block Time (POBT) and MOBT as cornerstones of the sequencing, while MOBT is not agreed by partners and keeps changing every time a new sequence is computed by the DMAN. The use of an agreed TSAT time (common between ATC, the airline and the airport manager) was strongly demanded by ATCOs.

The upgrade of control HMIs led to the development of a new CLD HMI (DIGISCUS). On that aspect

RTS2 has shown that:

2. The coloured label used to display the DMAN information of departure is very satisfactory for ATCOs. However, the coloured scheme proposed during RTS2 was considered inadequate. The appropriate colour scheme to display such information seems to be:
   - Green, when the ATCO can provide the DCL (i.e. TSAT minus 10 min in CDG)
   - Orange, when the flight can reach its slot if given priority during taxi
   - Red, when the flight is late and has to file a new flight plan.
3. The two-bay main window (with pending and waiting flights) as much as the activated and de-icing[7] tabs were considered very satisfactory by ATCOs. The MOBT sorting proposed on the main window was considered useful but would need to be improved since the permanent update of the sequence by the DMAN leads to a permanent update of the MOBT. This problem is solved on the future operational display by using TSAT sorting. The alphanumerical sorting was considered useful by ATCOs especially at pilot R/T contact when traffic is heavy.
4. Slot time and TSAT should be accessible to controllers at a glance. The HMI presented to them in RTS2 required that they open the activation window to access such information. ATCOs considered the information important enough to be displayed directly on the Dynamic Flight Plan (DYP), i.e. the electronic representation of the flight plan on the HMI.
5. Regulated flights should be clearly highlighted on the HMI. The highlighting proposed and developed in the HMI was not assessed during trials, since the CFMU was not simulated. The solution proposed was shown to ATCOs and was considered satisfactory.

Although satisfied with the DMAN information provided regarding departure clearances, ATCOs proposed improvements regarding different aspects of the sequencing, such as:

- Information on traffic load (number or flights or waiting time at runway threshold for instance) for the next half hour should be given.
- Up-to-date information about flights having complied with their slots should be given.
- A what-if functionality should be provided that could help the controller see what happens if he does not exactly follow the DMAN sequence. In case a pilot is ready for start-up, the controller could see whether the aircraft could be authorised for start-up or if it would interfere with the sequence.
- Regarding waiting aircraft (when pilots called too early regarding their MOBT and are put in a waiting list by CLD), the controller should be able to enter information on the underlying cause of the delay (local management, technical problem etc.).

The GND control HMI (VigieStrips) was slightly updated to broadcast DMAN information to the GND controller. RTS2 showed that:

6. Slots alerts should be displayed on the GND HMI and should be calculated as such (for CDG): ahead of slot before <u>slot time – (5 min + 2 min take-off)</u> and behind slot after <u>slot time + 10 min</u>.
7. TSAT should be permanently displayed and updated before push-back on the GND control HMI in order to verify that the aircraft is calling on time.
8. Ground sequencing information (taxiing time, holding time etc.) would be useful to the GND controller. According to ATCOs, it would be very useful in case of re-routing or when deciding to give priorities to certain flights. This functionality was not implemented in the GND HMI and, thus, was not tested in EMMA2.

Apart from the DMAN information presented to ATCOs, the DMAN information circulation was assessed in RTS2. It was shown that:

9. Alerting the CLD controller of a late push-back[8] was considered useful by ATCOs. However, the implementation (i.e. clearance input from the GND controller) was found irrelevant since time may pass between the clearance and the actual movement and it may also happen that the GND

[7] The de-icing tab was shown to ATCOs but not used during the trials.
[8] Late push-back means that the aircraft was cleared for departure and did not leave its gate after a given amount of time.

controller provides the push-back clearance without making the required system input. The use of radar detection or the manual input by a ground operator (accessed via CDM) would be more suitable.

10. R/T communication and workload were not improved when using DMAN information via DIGISCUS and VigieStrips. According to ATCOs, the calls made were as long as (if not longer than) they currently are. This can be explained by a higher quantity of information processed, but also by the fact that the simulator did not allow simulating data link DCL.
11. ATCOs have estimated that the DMAN interoperability with A-SMGCS is promising and could have been pushed a step ahead, for instance by updating the MOBT of the activated aircraft with late push-back information that can be taken into account for the MOBT calculation of the pending flights such as to improve the reliability of the departure sequence..

Toulouse On-site Platform Results

In the framework of the EMMA2 project, DMAN interoperability trials were performed in the Toulouse Blagnac test room in October and November 2008. The trials were performed with alternatively one or two ATCOs managing both GND and CLD positions.
The Departure Management System installed at the Toulouse test site provided the following services:

- Allocation of a holding point / runway / SID for each departure flight of the managed airport according to a given departure strategy and the TMA configuration.
- Computation of the departure sequence, from the block to the runways of the managed airport.
- Providing other ATC systems with departure information to assist the Delivery Position (CLD) in issuing departure and start-up clearances according to the departure capacity of the airport.

Departure managers try to balance departures in order to maintain a given traffic load at the runway. Even if the DMAN is not considered an A-SMGCS tool itself, such a tool requires to be integrated in an A-SMGCS environment.
The interoperability of DMAN with A-SMGCS was assessed through the development and integration of an advanced CLD HMI designed to support controllers in scheduling departing flights (Figure 3-7). During the process of tuning the DMAN, it appeared that, even though departure peaks are rather low in Toulouse-Blagnac when compared with other airports having the same amount of traffic, DMAN sequencing would still be beneficial.

A simplified DMAN, merely sorting departures without changing the traffic load at the runway, was thus installed and connected to the new CLD HMI. Trial controllers assessed both the Toulouse implementation (on site) and a CDG implementation for advanced functions (demonstrator).

1. For what they have tested, ATCOs considered that the tool proved to be useful and usable.
2. The HMIs proposed, especially the CDG enhanced version including CDM, were considered relevant by ATCOs. They said that such a system would allow for a more efficient traffic management, improve situational awareness and help improve capacity.
3. By postponing start-up times and reducing taxiing and holding times, ATCOs felt that such a tool could reduce pollution.

The improvements could not be measured. Long-term trials would be required.

When asked about other possible enablers for better departure management ATCOs mentioned the following:

4. Although considered useful, there might be no need for a dedicated CLD HMI. Most information could be included in the GND electronic flight strip system itself.[9]
5. ATCOs found the concept of interoperability very satisfactory in terms of integration of different sources of information and display of the relevant information, in particular the display of an off-block time computed with flight plan and surveillance information. They missed the use of a more

[9] In Toulouse-Blagnac, the same ATCO acts as the ground and clearance delivery controller.

collaborative scheduling of the departures: information related to departures would not only come from the A-SMGCS (detection of push-back and taxi) but also from other airport stakeholders for a better planning (as in a CDM environment).

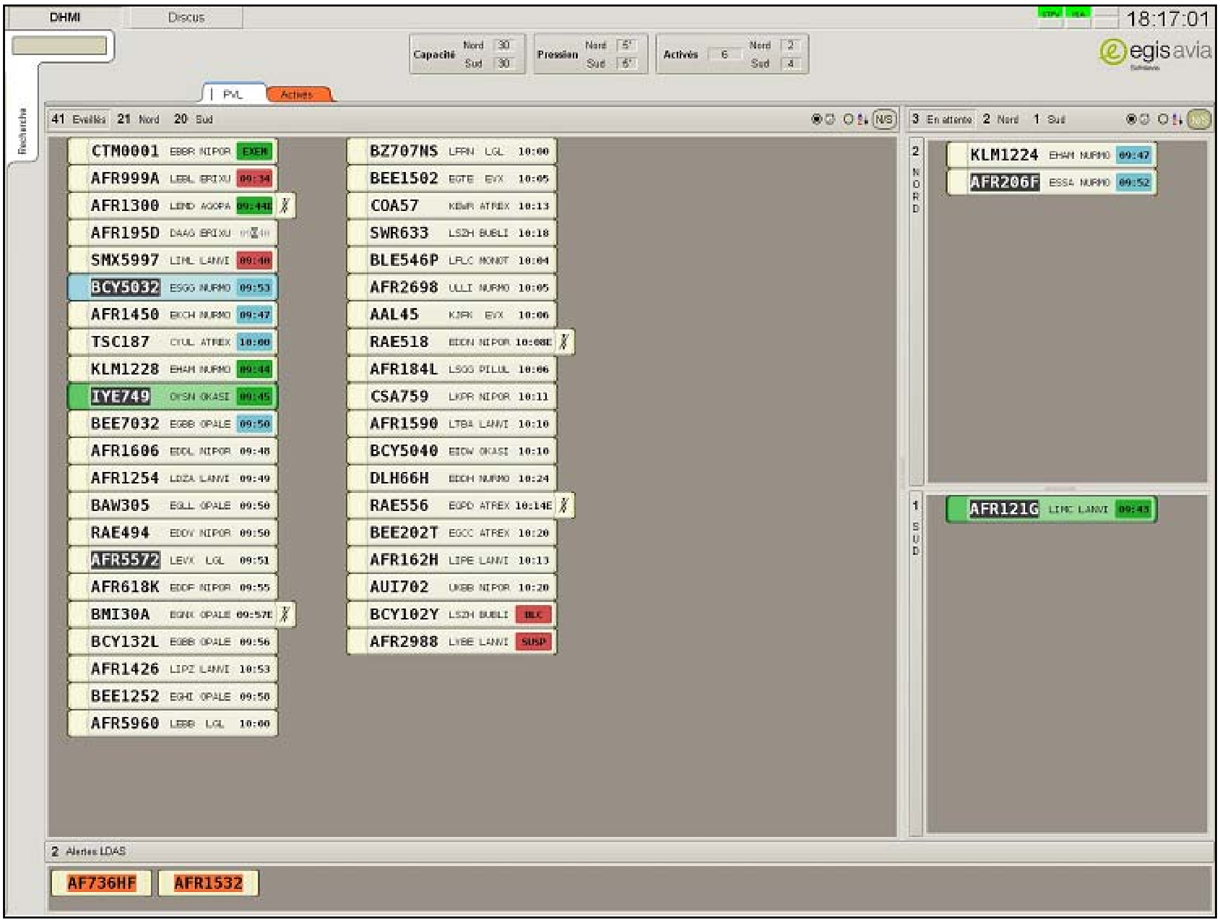

Figure 3-7: Clearance Delivery Control Position HMI at Toulouse Test Site

3.4 Guidance

The following guidance system components were proposed in the EMMA2 SPOR (see also Ref. [9]) for a fully-fledged A-SMGCS:

- Segmented switchable centre line lights (see ICAO Annex 14 in Ref. [23])
- Stop bars (interlocked with centre line lights)
- Appropriately designed lighting control system (actuation/feedback in 2s, reversion in 0.5s)
- Appropriately designed lighting monitoring system (including automatic fallback)
- Integrated controller HMI for implementing ground or onboard guidance means
- Route uplink by data link (e.g. TAXI-CPDLC)

Signs or lighting systems, however, were not part of the EMMA2 assessments. Thus, only route uplink via data link was considered.

3.4.1 Route Uplink

This concerns the results of data link uplink of route information and display of such a route. Such communication was part of the TAXI-CPDLC activities as described in Chapters 3.2.3 and 4.5.

4 Analysis and Description of Services to Flight Crews

The A-SMGCS onboard services provide additional information, such as own-ship position and traffic and guidance information, to flight crews with the aim to increase their situational awareness and improve the efficiency of surface operations.

In a nutshell, the A-SMGCS services to flight crews proposed in the EMMA2 SPOR (see Ref. [9]) for a fully-fledged A-SMGCS were:

- Airport Moving Map (the research version is called Integrated Moving Map)
- Surface Movement Alerting (onboard)
- Ground Traffic Display
- Traffic Conflict Detection (onboard)
- TAXI-CPDLC (onboard)
- Braking and Steering Cues
- Head-up Display with Surface Guidance System
- Ground-to-Air Database Upload

EMMA2 in particular did not look at Braking and Steering Cues in any of the assessments.

4.1 Airport Moving Map (Integrated Moving Map)

THALES Avionics Flight Simulator Results

Detailed results of the evaluation of a research type of an Airport Moving Map, also referred to as Integrated Moving Map (IMM), at the Toulouse test site are presented in the following. The evaluated IMM was displayed on a wide screen (13 by 8 inches). It included additional components for taxi route display, ground traffic display, and an indication for being on the runway. The moving map was connected to the HUD display hosting the SGS function (see also Chapter 4.6). The input device was a Cursor Control Display. Pilots gave their opinion on different feasibility and performance aspects (see Figure 4-1).

Situation Awareness:
All pilots strongly agreed that IMM improves situational awareness and ground navigation whatever weather conditions.

The IMM with taxi route and ground traffic display system was highly appreciated by pilots because it provides:

- An intuitive representation of the global airport structure
- A good perception of the own-ship current positioning on the airport surface with a global and local view according to the scale level selected
- An efficient navigation help allowing pilots to locate their next clearance, their destination or the composition of the future expected routing
- A good way to locate more easily other mobiles referred to in ATC communication

Incontestably, all this information increases the situational awareness of the pilot. Common navigation errors, such as runway incursions or taxiing errors on a complicated taxiway structure could be avoided and the safety of the taxi operations would increase.

Performance:
It was observed that the taxi preparation phase is simplified because the global and local situation is much easier to understand. Indeed, with the different map ranges and modes, pilots obtain global navigation information about the destination of the taxiing operation (gate, parking area or runway

threshold), which reduces the number of taxi route errors. The system also gives an overview of the route to follow to reach the destination.
According to the pilots, the system also simplifies the navigation task on the airport during taxiing by providing information on the immediate environment around the aircraft (connected taxiways, next intersections, turns etc.). However, in particular situations (large aircraft and complex intersection configurations), the correlation between the location of the aircraft on the map and the outside view may be difficult.
Some pilots thought that the taxiing duration would be decreased because the IMM improves the ability to anticipate situations, which reduces doubts and increases the feeling of security. Moreover, the situational awareness provided by the IMM would allow pilots to optimise taxiing and thus to reduce petrol consumption and the number of intermediate stops. However, taking into account the current ranges available in the IMM implementation and the lack of accuracy provided by present positioning systems, pilots thought that the IMM could not improve the precision of the route followed.

Workload:
Due to the simplification of the briefing and the taxiing phases mentioned above, the complete navigation task is facilitated. Moreover, pilots did not complain about the workload introduced for handling the IMM. Furthermore, some pilots said that the IMM handling is more comfortable than the use of a paper map.

Usability:
Most pilots found that the location of the IMM in a central display unit (usually dedicated to the Navigation Display) is very suitable as compared to a paper or an electronic map located on the side of the cockpit. Moreover, pilots thought that the information displayed on the IMM is sufficient and not too dense. Thus, the IMM does not reduce the legibility of the map, which is an essential operational need.
Opinions about the input device for the IMM were divided among pilots. Some thought that a dedicated device like a Cockpit Control Display (CCD) is efficient because every command is at hand. Others preferred the reuse of existing control panels like the Flight Control Unit (FCU), for instance to set the range of the map.
In order to prepare the taxi route and check clearances, the IMM PLAN mode was considered well adapted because the mode is similar to the handling of paper maps. In this mode, different ranges can be used to obtain a global impression of the route or concentrate on a detailed part of the airport (e.g. a complex intersection).
During taxiing, the PF would set an ARC mode with a small range (0.1 NM to 0.5 NM) as he performs tactical navigation tasks that require a detailed view of the immediate situation around the aircraft. The display of ground speed on the IMM was appreciated, especially if it is not indicated anywhere else in the cockpit. This is the case if the IMM replaces a classical Navigation Display. Concerning the aircraft symbol, some pilots suggested that it would be better to have a layout that is consistent with other displays and instruments, in particular the Navigation Display in terms of colour, shape and reference position.

Crew Task Sharing:
Due to task sharing and cross-checking between Pilot Flying (PF) and Pilot Not Flying (PNF), the IMM displays should be available on both sides of the cockpit. However, these two displays should be adaptable to the pilot needs (different formats, different values for scale and range defaults etc.). While the PF prefers a full-screen map of the airport being well adapted to the taxiing operation, the PNF prefers a screen that is split into the electronic map display and a permanent window dedicated to ATC radio and/or data link communication, as the PNF is in charge of this task.
Furthermore, most of the time, the PF needs small ranges for tactical navigation (short-term view) and the PNF needs larger ranges for strategic navigation (middle and long-term view).

In summary, the following recommendations were given as a result of the Operational Improvement Tests:

- The displayed aircraft symbol should be relatively bigger than or equal to the real aircraft size to ensure that the pilot keeps a secure distance to obstacles (vehicles, etc.).
- The displayed aircraft symbol should take into account the evaluated positioning precision for safety reasons.
- The ground speed should be displayed on the IMM if it is not indicated anywhere else.
- The display of the wind direction would be useful.
- The PF and the PNF should have their own IMM display with a custom configuration (for range, mode etc.).
- The IMM should be displayed on a screen close to the windshield to facilitate consultation.
- Aircraft symbols in the IMM should be consistent with aircraft symbols in other cockpit instruments (e.g. Navigation Display) in terms of colour, shape and reference point to avoid any confusion.
- The colours used for the map elements should be unsaturated to obtain a better visibility of the symbolic elements pictured on top of the map.
- The PF should interact with the IMM only when the aircraft does not move. The PNF might need access to the IMM of the PF to change parameters (e.g. range and mode) when the PF is taxiing and when asked to do so.

Figure 4-1: THALES Cockpit Simulator with IMM Display and HUD

4.2 Surface Movement Alerting Function

TU Darmstadt Flight Simulator and TUD Test Van (FAV Test Aircraft) Results

The Surface Movement Alerting function was successfully validated through real-time simulation tests as well as on-site trials in Prague.

The main purpose of the SMA function is the avoidance of runway incursions by preventing the own aircraft, through timely alerts, from entering, crossing, taking off from or landing on runways without a corresponding clearance or closed runways. The SMA function can be used in two modes. When CPDLC functionality is not available, the function uses only D-ATIS/NOTAM information (see Chapter 4.7) on closed or partially closed runways. In case CPDLC is available, the function uses clearance information to enable a more precise alerting scheme.

The alerting concept, that consisted of visual indications on the EMM, textual information on the PFD, and an audible alert, was well received and accepted by the pilots. Pilots considered the generated alerts as operationally relevant and added that they were necessary in spite of an already increased situational awareness provided by the EMM enhanced with the display of electronic Pre-flight Information Bulletin through the Ground-Air Database Upload function.

The SMA function uses the speed, heading and acceleration information of own-ship to detect the right moment to alert the pilot. The timing of the alert must be early enough to enable the pilot to correct the course, but should also prevent nuisance alerts. In both the real-time simulations and the on-site trials, the timing of the alerts was accepted by the pilots.

Pilots agreed that the alerts generated by the SMA are operationally relevant. The pilots added that even though situational awareness is already improved by the Electronic Moving Map (EMM) and the display of the electronic Pre-Flight Information Bulletin data on the EMM (see Ground-to-Air Database Upload) all the alerts covered by the SMA are still needed.

4.3 Ground Traffic Display Function

DLR Flight Simulator and DLR ATTAS Results

Real-time Simulations:
The cockpit simulator was integrated into a highly sophisticated simulation environment at DLR Braunschweig, which simulated Prague ground traffic and included a Tower Simulator with three controller working positions. ATCOs from ANS-CR handled 52 movements per hour. The movements were operated by pseudo-pilots and included the cockpit simulator, which appeared as a normal flight in the ATCOs' tower simulation. The complete surrounding traffic was shown on the pilots' Electronic Moving Map (EMM) in the cockpit. Even though the traffic information accuracy could only be simulated, important feedback could be gained in terms of operational feasibility with regard to human-machine interactions.

It was proven that the GTD HMI design fits the pilot needs and that it works reliably in an intuitive and interactive way. In general the GTD was accepted by the pilots while they stressed, as expected by the validation team, that the outside view through the cockpit windows remains their main source of information.

In terms of usability, pilots agreed that the GTD is very easy to use without inconsistency. They reported that they did not need to learn a lot before they could use the GTD properly. The very intuitive approach of the GTD was appreciated and highlighted by comments in the debriefing sessions (see Ref. [21]).

With the addition of displayed traffic, the onboard display provided pilots with a complete airport traffic situation, allowing a rapid situation assessment. They agreed that it is easier to locate and identify aircraft when using the GTD.

Furthermore, the GTD allowed pilots to utilise the display capabilities (e.g. range scale selection, brightness, and map overlays). This was realised in the DLR setup by soft buttons keys on the display and the mode and range selector in at the EFIS. In the TUD setup, this was realized by overhead buttons as well as the mode and range selector in at the EFIS.

The different modes (PLAN, ARC and NAV[10]) and the zoom functionality of both the DLR and the TUD displays were highly appreciated and considered intuitive to use.

According to pilot feedback, the GTD maintains a balance between human and machine tasks. It permitted them to retain the power to make decisions for those functions for which they were responsible.

In the debriefing sessions, pilots reported that the head-down times when using the GTD display (located on the navigation display) were acceptable.

On-site Trials:
During the on-site trials at Prague Airport the transmitted traffic information (TIS-B and/or ADS-B) was displayed on the ATTAS EMM, showing the pilots the surrounding ground traffic (GTD).

The received data quality was checked subjectively when the ATTAS was parking at its stand and also during taxiing. This was done by visual observation comparing the displayed traffic and the real outside traffic as well as by checking whether the targets were displayed on the yellow centre lines shown on the EMM, as pilots normally taxi relatively precisely along the centre lines.

The testing of the GTD function had to be performed under certain limitations:

- Due to safety constraints, the implementation of TIS-B as the technical enabler to make the ground traffic situation available on board provided coverage only for the northern part of the airfield (see Chapter 3.1.1).
- In order to overcome the jumping targets problem (see also Chapter 3.1.1), the Mode S addresses in the transmitted TIS-B target reports had to be replaced by dummy addresses. Thus, the MLAT system would not detect the same target both at its actual position and at the TIS-B transmitter antenna position.
- Due to safety reasons and in order to avoid any obstruction to the normal traffic flow, the test aircraft ATTAS had to perform ground movements only during periods of low traffic density and at certain airfield and apron areas. Thus, it was not possible to show a complete coverage of the GTD functionality for the whole airfield area and also not in high traffic density scenarios.

The pilots gave the accuracy of the GTD a high rating. The accuracy of the GTD was rated by the pilots as very good, which means that the displayed traffic situation as well as the target positions and movements matched the reality observed through the cabin windows.

However, a closer inspection of the TIS-B onboard receiver output data revealed, that apart from the position data, some other data in the TIS-B reports was missing either completely or only in some target reports.

[10] PLAN means North-up, ARC means Heading-up, and the NAV mode is a 3D exocentric view.

Altogether it should be stated that a complete technical verification of whether TIS-B meets the A-SMGCS performance requirements has to be done yet, and will require considerable effort. It should also be mentioned that onboard related operational requirements for the display of ground traffic do not exist as yet.

In conclusion, operational feasibility of the GTD was proven subjectively in simulation and in on-site trials and revealed that TIS-B would be a promising candidate to transfer the ground traffic situation on board. As the TIS-B information is based on the same data which is presented to the controller, the GTD provides consistent traffic situational awareness both on board and on the ground.

Figure 4-2: ATTAS EMM Showing Own Position (Magenta) and Surrounding Traffic

THALES Avionics Flight Simulator Results

Simulation Environment:
An important aspect of displaying ground traffic on the moving map is the precision of the traffic position. In order to get to meaningful results in a simulated environment, it has to be assumed that the necessary precision is reached. No additional tests on ADS-B and TIS-B data quality were carried out. Therefore, simulations including error models for accuracy, latency, and integrity with specific scenarios would still need to be performed to ensure the necessary precision.
For the scope of EMMA2, all pilots taking part in the simulations considered the simulation environment realistic. Moreover, different weather conditions (fog thickness variation) were tested to take into account the pilots' behaviour in different realistic weather conditions. Night conditions were not tested.

- There were between 7 and 10 aircraft moving on the whole airport during the simulation. For all pilots, this traffic density was not realistic enough to be representative of a real situation. However, traffic was simulated for the specific purpose of each scenario. The scenarios were developed in such a way that aircraft would cross the way of the own-ship route and generate conflict situations. In the scenarios, traffic density was judged light but realistic around the own-ship route.
- The dialog between ATC and other aircraft was not simulated, thus the pilot did not hear other ATC VHF calls than those addressed to him.
- The usage of TCAS on ground was not evaluated, but a majority of pilots noticed that it was missing.
- The flying traffic was not simulated: landing aircraft, aircraft in take-off, etc. For many pilots, this point is an important part of the surveillance activity.
- Non co-operative traffic or parked aircraft were not simulated.

In summary, the following recommendations were given regarding improvement of simulation environment:
- Each aircraft should display a realistic behaviour (regarding trajectory, speed, heading, etc.).
- The simulation environment should be compliant with the traffic conditions (the traffic should be displayed on the screens for outside view).
- According to the pilots participating in the tests, communication between ATC and other traffic should be simulated (full ATC communication).
- A realistic traffic density should be simulated (Non co-operative aircraft, parked aircraft, approaching aircraft, etc.).
- A TCAS system should be available during simulation to account for the current usage of the system.

Traffic Symbols:
- Interpretation of Symbols
  During the evaluations, none of the pilots was confused about the localisation of aircraft. The symbols seemed well adapted to the operational need. Indeed, the symbols were well interpreted as other aircraft by all the pilots. Moreover, the displayed arrow and the symbol orientation gave a good idea of the aircraft heading and were well interpreted without any explanation on this point. However, a majority of pilots expressed the need to highlight dangerous traffic.
- Runway Occupancy
  The display of a cross and an arrow were especially appreciated when the own-ship was on the runway and wanted to understand the behaviour of traffic in proximity of the runway. Some pilots asked for and would like to have graphical information about runway occupancy.
- GPS Positioning Accuracy
  Since the traffic position is usually defined by on-board GPS data, the accuracy of the aircraft locations is not good enough to allow the pilots to compute the exact separation distance between their own aircraft and a conflicting mobile. In order to avoid problems concerning this lack of accuracy, it is therefore essential not to draw the traffic in a real size scale. All participating pilots thought that it was essential to represent them bigger than in reality to avoid collision risks. It was found that, in spite of such an extended symbol, the legibility of the map was not reduced.

Traffic Filtering:
- Filtering Rules
  Pilots were interviewed regarding the display of the entire traffic on the map. They believed that it is not necessary to show all the mobiles because it is essential not to display useless information. The mobiles that should be displayed are:
  - The mobiles behind the own–ship position,

   - The mobiles in front of the aircraft but located behind a certain safety distance (this distance depends on the own-ship location: taxiway or runway),
   - The mobiles parked,
   - The aircraft in approach (TCAS allows to locate them) and
   - The vehicles that do not have priority on aircraft (the FLYCO and the emergency vehicles should be displayed).

  However, one of the pilots said that all the traffic on the runway should be displayed (aircraft and vehicles).
- Responsibilities
  One pilot noticed that pilots must be informed that the non co-operative aircraft are not displayed on the map. He insisted on the fact that this traffic display system must be considered as an assistance tool and not as primary means of navigation. For him, in the worst case, if a non co-operative mobile comes into conflict with the own ship, the control tower is in charge of traffic safety and will warn the own ship of the potential danger. It was noticed that pilots do not want to be responsible of traffic management even with the traffic display system on board. Indeed, at present this task is dedicated to the controllers.

Traffic Information:
- Required traffic information
  The majority of pilots said that specific traffic information is useful. In particular, ground speed and aircraft type need to be displayed to give pilots an idea of the aircraft wingspan and behaviour and to anticipate possible conflicts. Some of the pilots said that when they follow another aircraft they also need information about the distance between them and the other aircraft. All the pilots said that they prefer to get the traffic ATC call sign for identification instead of the registration number, particularly for the purpose of understanding radio communication (e.g. when the tower gives clearances to other traffic). The ATC call sign is also useful to contact other traffic.
- Operational need
  Moreover, in operational situations, the pilot can have a look at the map to prepare his future taxiing phase when he is stopped or when he is on a straight route. Usually, the pilot not flying (PNF) is in charge of observing other traffic. This is why the PNF should be able to get traffic information.
- Traffic display system interactions
  It was not considered a burden for pilots to obtain information by clicking on the traffic symbol. For selecting traffic information, pilots used the Cursor Control Display (CCD) device. Generally, all the pilots succeeded to interact efficiently with the system even if it took them some time to adapt.

In summary, the following recommendations were given regarding the improvement of system design and feasibility tests:
- The colours and shapes should be chosen in such a way that they cannot be confused with other map items.
- The heading and the immobility information of the aircraft should be displayed.
- The runway occupation should be represented.
- The traffic filtering should be compliant with operational needs and not saturate the map display. Remark: Filtering can depend on the taxiing phase (on the runway, stopped to prepare the taxiing phase etc.).
- Traffic information should be available for all the traffic displayed on the map.
- The ground speed, the type of aircraft and the ATC call sign should be provided as well as the distance between the own-ship and the followed aircraft.
- The displayed traffic symbols should be bigger than or equal to the real traffic size to prevent that pilots are using the system to interpret the distance between aircraft and traffic.

- The displayed traffic symbols should take into account the evaluated positioning precision (for safety reasons).
- A mere traffic display is not sufficient. The conflicting traffic should be highlighted on the map.
- It could be interesting to assess the system with the application of an error model simulating the real GPS use.
- The controllers should keep their responsibility concerning traffic separation.

Situational Awareness:
The pilots obtain a global traffic situation during several phases:
- To prepare the taxiing phase the pilots look at the IMM to anticipate the traffic load,
- Before taking a new taxiway, runway or entering a stand, the pilots can check whether it is free/unoccupied or not,
- When pilots are informed that traffic is next to them, they look at the IMM for confirmation and to obtain more precise information.

Moreover, they can obtain more accurate information about any mobile displayed on the map, like the heading, the speed, the aircraft type and the ATC call sign. This situational awareness allows to comprehend the traffic density and the dangerous areas, to check and anticipate the ATC instructions and thus, to increase the safety on board. It was noticed that most of the pilots would like to receive the routing information of other traffic to obtain a more accurate situational awareness.

Efficiency:
- Quick danger anticipation
  The traffic displayed on the map, allows pilots to anticipate potential conflicting situations more rapidly. For instance, pilots can foresee occupancy of runways and taxiways or they can quickly look in the right direction to observe dangerous mobiles in the vicinity. In this way, it would be interesting to display potentially dangerous traffic with a specific colour or shape. This prediction seems to decrease the collision risks. Furthermore, the level of stress and the workload seems to decrease so that safety increases. However, more specific studies should be performed to confirm this point.
- Information accessibility
  In order to better anticipate a potential danger, pilots need to quickly obtain information about the source of the danger (vehicle or aircraft). It was found that the information being supplied to pilots was sufficient and easily accessible.
- Map legibility
  In spite of all the information displayed on the map, it was found that its legibility was not degraded.
- Taxiing efficiency
  Analysing the pilots' behaviour during the assessments, it was also observed that the taxiing efficiency is not disturbed by the traffic display system interactions.

In summary, the following recommendations for designing operational improvement tests were given:
- There should be an option to display the traffic routing on the map (either by selection of traffic or automatically for conflicting traffic).
- The conflicting traffic should be highlighted.

4.4 Traffic Conflict Detection Function

<u>TU Darmstadt Flight Simulator and TUD Test Van (FAV Test Aircraft) Results</u>

The Traffic Conflict Detection (TCD) function was successfully validated in real-time simulation and in on-site trials at Prague.

The main purpose of the Traffic Conflict Detection function is the avoidance of runway incursions by providing timely alerts if other aircraft infringe the protection zone of a runway that is used or has been cleared for own-ship operations. The Traffic Conflict Detection function also provides alerts for potential conflicts with other aircraft on the taxiways. A prerequisite for the function is the display of ground traffic on the EMM.

Pilots agreed that the presented function could be used appropriately in the surface movement area. Both the Traffic Conflict Detection alerts on the taxiways and on the runways were accepted by the pilots, though the operational relevance of the alerting on the taxiways was deemed lower than the alerting on runways.

The visual warnings with different colour codes for level 1, level 2 (master caution) and level 3 (master warning) presented on the EMM and on the PFD as well as audible warnings would attract the pilots' attention in case of conflicts. Pilots considered the chosen HMI for the alerting intuitive, easy to interpret and acceptable.

As for the Surface Movement Alerting function, the right timing of the alerts is essential for the acceptance of the pilots. Concerning reactive runway incursion alerts, the timing was generally accepted by the crews. For the traffic alerts on the taxiway, a fine-tuning of the function is still needed to prevent some nuisance alerts.

During the on-site trials it was noted that the quality of the available ADS-B traffic data in Prague was too poor for the conflict detection function on the taxiways, mainly because of the latency for slow vehicles and aircraft. It is assumed, that this is linked to the reduced squitter rate of Mode S transponders when the mobile is stationary or moving very slowly and the associated delay in switching between squitter rates. In this condition, only the runway related functions are assumed to be relevant, where the take-off and landing speeds are sufficiently high not to trigger the reduced squitter rate.

4.5 TAXI-CPDLC

DLR Flight Simulator and DLR ATTAS Results

Pilot feedback for requesting and receiving clearances by TAXI-CPDLC for start-up, push-back, taxi-in, and taxi-out operations was predominantly positive. It must be distinguished clearly between the positively rated graphical information on the EMM display and the rating of the usability of the Cockpit Display of Traffic Information (CDTI), which was used for selecting and sending CPDLC messages and for the textual display of received clearances.

The pilots stated that the EMM display provided them with a very effective human-machine interface to operate a data link communication with ATC. Nevertheless, the CDTI input device needs important upgrades if a further use of the CDTI is foreseen in simulation and flight trials.

Pilots highly appreciated and trusted the displayed taxi routes and the clearances. The visualisation of taxi routes on the EMM was appealing to them. Especially the exocentric perspective view was used by the PNF to obtain advance information during taxiing. Pilots responded that they would like to use the TAXI-CPDLC in the future and that they agree with the EMMA2 concept definition and implementation. They agreed that the used terminology and symbology to represent a taxi route were easy to interpret. Paper charts were only retained as a back-up, as expected.

Regarding the preliminary taxi route information, pilots were not convinced of its usefulness. In the simulation trials, such preliminary information was always given before the departure clearance for outbound flights and before the outer marker for inbound flights. However, for nearly 50% of the flights the actual clearance given deviated from the preliminary taxi route information. This was done to get the pilots' attitude on whether they find such preliminary information useful even if it deviates from the actual clearance. Pilots agreed that a preliminary taxi route could bring additional operational improvements as long as the information is reliable enough, i.e. the preliminary taxi route information must be identical to the actual clearance in most cases. Otherwise, it would be useless spending mental effort on information that is not valid anymore a few minutes later.

Some of the proposed procedures were perceived as being clumsy. For example, pilots recommend that the CDD should issue departure clearance, start-up and change to ground frequency in one step, when the situation allows it.

Pilots appreciated the initial voice call at the beginning of each TAXI-CPDLC dialogue at each new ATC position, which established R/T as back-up.
In the trials, the safety critical crossing clearance was performed by voice communication. This led to the situation that the pilots in the cockpit had to switch off the red crossbar (received from the ground controller as the clearance limit) on their EMM. This procedure was criticised by the pilots. They agreed that this task must be performed by an ATCO. Further testing of adapted procedures would be needed, e.g. giving the crossing clearance by TAXI-CPDLC, or by a voice clearance combined with an automatic deletion of the displayed stop bar by the ATCO. This could be realised by the ATCO pressing a "crossing clearance" button on the EFS.

Figure 4-3: DLR Generic Experimental Cockpit (GECO)

Airbus A320 Cockpit Integration Simulator Results

Several series of trials were performed on the Airbus cockpit integration simulator:
“Internal” trials involved a “pseudo-controller” position (connected to the cockpit simulator via the real ATN network).
The last trials were done with a connection to the Toulouse-Blagnac control tower and DSNA controllers using the TATM (TR6) HMI test system. The outcome of these shared trials and debriefings with pilots and controllers is presented in Chapter 3.2.3.

The “internal” trials enabled the testing of scenarios on the complex Paris CDG Airport surface, with nominal traffic surrounding the own-ship position and under various visibility conditions. The scope of these trials included:

- All functions tested or discussed further with Toulouse-Blagnac Control Tower:
  - Mixed mode voice/data link: how to switch, data link use limits, etc.
  - Procedure for taxi-out and in taxi-in (based on ground forwarding between ACCs or the SWIM concept): data to be exchanged, phraseology, best timing, etc.

- Taxi timing and smoothing of the taxi flow
- Expected routing for taxi-out and taxi-in
- Clearances in the runway area (crossing and line-up)
- On-board HMIs
- Several additional data link messages, such as messages related to switching from data link to voice
- Appropriateness of operational timers (time-outs)
- Performance of ATN communication (with a low number of users on the network)

Additional outcome mostly concerning the on-board part is presented below:

- Mixed mode communication was considered difficult but was not seen as a “show-stopper”: procedures should be defined appropriately.

  For instance, the use of the CPDLC revised taxi route was considered as being suitably integrated into TAXI-CPDLC services. This would, however, concern only long-term revisions, whereas short-term revisions should be handled by voice (Remark: the use of the CPDLC revised taxi route was considered to be independent of the traffic situation).

- Taxi time could be significantly reduced (smoother taxi flows in low visibility conditions, less stops, no excess speeds). This would help to overcome traffic congestion and provide operational cost reductions (fuel consumption reduction, flight durations shortened, delays avoided).

  The greatest benefit is expected for taxi clearances. Start-up and push back services should be taken into account to ensure a global and integrated service for CPDLC use on ground.

- Expected routing information would be helpful both for taxi-out and taxi-in, if timely and stable: Pilots appreciated the EXPECT ROUTING information message provided before the first taxi clearance, because it enabled them to prepare the taxiing.

  The EXPECT ROUTING information for taxi-out should be delivered together with the departure clearance.
  For taxi-in, it should be delivered before the final approach phase, once the runway exit is defined using systems such as Brake-to-Vacate.

- Clearances in the runway area are not expected to be achieved in the first step, but it seems necessary to consider them on a long-term basis (especially for runway crossing, see Chapter 3.2.3).

  In Toulouse, when a runway was to be crossed, the following phraseology was used: "TAXI TO HOLDING POINT M8 RWY 14R VIA TWY T40 P40-P70 N8 HOLD SHORT OF RWY 14L". A suitable procedure could be, in a first step, to use voice for the runway clearance, with the support of the associated data link message, which would only aim at presenting a graphical confirmation of the voice clearance (no pilot acknowledgment required for this message). This proposal could be envisioned for runway crossing, line-up and take-off clearances.

  Thus, for runway crossing, line-up and take-off clearances, route information uploaded by data link should enable moving map update and provide alerting capability without additional workload for pilots (no acknowledgement needed).

- HMIs need refinement, especially in the runway area:
  Cockpit HMIs must be able to cope with operational constraints especially in the runway area (no additional workload, intuitive, etc.).

- Data link messages mostly appeared to be appropriate but needed slight refinement.

- Operational timers (time-outs) need to be defined according to the type of message (tactical or strategic).

  The use of WILCO or ROGER to acknowledge CPDLC messages is mandatory, except in the runway area where additional workload is not acceptable.

  The CPDLC message “UNABLE”, however, does not seem to meet operational needs. Depending on the context, pilots would most likely switch to voice.

  An acoustic signal in addition to a visual signal (as already defined for en-route CPDLC) is appreciated by pilots: it enables them to distinguish the urgency level related to the CPDLC message.
  A visual signal may not be sufficient in the cockpit, e.g. in bright sunlight.

Safety would be increased especially in the runway area by better situational awareness, reduction of misleading information, and the party-line effect.
Taxi routes and traffic flow could become more predictable and facilitate planning.

Some issues need to be addressed in order to enable these new services:
- Integrity of the information is a must: this implies both cockpit and ground systems.
- Databases relevant information for routing should be shared between ground systems and cockpit.
- Deployment on airports should be harmonised in the sense that services should be “clustered”: On-board procedures cannot change drastically from one airport to another (counterpart of the handling of “mixed’ equipped/non-equipped traffic for the controller).
- Ground forwarding/SWIM concept is needed for the taxi-in.
- Further studies should be conducted on the capacity with nominal and high number of users on the network. If risks are identified, means different from CPDLC could be studied in order to be able to cope with network capacity.

Figure 4-4: Outside View of Airbus Cockpit Simulators in Toulouse

Figure 4-5: Inside View of Airbus Cockpit Simulator in Toulouse

4.6 HUD Surface Guidance System Function

THALES Avionics Flight Simulator Results

As part of EMMA2, the HUD Surface Guidance System (SGS) function developed in EMMA was upgraded, meaning that new symbology was developed to present information regarding the Traffic Awareness and Surface Movement Alerting functions on the HUD. THALES Avionics organised evaluations on a cockpit simulator. The following summarises the results.

IMM versus HUD/SGS Services:
The campaign EMMA2 was composed of two sessions of five evaluation days called RTS1 and RTS2. In the second session, the IMM was validated together with the HUD/SGS service.

For the two sessions, all pilots used the IMM to prepare the taxi route and to check ATC messages (expected route and clearance). However, in the second session it was found that, during the taxiing phase, the PF almost never looked down at the IMM as all information concerning the route and the connected taxiways was displayed on the HUD. There were exceptions, though: the IMM was checked when traffic came close to the aircraft and when the next turn was anticipated.

Taxi Route Symbols:
All pilots stated that taxiway borders were important to assess distances and ground speed. Therefore, it should be important to normalise the distances between these borders. In that way, counting the symbols could help estimating distances and speed. Some pilots said that the centreline and the taxiway borders would be sufficient for taxiing small aircraft. Moreover, for safety issues, pilots say that taxiway borders should be inside the real pavement of the taxiway to avoid going off the track.

2D Top Sight View:
Most pilots judged that the 2D view enabled them:
- to have a good overview of the aircraft situation on the taxiway
- to control the location of the landing gear

Guidance Symbol:
All pilots tested several newly designed guidance symbols. They thought that the most efficient is the square with the round aircraft symbol inside. Most of the pilots considered that this guidance symbol is easy to use and to interpret. Moreover, all pilots agreed that this symbol is useful to taxi aircraft and should be present permanently.

Surface Movement Alerting Indication:
All pilots agreed that the message “On Runway” is a very useful piece of information because several accidents were due to runway incursions. However, one pilot pointed out that the message occurs too early some times. Indeed, the last holding line before the runway triggers this message in the system when the aircraft is not yet on the runway.

Situational Awareness:
All pilots agreed that HUD/SGS improves their awareness of the nearby situation by providing the name of the taxiway where the aircraft is, and the connected taxiways. As this information is displayed in a conformal way, they can correlate it with the outside view. This is the reason why HUD/SGS makes the local situational awareness almost independent of visibility conditions. Thus, no pilot was lost on the airfield in scenario four with bad visibility conditions. However, the danger is that obstacles (traffics, roadwork, etc.) are not represented in the conformal view. Indeed, as the taxi route symbol is displayed on top of the external view the pilots could consider that a taxiway is totally free, when in fact it is not.

However, it was observed that every time the pilot needs information about the global situation (to prepare the route, to anticipate the next clearance, and to locate traffic) the IMM remains his preferred medium.

Performance:
According to pilots, the HUD/SGS guidance means provide an easy way to taxi an aircraft regardless of the external conditions. This means:

- Even if the pilot does not know the airport and whatever the complexity of this one
- In fog conditions
- For large aircraft where the pilot location is far away from the wheels.

Moreover, one pilot pointed out that visualising the taxi clearance and, therefore, assessing the remaining distance allows a better control of the speed and the heading due to a better anticipation of the situation.
For these reasons, some pilots thought that the taxi duration could be decreased, particularly in bad visibility conditions. Moreover, this system could allow more types of aircraft to navigate regardless of the weather conditions.

Usability of Taxi Route Symbols:
The representation of the taxi route by a conformal centre line and taxiway borders was very intuitive for all pilots.

Usability of Guidance Symbols:
Pilots felt at ease with the indication hints provided by the guidance symbol. The guidance symbol does not require any particular training. Further, as a result of remarks of first EMMA HUD/SGS evaluations, the filtering was refined and it was observed that pilots do not have any problem to follow the guidance symbol even during turns.
However, it was also observed that introducing anticipation indications in the guidance symbol generates confusion in the pilots' mind. Indeed, they interpreted two different cues (anticipation and guidance) at the same time and they did not know which one they should follow.

The 2D top sight view was very intuitive and easy to handle for all pilots. However, the pilots' opinion was divided concerning the respective role of guidance symbol and 2D top sight view. In most opinions, the 2D sight was complementary with the guidance symbol to allow for accurate tactical navigation particularly in sharp turns. However, one pilot said that, as the guidance cue is sufficient, the 2D top sight view is useless. Finally, it seems that the guidance symbols should be adapted to the aircraft category. For very large aircraft (A380), both guidance means would be useful. For small and medium-sized aircraft (business jet or even A320) the layout of the taxi route (centre line and borders) should be sufficient.

4.7 Ground-Air Database Upload

TU Darmstadt Flight Simulator

On-board aerodrome databases with mapping information, like FMS route and navigation databases must be updated regularly (cyclic updates) to ensure database consistency in case of permanent changes to an airport (e.g. new parking stands, taxiways, runways or altered designations of existing structures). On-board database update and upload concepts and their integration into existing maintenance cycles were simulated in selected scenarios by TU Darmstadt (TUD), Euro Telematik (ETG) and Diehl Aerospace (DAS) in the TUD Fixed-base Research Flight Simulator.

The introduction of the Ground-to-Air Database Upload function into the cockpit to enable the display and the use of the electronic Pre-flight Information Bulletin (ePIB) data in the Surface Movement Area did not lead to any undue increase of workload in critical flight phases.
The pilot interacted with the Ground-Air Database Upload function through the MCDU. The MCDU is a well-known means and pilots are familiar using it. The pilots did not have any problems to interact with the dedicated MCDU Airport Menu to update or load restrictions. Further development could be the introduction of a trackball or computer mouse to interact with the system.
Most of the pilots thought that it was very useful to have information about runway or taxiway restrictions. Also, the presentation of this information was very intuitive because the symbology and the colours used in the Surface Movement Awareness and Alerting System (SMAAS) in the TUD display were well-known and intuitive. One improvement could be to show different statuses for one runway. For example, if construction works are taking place on one half of the runway, this part of the runway could be shown with red crosses signifying that it is “completely closed”, whereas the other half of the runway, that could be crossed without danger, would be shown with white crosses, meaning that it is “closed for landing and take-off”.

5 Analysis and Description of Services to Vehicle Drivers

Services to vehicle drivers that are mentioned in the ICAO A-SMGCS Manual (Ref. [24]) primarily concern the following functionality:

- Provision of information on location and direction at all times
- Indication of the route to be followed
- Guidance along the route being followed or guidance to remain within designated areas
- Information to prevent collision with aircraft, vehicles and known obstacles
- Location of an active runway
- Extent of runway clear zone and graded area and strip
- Extent of navigation aid critical and sensitive areas
- Alert of restricted area intrusions

In addition, drivers of emergency and operational vehicles should be provided with:

- Information to locate the site of an emergency within the displayed range of the system
- Information on special priority routes

In order to achieve this functionality, the EMMA2 SPOR (see also Ref. [9]) suggested the following services for vehicle drivers as part of a fully-fledged A-SMGCS:

- Airport Moving Map
- Surface Movement Alerting (vehicle service)
- Ground Traffic Display
- Traffic Conflict Detection (vehicle service)
- Vehicle Dispatch and Guidance (via data link)

In EMMA2, there was only an assessment of a Vehicle Moving Map. Additional vehicle driver services such as Surface Movement Alerting (SMA), Ground Traffic Display (GTD) and Vehicle Dispatch and Guidance by Data Link, as mentioned in the SPOR (Ref. [9], Section 2.3), were not tested in EMMA2. Aspects of SMA and GTD were incorporated in the system tested in Toulouse (see Section 5.1).

5.1 Vehicle Moving Map Function

DSNA Test Vehicle Results

Vehicle moving map trials were performed at Toulouse-Blagnac Airport in October and November 2008. ATCOs did not participate to the trials, but technical personnel from Toulouse-Blagnac assessed the system provided on the airport surface.

Surveillance of vehicles was tested during EMMA2 with ADS-B. Since every equipped car broadcasts its position (received through GPS), it was proposed to display this position on a moving map in order to enhance the situational awareness of drivers. Besides displaying the vehicle position, the device was meant to trigger an alert when the vehicle infringed a pre-defined restricted area.

The system was tested by technical personnel of Toulouse-Blagnac airport.

1. The system installed demonstrated to work and accommodate every speed and direction necessary for operational use. The alerting system worked effectively and triggered alerts at incursion of a restricted area.

However, the proposed prototype system was not yet considered suitable for operational use, in comparison to available commercial products. The boot time, the map layout and the considerable amount of work required to install it in a car will have to be reconsidered before making it an industrial product.

Two types of drivers were distinguished in the trials: *regular drivers*, who know the airport very well and use cars that are permitted to drive on taxiways and are equipped as such; and *occasional drivers*, who are authorised to drive on the airport but mostly have a dedicated mission (i.e. they do not do this frequently). These two kinds of users proved to have different needs:

2. *Regular drivers* know the airport well. According to them, their need of a moving map display would be in low visibility conditions and they would rely on it only if the surrounding traffic was displayed.
3. *Occasional drivers* would need a moving map display in any visibility condition, but the system would have to be portable and for plug-in use in order to be able to equip all cars equally.

Eventually, it should be noted that the introduction of a vehicle moving map for occasional drivers is supportive but will not improve their knowledge about the airport or its layout.

Figure 5-1: Vehicle Moving Map Installation at Toulouse Test Site

6 Summary and Conclusions of the Analysis

6.1 Comparison and Analysis of Results

In the upcoming sections, each of the A-SMGCS functions tested in EMMA2 will be analysed by either presenting or comparing the results of the verification or validation activity carried out. In that way common results are highlighted. When results turned out to be different or even contradictory, possible reasons for this are elaborated and conclusions are indicated.

Testing of Technical Enablers (ADS-B and TIS-B)
At the two test sites Malpensa and Prague technical ADS-B and TIS-B trials were performed. At the Toulouse site, ATCOs were asked about their operational opinion on the TIS-B service (ADS-B tests were already performed as part of the first phase of EMMA).

Although ADS-B Out transmissions from aircraft and vehicles were successfully received at the Prague and Malpensa test sites and all A-SMGCS interoperability requirements were met, performance requirements for accuracy and timeliness of the information could not be met. According to both sites, the reason for this was that the current 1090 MHz ADS-B standards do not consider A-SMGCS requirements.
One of the A-SMGCS requirements is that the Navigation Accuracy Category of position (NACp) should be 10, which is the highest value and only achievable when the onboard measurement is made using differentially corrected satellite navigation information.
A more serious drawback is that the time of the position measurement is not transmitted with the 1090 MHz Extended Squitter and, moreover, the end-to-end latency is variable and can be as much as three seconds, which is not acceptable for rapidly manoeuvring objects like aircraft and vehicles on the aerodrome surface.
In summary, the Prague test site concluded that ADS-B could only be used for A-SMGCS when the respective standards and requirements for transponders consider the A-SMGCS requirements and when they are strictly followed, especially regarding data quality. For vehicles, the situation was somewhat better at Prague as they were fitted with low-latency technology so that the timeliness issue was less grave. A number of recommendations were made regarding the frequency band, message set, and the antenna design for vehicle squitter beacons.

TIS-B technical tests were performed at the Prague Ruzyně, Toulouse-Blagnac, and Milan Malpensa test sites as well. In Prague the TIS-B Server operated in full surveillance mode broadcasting all targets within the Traffic Information Volume and interoperability requirements were fully met. However, RF coverage volume and latency were deliberately degraded for safety reasons. The Prague tests further revealed a hazard that might occur when the MLAT system is not able to distinguish between ADS-B and TIS-B messages. Cause of the hazard and mitigation of the risk were discussed (use of Mode-S Transponder MOPS in RTCA DO-260A). Finally, it was stated that the TIS-B ground system technology had reached a high level of maturity.
Technical tests with the ATTAS at Prague, Toulouse-Blagnac, and Malpensa confirmed this and additionally showed that TIS-B could also work in gap-filler mode (only ADS-B non-equipped traffic is shown). ATCOs found the service interesting and expected that pilot situational awareness would be enhanced.
Similar results were obtained in Toulouse where controllers had the same expectations regarding pilot situational awareness and safety perception. They would also use the service without change in current procedures for conditional clearances, provided the same information is provided for both controllers and pilots. However, currently ATCOs would not rely on TIS-B alone for separation. Nevertheless, they thought that throughput would be increased due to a better confidence of pilots and workload might even be reduced under low visibility conditions.

Electronic Flight Strips
In the simulations that took place at the Toulouse, Prague and Malpensa test sites, the Electronic Flight Strip (EFS) Systems were used as enabler for a number of different A-SMGCS services.

Especially at the Toulouse and Prague test sites, the EFS was very advanced regarding HMI design and functionality, so that both systems were well accepted by controllers. At the Toulouse site, the EFS HMI itself was not part of any of the evaluations. Prague controllers, however, were questioned about their opinion on the EFS and rated the system as useful and ready for operational implementation. Prague controllers indicated that the design fitted their needs, was able to carry the implemented services for departure management, TAXI-CPDLC, routing and alerting, and was reliable, intuitive and interactive. Operationally, it did not impair a comfortable workload level and had a positive effect on situational awareness.

The Milan Malpensa EFS system was also considered intuitive, i.e. consistent with working procedures, compliant with the needs and easy to use. However, controllers had a number of remarks that would have to be taken into account in upcoming development cycles. These remarks mainly had to do with undo actions, fall-back procedures, recognising system failure states, but also with the HMI itself and the way the active flight strip is marked and the way the strips are sorted. All these comments would require further development loops, as well as verification and further validation activities to improve the system. Nevertheless, ATCOs indicated that they were supported by the EFS regarding prediction of traffic evolution, and planning and organisation of the work. They found the A-SMGCS information provided by the EFS useful. In addition, they did not perceive a decrease of situational awareness or an increase in workload.

Route Conformance Monitoring
Both the Toulouse and Prague test sites used EFS as an enabler for monitoring the conformance of flights with the cleared taxi route. Alerts were given on the traffic situation display (TSD) and on the EFS display in case of route deviations and non-conformances with the clearances given.

For the Toulouse test site, the route conformance monitoring system was considered unusable as it required too many actions from controllers to select and input data on the EFS and the TSD. Furthermore, they considered it not being in line with some of their working methods and the HMI needed further work and attention. Controllers stated that the system inputs should not require more time and attention than a simple radio call.

In Prague, the service was available but not tested operationally, as it was obvious that it would need further tuning and testing in order to minimise nuisance alerts and provide the desired alerts at the right time. Long-time testing and adjustment would be necessary.

Both results show that the route conformance monitoring systems tested were not tuned for the operational environment they were supposed to work in and in their current state would lead to too much workload rather than contributing to safety. Further development loops and longer dedicated test periods would be necessary to bring them closer to implementation.

Surface Conflict Alerting
In EMMA2, two different kinds of Surface Conflict Alerting systems were tested. At the DSNA Athis-Mons site for Charles-de-Gaulle Airport (CDG), an Advanced Runway Safety Net (A-RSN) was developed and integrated, taking into account control instructions that were entered into the system through electronic flight strips. In the NARSIM-Tower validation environment for Milan-Malpensa (MXP), a taxiway conflict alerting tool based on a separation bubble algorithm (warnings and alerts are issued when the virtual safety bubbles around two aircraft touch) was implemented on top of the existing runway incursion safety net.

As both approaches differ in both concept and trigger mechanisms for alerts, they cannot be compared directly. Instead, the focus of the analysis will be laid on the comments received by controllers and the recommendations given for further improvement for each of the systems.

Using the tool for Paris CDG, it was found that conflict detection is anticipated when the system is able to process controller instructions (cf. Section 3.2.2.1 on route conformance). No statements regarding frequencies or differences in detection times were made though.
It should be considered that alerting was mainly depending on the correct input of given controller instructions into the system with the help of EFS. One of the shortcomings of the EFS was the fact that controllers could not implement conditional clearances, meaning that unwanted alerts were triggered due to a lack of clearance information given. Other nuisance issues concerned incoherent display of information on EFS and TSD and conflict situations in which more than two aircraft were involved. Surface conflict detection purely based on clearance information was considered operationally irrelevant as it would not consider any distances between moving objects at all. Additional speed testing around stop bars was considered feasible, but did not lead to significant safety improvements. Further, it was determined that the conventional definition of the Runway Protection Area (RPA), which is in fact a rectangle around the runway, was not sufficient to guarantee the timely triggering of alerts. For the trials, the preferred definition of the RPA was a polygon with side lines linking the actual runway stop bar positions.
As a specific operational issue for CDG, it was found that a different set of alerting rules might be necessary when runways are used in different configurations. Depending on the airport layout and operational rules in use, this might be true for many airports. However, the trials could neither confirm nor reject this assumption.
A major recommendation that was made regarding the implementation of the system was to assess a small number of specific rules at a time, i.e. incrementally and with testing the limited set for several months, rather than trying to validate the whole set of rules available. Priorities for certain rules would need to be defined locally.

The Milan Malpensa SCA (E-SCA) that was tested in the NARSIM-Tower environment was studied as part of a safety assessment. Its basic functionality was already assessed during verification activities in EMMA1 (Ref. [7]).
The safety assessment determined that E-SCA delivered a small positive effect on the safety of two particular conflict scenarios, namely conflicts involving taxiing aircraft and an aircraft in take-off, and conflicts involving taxiing aircraft and landing aircraft. As both scenarios were an actual part of the Runway Incursion Alerting, this result was not entirely surprising; also considering that good visibility conditions were assumed in the tests, which implied that pilots of the involved aircraft and ATCOs were already well capable of detecting and resolving conflicts. To further decrease the risk related to conflicts involving two taxiing aircraft, it was recommended to explore the possibilities of using the crossing conflict detection (CROS) and/or opposite direction conflict detection (ODIR) in good visibility conditions. Both CROS and ODIR were available in E-SCA, but were not part of the EMMA2 operation under investigation.

Thus, as a conclusion for the comparative analysis, it must be stressed that results for SCA at Paris CDG and Milan Malpensa were looked at from different angles, both revealing valuable results. While the Paris CDG experiments focused on tool functionality and performance as well as operational aspects at the runway, the Milan Malpensa exercises looked at detailed safety aspects in the complete manoeuvring area highlighting that most safety benefits are obtained when looking at conflicts involving aircraft on the runway. Both tests showed that the most severe conflicts will occur on the runway, and that the most obvious conflicts caused by non-conformance to clearances also concern issues of aircraft entering the RPA.
As a recommendation, it was suggested to further test SCA on taxiways for crossing conflicts or opposite direction traffic conflicts under good visibility conditions. Operations under low visibility

conditions were not tested. Thus, much more testing will be necessary, particularly under low visibility conditions where most of the benefits are expected.
Furthermore, local particularities, such as operational rules and runway configurations, will play a major role for implementation. The type of conflict detection methods and algorithms used will also have an impact on acceptance, as they might lead to different amounts of alerts that are considered nuisance by controllers. In order to effectively tune the alerting system as a whole, all these issues must be considered, and, as suggested for Paris CDG, incremental introduction of rules will be important to successfully comply with the requirements and gain acceptance among controllers.

TAXI-CPDLC (Ground and On-board)
Extensive TAXI-CPDLC trials, including both simulations and field trials, were performed at different test sites. Specifically, the ATTAS aircraft was used in field trials at Prague Ruzyně and Milan Malpensa Airport. Simulations, where tower simulators and cockpit simulation platforms were linked, were done in Toulouse, with a TATM tower simulator and an Airbus 320 cockpit simulator, and at the DLR tower and cockpit simulation facilities.

Feedback was mainly received on TAXI-CPDLC operations with start-up, push-back, taxi-in and taxi-out clearances, and handover operations. Three major issues were discussed with controllers and pilots in Toulouse. They considered the questions, how the party line effect and data link could co-exist on the runway, how controllers were able to cope with mixed mode, and what controllers and pilots thought about the preliminary taxi route information ("expect routing").

The scope of the taxi clearance was related with another important issue, namely the absence of the party-line effect when using data link, which was considered especially grave in the vicinity of runways. Pilots and controllers in Toulouse recommended that, in the runway area, voice should be used in parallel with sending data link and that read back should only occur by voice. This would avoid additional workload for pilots, and at the same time up-to-date information could be displayed on board (e.g. changed status of stop bar at runway crossing). Generally, the party-line effect would persist for runway areas and for urgencies on the remaining movement area.

A similar scenario was assessed in the Prague trials where the decision was taken to transmit the complete taxi-out route, cleared until the clearance limit[11] and followed by a "NEXT EXPECT taxi route" until the holding point of the departure runway. After data link transfer from ground to runway control, with the aircraft close to the clearance limit, the runway controller further controlled the flight by voice exclusively. The provision of the complete taxi route composed of a cleared part and a "NEXT EXPECT" part, which was cleared by the runway controller by voice, was well accepted by pilots and controllers. All runway related clearances were handled by voice, thus pilots did not complain about an impaired party line effect. However, when crossing a runway, pilots in the cockpit had to switch off the red crossbar on their EMM representing the clearance limit. This procedure was criticised by the pilots. This means that, although the use of data link up to the runway was accepted by controllers, there were also indications that more testing would be necessary, especially as regards the use of TAXI-CPDLC messages for runway crossings in parallel to voice instructions.

Giving safety-critical instructions, such as clearances for line-up, take-off, and landing or a hold instruction, via data link was not assessed in the DLR simulations. The Toulouse team thought that such instructions via data link could be sent as long as voice is used in parallel. The Prague controllers wanted to defer a decision on that issue until further tests were done.

The Prague trials additionally looked at the question of how to provide the taxi-in route. During approach preliminary taxi routing information was given to the pilots. After landing, vacating and handover to the ground controller, Prague ATCOs and pilots accepted the procedure to clear the

[11] The clearance limit could be a runway to be crossed or, without a runway to be crossed, the final holding point at the departure runway.

remaining part of the taxi route until the final parking position via TAXI-CPDLC. The Toulouse team considered the same procedures for taxi-out and taxi-in once the first taxi clearance had been given (based on “expect routing” information updated by ATCO).

The Prague team also discussed the question of revising a taxi route while the aircraft is taxiing. Controllers considered the chosen approach as potentially feasible but thought that more testing would be needed as the procedure depended very much on the actual traffic situation. The Toulouse team considered the revisions of taxi route in the nominal procedures of taxiing, which were accepted by both pilots and controllers.

Regarding the issue of mixed mode traffic, Toulouse controllers made the general statement that non-equipped aircraft would appear as a constraining factor. However, they did not indicate whether this could lead to unacceptable working conditions or not. It was seen as fundamental that voice communication had a priority on data link. In that regard, it was considered necessary that there were instructions to notify a change of communication means, such as “RESUME TAXI” or “REVERT TO DATA LINK”. They also agreed that the choice of the communication means should not be constrained by procedure but left to the users, meaning that a switch to voice communication should always be possible in case of time critical situations.
At the Prague test site, the mix of equipped and non-equipped aircraft did not lead to confusion or safety-critical situations. Still Prague controllers also highlighted the importance of voice communication and suggested that handover instructions could be given by TAXI-CPDLC, but that the pilot’s initial call with the next position should be done by voice to assure that R/T contact is established. Regarding the issue of being triggered, Prague controllers considered that an acoustic signal for incoming data link messages might be helpful. They also indicated that they would only like to be informed of transmission failures rather than receiving a positive acknowledgement (LACK) message every time that transmission was successful. Special time-out values for both technical and operational feedback have yet to be defined considering the type of message, i.e. whether it is of a tactical or more strategic nature.

The issue of sending preliminary taxi route information (“expect routing”) via TAXI-CPDLC was seen as essential in Toulouse. Controllers considered this functionality as a strategic service that could increase throughput by information sharing through the “expect” message, which was very much appreciated. Pilots stressed that a prerequisite for receiving such information was that it was timely and reliable enough to be accounted for. Controllers would expect that such information is transmitted automatically, however, with a possibility for changing it. For departures, such a message should be given with the departure clearance and for inbound traffic it should be retrieved together with the ATIS message. Prague controllers were not concerned about the automatically sent “expect routing” information, as long as they remained the supreme authority to finally clear a taxi route. When the cleared taxi route deviated from the former automatically sent “expect routing” a “REVISED” message was sent to the pilot automatically. Pilots agreed that a preliminary taxi route could bring additional operational improvements as long as the information is reliable enough, i.e. if the preliminary taxi route information is identical to the actual clearance most of the time.

Thus, in conclusion, it can be stated that voice communication remains a very important factor in controlling ground traffic, even when data link is available. This is especially true in time-critical situations that require fast and immediate action, and in safety-critical areas close to the runway. Data link was seen by Toulouse controllers as a tool that is particularly helpful in the more strategic taxi planning situations. The Prague team, however, who were dealing with high amount of traffic in the simulation, where 50% of the aircraft were equipped, observed and stated that giving clearances by data link did not prove to be as difficult as they had expected. Still, the use of data link in tactical and safety-critical situations would need more attention.

Pilots at the Prague test site especially highlighted the EMM as a very effective HMI presenting the needed graphical information. However, the CDTI display that was used as input device needs major upgrades before further use in simulations or flight trials. Pilots highly appreciated the display of taxi routes and clearances. The used terminology and symbology were easy to interpret. Similarly, in the Toulouse simulation set-up it was found that the HMI needed refinement with regard to operations in the runway area. Data link messages appeared to be appropriately chosen and needed only slight refinement. This was also confirmed by the Prague test site, where one of the suggestions for such refinement was to combine the departure, start-up and change-to-ground-frequency clearances in one step, if possible.
Furthermore, pilots at the Toulouse test site felt that taxiing time could be significantly reduced by using CPDLC, which would lead to a reduction in operational costs. Safety would be increased by improved situational awareness. Mixed mode communication was considered difficult but was not seen as an impediment for the service.

Nevertheless, field trials proved the technical feasibility of giving taxi clearances via data link, both at Prague and Milan Malpensa airports. On the onboard side the transmitted taxi route was presented on the moving map display. Such presentation on graphical systems was also seen as helpful support by both controllers and pilots in Toulouse. They all stressed the importance of the quality of data and the efficiency of the HMI. The consistency of the data between ground systems and cockpit was considered as a paramount pre-requisite for the operations.

Routing
In EMMA2, the route planning or routing function was seen as an enabler for other services such as TAXI-CPDLC, DMAN, and route conformance monitoring rather than a service of its own. This is the reason why routing was not evaluated at the Toulouse or Paris test sites and only received small attention at the Prague test site. For Prague not all possible routes were implemented, which only led to partial acceptance by controllers. Furthermore, all routes were taken from a table and alternative routes were not always available. This made it difficult for the tool in Prague to always generate a valid route considering all constraints.

At the Milan Malpensa test site, such functionality was available, so that an evaluation of the tool by controllers could be performed. The Malpensa Route Planning (RP) tool calculated and proposed a route that apart from start and end-point of the route was taking into account airport configuration, intermediate waypoints, local taxi restrictions and local standard routes. In that way, a default optimal taxi route was proposed on the EFS display as a string indicating taxi route segments. The controller could accept the route or select an alternative route from a list of available taxi routes.
As an improvement, controllers suggested that the tool should be more dynamic and consider the planned and real-time evolution of the traffic as well as the input of other support tools, such as the DMAN. Also, it should be used in combination with route conformance monitoring. Other suggestions concerned the possibility for the controller to always be able to override the RP proposal, even if the selected route was not part of the calculated list or not conflict-free. Controllers also stated that no more than 5 taxi routes should be suggested, and that the standard taxi routes should have higher priority than any of the calculated distance-optimised and conflict-free routes.
Finally, it was recommended to include the aircraft type as a parameter for the route calculation (some routes are not available for certain aircraft types).

Departure Management
Research prototypes for a DMAN were tested at three test sites within EMMA2: in an on-site test at Prague and Toulouse, and in simulation for Prague, Paris and Toulouse.

At the Prague test site, the DMAN presented three calculated flight plan data items (target times for start-up and take-off as well as the time until the next clearance) and the sequence number for each departure in the flight strip. In summary, it could be shown with statistical significance that DMAN

enabled controllers to work more efficiently, that excessive queues are avoided, and that taxi times are reduced. The DMAN smoothed departure peaks by keeping aircraft at the stand until a free runway slot was available. This was not done if the stand was required by another aircraft. From the runway slot (TTOT), the DMAN calculated a target time for start-up.
For Paris CDG, the DMAN worked in more or less the same way, although the times used in the sequencing were off-block times. One of the remarks of controllers was that TSAT could be better used instead. In general, it was considered undesirable that the operational times were changed after each DMAN sequence update, which means that more stable times should be indicated to controllers to support them in their operational task. As a common remark at each test site, controllers highlighted the necessity of the DMAN being integrated into a CDM environment to have access to more reliable planning information.

For Prague it was highlighted that the planning process for outbound traffic is very complex due to a number of uncertain variables and that many local peculiarities, such as runway entry points, standard taxi routes, runway and SID dependencies must be better accounted for. Therefore, it was also not surprising that the Paris and Toulouse test sites found differences in the applicability of the DMAN. The Toulouse results showed that departure peaks at Blagnac were rather low, which would remove the necessity to smooth them, but that DMAN sequencing was still considered beneficial. Controllers also thought that there might be no need for a dedicated CLD HMI as much of the information needed in Toulouse could be included in the EFS system itself.

The Paris CDG simulations were very much focused on the interoperability of an existing electronic flight management display for CLD controllers (DIGISCUS) and the subsequent EFS for ground controllers (VigieStrips) with the DMAN. DIGISCUS received valuable comments from controllers regarding the display philosophy (colours and bay windows) and additional sequence information that might be useful for the CLD controller, such as current traffic load, number of flights complying with the slots. Slot time and start-up times (TTOT and TSAT) were considered the most important planning elements and were given preference before off-block times, especially as regarded display and sorting of the electronic strips. Furthermore, CLD controllers were interested in a what-if assessment option, in order to get an impression of the consequences for the sequence if a pilot requests start-up earlier than planned. Another comment received concerned the indication of push-back delays to the CLD controller. Controllers wished to have that information as early as possible. The current information that was based on the push-back clearance input of controllers was considered inadequate to determine the exact point of time that the aircraft left the stand. Instead, information from either the A-SMGCS or the ground operator would be required.
Thus, in general, it could be shown that even though the integrated A-SMGCS departure management process is very complex and needs to be adapted to the local peculiarities of the airport concerned, benefits in reduced taxi times and departure queues can be achieved. R/T workload, however, will not be reduced. More benefits in terms of more reliable and stable planning information are expected as soon as DMAN is integrated into a CDM environment that receives input from the relevant stakeholders (ATC, airline, airport, and ground operators).

Integrated Moving Map
In the previous phase of the EMMA project the moving map display was already evaluated. In EMMA2, the IMM functionality incorporated own-ship position, surrounding traffic information, and route and clearance information for navigation purposes. The IMM was only evaluated by pilots for the Paris CDG Airport layout at the THALES Avionics test site in Bordeaux.

Pilots agreed that the described functionality would increase situational awareness, thereby reducing navigation errors and increasing the safety of taxi operations. Some pilots also assumed that the efficiency of taxiing operations would increase, which would lead to a decrease in taxiing time (less intermediate stops) and a reduction in emissions. Pilots did not complain about the required workload for handling the IMM and suggested that it was more comfortable than the workload for handling a paper map.

Several remarks were made regarding the aircraft symbol in the map. Pilots thought that the size of the symbol should be related to the real aircraft size in order to be able to judge safe distances to objects or other traffic. Also, the symbol should take into account the precision of the positioning information on the map. Generally, the symbology used should be consistent with other instruments or displays regarding colour, shape, and reference point. Furthermore, elements of the map should not be as saturated as symbolic elements drawn on top of the map. The display of ground speed and wind direction was considered useful, especially when not displayed anywhere else.
Considering the configuration of the IMM display, it was suggested to have two displays in the cockpit (for PF and PNF) with custom configurations according to the pilot tasks (among others a split screen with communication display for PNF). The IMM should be displayed on a screen close to the windshield for quick reference when looking outside. Furthermore, the PF should not access the display during taxiing operations, so that the PNF must have access to the display of the PF and be able to change parameters (e.g. range and scale).

Surface Movement Alerting Function
Surface Movement Alerting was tested by TU Darmstadt in real-time simulations, and in on-site trials in Prague.

The alerting concept that consisted of visual indications on the EMM, textual information on the PFD and an audible alert was well received and accepted by the pilots. Pilots considered the generated alerts as operationally relevant and added that they were necessary in spite of an already increased situational awareness provided by the EMM enhanced with the display of electronic Pre-flight Information Bulletin through the Ground-Air Database Upload function.

The SMA function uses the speed, heading and acceleration information of own-ship to detect the right moment to alert the pilot. The timing of the alert must be early enough to enable the pilot to correct the course, but should also prevent nuisance alerts. In both the real-time simulations and the on-site trials, the timing of the alerts was accepted by the pilots.

Ground Traffic Display
Ground Traffic Displays were tested as part of IMM functionality in real-time simulations and on-site trials for Prague Airport and in feasibility and operational performance simulations for the Paris CDG Airport layout with pilots at the THALES Avionics test site in Bordeaux.

Generally, the HMI design at the Prague test site was well accepted by the participating pilots. They stated that the HMI worked reliably and in an intuitive way, and that it was easy to use without inconsistencies. An update rate of 5 Hz was considered sufficient for presenting surveillance information. Especially the zoom functionality and the different display modes were highly appreciated. Head-down times for using the system (located in the navigation display) were acceptable to pilots and integration of the displays was considered to be in harmony with other cockpit instruments.

For the Toulouse simulation at the Bordeaux site, more specific recommendations on the design of the HMI were given. According to the participating pilots, colours and shapes must be chosen appropriately. Information on traffic headings and static traffic should be displayed. Runway occupancy should also be presented on the display. Furthermore, filtering should occur to show only traffic that is relevant for the operational need. This need could change per taxiing phase (apron, crossings, and line-up). Generally, traffic information should be available for all the traffic displayed. This information should include ground speed, aircraft type and flight number as well as the distance to an aircraft followed. Displaying the ATC call sign (and not the registration number) was considered helpful regarding the ATC communication party-line effect. Another important comment regarding HMI design concerned the traffic symbols. Pilots recommended making them bigger or at least relatively equal to the real size of the object to prevent pilots from trying to use the symbol for estimating distances. Also, for safety reasons, the symbols should be displayed such that they take into account the evaluated positioning precision.

Regarding possible changes of the pilot role (delegation), Toulouse pilots recommended that controllers should retain the responsibility of separating traffic. Pilots at the Prague test site did not directly answer that question but indirectly mentioned that the GTD would help them in making decisions for those functions for which they are currently responsible. In that regard, they also stated that they were well aware that the GTD relied on co-operative sensors and was therefore not able to display non-equipped traffic. With TIS-B, this could change. However, TIS-B was not used for evaluating new operations. The main aspect of evaluating TIS-B was testing it technically and regarding data precision and update rate. Both were considered sufficient at Prague. Still, pilots stressed that they considered the look outside the cockpit as the main source of reference.

Both test sites came to positive results regarding the improvement of pilot situational awareness and efficiency of carrying out the tasks. Pilots stated that displaying other traffic on the map would help in anticipating potential conflict situations (on taxiways, runways and at the stands). Toulouse pilots recommended displaying routing information, also for other traffic, in order to enhance situational awareness. They also recommended displaying potentially dangerous traffic with a different colour or shape. However, no recommendation was made as to the question how such traffic should be detected.

Toulouse pilots felt that stress and workload seemed to decrease, but also mentioned that studies should be performed to confirm this. Regarding taxiing efficiency it was observed that pilots were not disturbed by any HMI interaction.

Traffic Conflict Detection Function
Traffic Conflict Detection was tested by TU Darmstadt in real-time simulations, and in on-site trials in Prague.

Pilots agreed that the presented function could be used appropriately in the surface movement area. Both the Traffic Conflict Detection alerts on the taxiways and on the runways were accepted by the pilots, though the operational relevance of the alerting on the taxiways was deemed lower than the alerting on runways.

The pilots accepted the warning concept, which is similar to the one for Surface Movement Alerting, i.e. with three different colour codes on the EMM and PFD, depending on the urgency of the detected conflict, and with an audible alert. The HMI was considered intuitive and easy to use.

As for the Surface Movement Alerting function, the right timing of the alerts is essential for the acceptance of the pilots. Concerning reactive runway incursion alerts, the timing was generally accepted by the crews. For the traffic alerts on the taxiway, a fine-tuning of the function is still needed to prevent some nuisance alerts.

HUD Surface Guidance System Function
HUD SGS was tested in simulator trials at the Toulouse test site only. New symbology was developed to present information regarding the Traffic Awareness and Surface Movement Alerting functions.

It was detected that during the taxiing the PF almost never looked down at the IMM but used the HUD for navigation. Exceptions were the cases of close proximity of other aircraft and anticipation of the following turn. In these two cases, the IMM was referenced to gain a better overview of the situation.

Regarding taxi route symbols, it was pointed out that the display of the centre line and the borders should suffice for smaller aircraft. For safety issues the taxiway borders should always be located inside the real pavement.
The developed 2D-view was appreciated and allowed to have a good overview of the aircraft situation on the taxiway and to control the position of the landing gear. However, pilots disagreed on the usefulness of this view.
Tests also resulted in the choice of a particular guidance symbol, a square with a round aircraft symbol inside. This symbol should be presented permanently, according to pilots.
Regarding the Surface Movement Alerting, the "On Runway" message was considered as particularly helpful. Although this message appeared too early, i.e. before the aircraft was actually on the runway, and was triggered by passing the last holding line before entering the runway, pilots thought that such a message could reduce runway incursions.
Situational awareness was also considered as improved due to the information on taxiways (current and connected) that is provided, and due to the conformance with the outside view which enables taxiing independent of the visibility conditions. As a danger, it was highlighted that not all objects might be displayed (e.g. roadwork).
Efficiency of taxi operations would also increase, according to pilots, as the anticipation of situations would lead to better control of speed and heading. Additionally, the symbology would be especially helpful to pilots not familiar with the airport, under low visibility, and for very large aircraft.
Finally, the usability of the taxi route and guidance symbols was considered intuitive by all pilots and would not require much training. An earlier problem of the guidance symbol for the pilots was to follow it during turns. Refined filtering eliminated that problem. The introduction of additional anticipation information in the guidance symbol was experienced as confusing. The adaptation of the symbols to different aircraft types was considered useful.

Ground-Air Database Upload

TUD together with partners from ETG and DAS tested update and upload concepts and their integration into existing maintenance cycles in the TUD Fixed-base Research Flight Simulator.

As the most important result, the introduction of the upload function of ePIB information did not lead to an undue increase of pilot workload in critical flight phases. Interaction occurred via the MCDU with which pilots are very familiar. Still, as a recommendation for further development, it should be considered to use a trackball or computer mouse for interaction. Pilots especially appreciated the provided information on taxiway and runway restrictions. Presentation of the information was considered intuitive due to the use of symbology already used in the TUD SMAAS.

Vehicle Moving Map Function

The only trials with a vehicle moving map in EMMA2 were performed by technical personnel at Toulouse-Blagnac Airport. The research prototype tested would show own-ship position on the map and would give warnings in case pre-defined restricted areas were entered.

Although the system worked as expected and correctly showed own-ship position and triggered alerts, it was not considered suitable for operational use. Essentially, there were two reasons for this assessment. Firstly, drivers who are familiar with the airport airside environment would only require the system to ensure safe separation from other traffic during low visibility conditions. However, the system did not show surrounding traffic information. Secondly, drivers who are not familiar with the airport airside environment would need a system that is portable and has plug-in functionality for easily equipping all kinds of cars. The tested prototype, however, required a considerable amount of work for installation in a car and was inferior to commercial products as concerns boot time and map layout.

6.2 Conclusions on Operational Requirements

As part of validating abovementioned services, each test site investigated in how far the operational requirements listed in the SPOR document (Ref. [9]) could be verified. In order to get to an understanding of what such a step means, it is necessary to revert to the E-OCVM (Ref. [3]).

The E-OCVM in its current form describes three aspects of validation that in their entirety provide a structured, iterative and incremental approach to operational concept validation. While the Structured Planning Framework, which is based on the MAEVA Validation Guideline Handbook, facilitates planning issues for R&D programmes, the Concept Life Cycle Model (Figure 6-1) gives an overview of the complete life cycle of an ATM R&D operational concept and indicates the type of validation activities necessary within those phases that represent the main focus of ATM R&D.

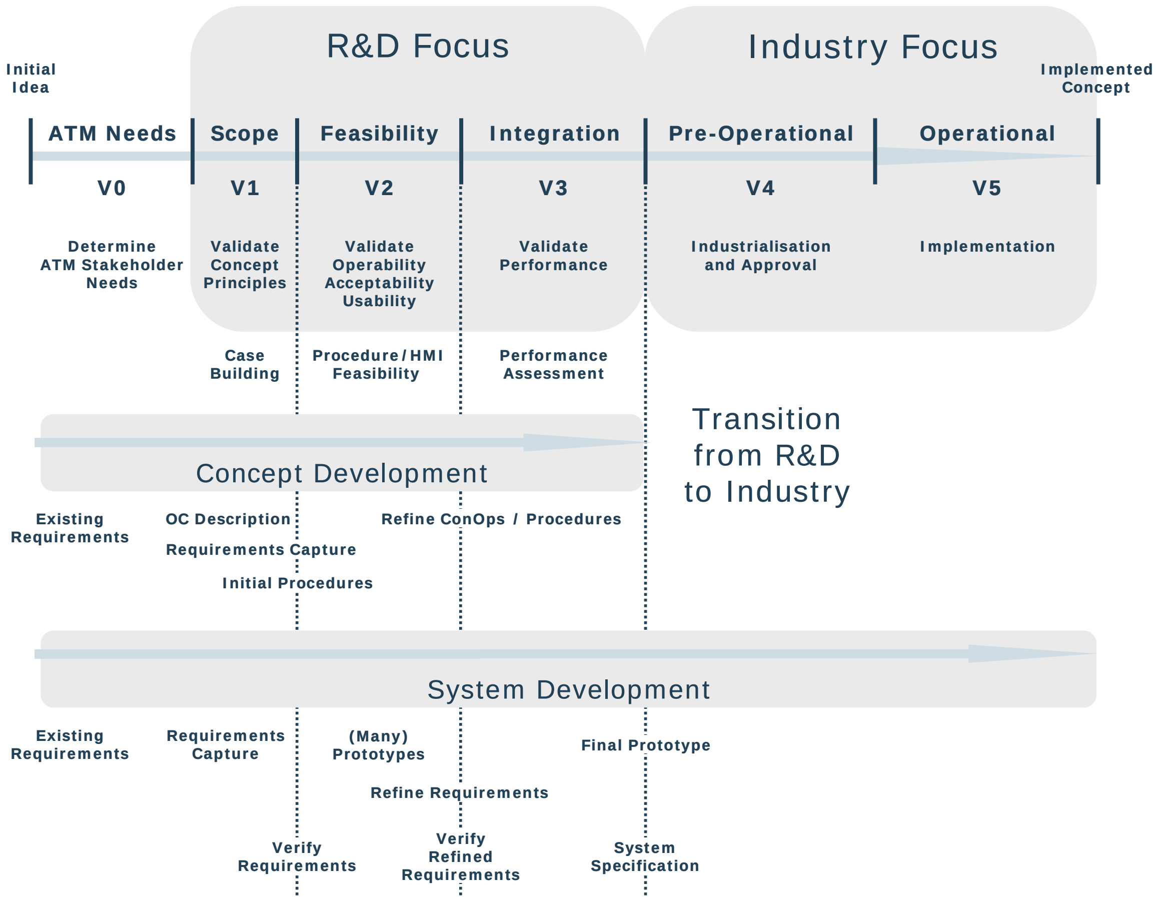

Figure 6-1: Operational Concept Validation Life Cycle Model (E-OCVM)

As such the model can also be complemented with a view on how concept validation interfaces with technology or product development and concept development, the latter being very closely related with the different validation life cycle phases. It also offers the possibility to have a closer look at how the third aspect, the Case-based Approach, relates to the other processes. This approach integrates validation results into key cases that directly address stakeholder issues about ATM system performance and behaviour.

Considering the earlier described results of EMMA2 at the different test sites and the fact that most of the new services, such as TAXI-CPDLC or the routing service, did not reveal a maturity level higher than V2, the feedback gathered mainly concerned operational feasibility. Since Prague provided the most complete simulation environment in terms of integrated A-SMGCS components, 204 operational requirements could be verified from a technical and an operational point of view at that site. This was accomplished by asking the users about their acceptance. The project concluded that nearly all of the operational requirements could be verified (see also Annex II of Ref. [17]).

It should be noted that operational requirements were also tested and verified at the other test sites, yet these results either served to prepare the validation platforms or were used to produce the results reported earlier on the basis of detailed hypothesis testing.

6.3 Lessons Learnt from EMMA2 Results

In EMMA2, it was shown again that the quality of the discussed services, especially the higher services, which include several planning, guidance and alerting tools, depends on the quality of the available surveillance information. It was found that ADS-B Out currently is not suitable for A-SMGCS purposes, as A-SMGCS requirements have not been considered in specifying transponder standards. Additionally, the varying latency of the information is detrimental to the use of ADS-B in surveillance data fusion and therefore for the use in any A-SMGCS component. Filtering out ADS-B in the data fusion led to more reliable results.

Furthermore, it could be shown that it is difficult to look at the benefits of different A-SMGCS components in isolation, in particular on the ground side. EFS, for example, were seen at all test sites as an enabler for other services as they allowed the controller to enter relevant data into the system without increasing workload, thereby making the system aware of the controller plan. This information was useful for anticipation of critical situations, and detection of inconsistencies in clearances.

The integration of a route planning system into the flight strip HMI was seen as enabler for Route Conformance Monitoring and a controller support for transmitting taxi route clearances via TAXI-CPDLC. Thus, apart from reducing R/T load the tool was also meant to reduce time for preparation of clearances. As was shown in the trials, the automatic delivery of planning information did not always lead to controller acceptance, simply due to the fact that there were either limitations in the tool to carry out all planning activities that can be done by a controller or due to the fact that the planning changed so frequently that the tool was not much of a help.

The use of a DMAN for departure planning seemed to offer controllers additional support in smoothing departure peaks thereby reducing the changes needed in taxi-route planning. This again shows that looking at the tools in isolation would lead to difficult assessments. The planning, monitoring and control chain from gate to runway and vice versa should therefore be seen as a coherent series of tasks that need to be supported by a coherent set of A-SMGCS components.

In EMMA2, different test sites with different system implementations looked at that series of tasks which led to results that are either very much dependent on a certain implementation of a tool, integration issues between different A-SMGCS components, or fine tuning activities for airport peculiarities. In the beginning, some of the trials showed that the systems tested did not reach the required maturity for the environment in which they were used, which led to very detailed comments by controllers, not only on HMI issues but also on operational details, such as alerting thresholds and standard routings. While these comments led to improvements of the specific tool in question and operational feasibility could be shown in another validation cycle, the results could not indicate whether expected performance targets for the overall concept could be reached.. The system

components in question (EFS, conflict prediction/detection/alerting, and conformance monitoring) would need to be validated again regarding their performance after each new development cycle in order to get to more conclusive results on an overall concept level. Iterative processes like this are rather complex and need to be investigated in the future.
As regards DMAN, a very important conclusion was that a more reliable planning of the start-up approval time via CDM mechanisms should lead to more operational stability in the subsequent processes of route planning and assignment.

Clearly, different levels of technological maturity of the different A-SMGCS components being part of the mentioned chain of tasks make it difficult to make quantitative comparisons of operational improvements. Still, controller and pilot comments made it possible to come to subjective results so that most validation exercises could at least show feasibility of concept and systems even if performance gains could not always be expressed in absolute terms. In order to bring the services further and obtain more objective results, future projects should build on these results and further validate the EMMA2 operational concept focusing on the role of air traffic controllers and their working environment and further elaborating task distribution between pilots and controllers.

This being said, innovative concepts could be developed that go a step further in integrating A-SMGCS components and purely look at the different tasks considering new technologies for data input, display, and interaction, potentially resulting in new controller roles and responsibilities. Such innovative approaches are suggested to become part of SESAR activities, as SESAR will lead the development approaches in Europe in coming years.

Looking at the airborne side, the situation regarding tools and interoperability heavily depends on the capabilities of the ground systems. Given the results of EMMA2, it seems that the IMM, which integrates different functionalities in a single interface and can therefore be seen as the counterpart of an integrated controller working position in the cockpit, is rather advanced in development. It combines valuable tools for guidance and control, even to the extent that delegation of certain tasks from the controller to the cockpit might be considered a possible topic for further research. Therefore, it was interesting to learn that the pilots assessing IMM and GTD in EMMA2 at the THALES Avionics and the DLR test site did not accept a possible change of responsibilities, such as the delegation of the task for separation on taxiways. Instead, they considered the proposed tools as helpful additions to get a better situational awareness of the overall traffic picture, which would help them in understanding certain controller actions. The pilots were of the opinion that controllers should retain complete responsibility of the separation task, since under low visibility conditions the display tools would not be sufficient to estimate safe separations on taxiways, e.g. when following a predecessor, which frequently happens under good visibility.

The TAXI-CPDLC service, which must be an integral part of both ground and airborne working environments, was tested in EMMA2 with promising results. While refinements are still necessary in the proposed solutions for data input on both the controller and pilot positions, the result regarding workload and situational awareness on both the airborne and the ground side were encouraging, at least for start-up, push-back, and taxi clearances. As regards the more demanding and dangerous operations close to runways, such as runway crossings, line-ups and take-off, a solution of parallel data link and voice exchanges could lead to improvements in situational awareness (with on-board displays being kept up to date) and would not impair workload (read-back would be done by voice only). Additional work will have to be done in this area, though. The results point into the direction of human factors and safety studies. Such studies should indeed be performed on the complete system rather than individual components of an A-SMGCS.

As an important part of its safety assessment, EMMA2 showed that human factors and safety studies can be performed in combination with real-time simulations, as was done for the Milan-Malpensa trials on the NARSIM platform, where initial prototypes of systems were placed in a simulated real-life operational environment. Results will help to assess critical operational situations. In order to get the complete picture, full-scale human and hardware-in the-loop real-time simulations will need to be performed on flexible simulation platforms that allow assessing the complete hardware solution for the chosen A-SMGCS set for a generic airport of a certain type. Eventually, on-site shadow-mode trials must prepare implementation of the complete solution of high-level A-SMGCS components, not only parts of them.

Regarding vehicle movements on the airport, EMMA2 showed that the research prototype had disadvantages when compared to commercial navigation products with respect to boot time and map layout. Thus, in the future, it should be ensured that research prototypes with extended functionality, such as showing surrounding traffic, deliver the same performance as commercial platforms to be operationally accepted.

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Acronyms

Acronym	Meaning
2D	2-Dimensional
ADS-B	Automatic Dependent Surveillance
AOC	Assumption of Control
ANS-CR	Air Navigation Services of the Czech Republic
APP	Approach
A-RSN	Advanced Runway Safety Net
A-SMGCS	Advanced Surface Movement Guidance and Control System
ASTERIX	All Purpose Structured EUROCONTROL Automated Radar Information Exchange
ATC	Air Traffic Control
ATCO	Air Traffic Controller
ATIS	Automatic Terminal Information Service
ATM	Air Traffic Management
ATN	Aeronautical Telecommunications Network
ATS	Air Traffic Services
ATTAS	Advanced Technologies Testing Aircraft System
AVMS	Advanced Vehicle Management System
BETA	Benefit Evaluation by Testing an A-SMGCS (a project in the Fifth Framework)
B-RSN	Basic Runway Safety Net
CCD	Cockpit Control Display
CDD	Clearance Delivery Dispatcher
CDG	Charles-de-Gaulle Paris Airport (IATA Code)
CDM	Collaborative Decision Making
CDTI	Cockpit Display of Traffic Information
CF	Certainty Factor
CLD	Clearance Delivery
CPDLC	Controller-Pilot Data Link Communication
CROS	Crossing Conflict
CTOT	Calculated Take-Off Time
CWP	Controller Working Position
DCL	Departure Clearance
DF	Downlink Field
DIGISCUS	Electronic Flight Strip System for Clearance Delivery (no abbreviation)

Acronym	Meaning
DLIC	Datalink Initiation Capability
DMAN	Departure Management
DSNA	Direction des Services de la Navigation Aérienne
D-TAXI	Data Link Taxi Clearance Service
DYP	Dynamic Flight Plan
EFS	Electronic Flight Strip
EMM	Electronic Moving Map
EMMA	European Movement Management by A-SMGCS
EOBT	Estimated Off-Block Time
E-OCVM	European Operational Concept Validation Methodology
ES	Extended Squitter
ESB	Electronic Strip Bay
ESRA	EUROCONTROL Statistical Reference Area
EUROCONTROL	European Organisation for the Safety of Air Navigation
FCU	Flight Control Unit
FISSA	Filet de Sauvegarde Sol Avancé (Advanced Ground Runway Safety Net)
FLYCO	Flying Co-ordinator
GEC	Ground Executive Controller
GND	Ground
GPS	Global Positioning System
GTD	Ground Traffic Display
HITL	Human-In-The-Loop
HMI	Human-Machine Interface
HUD	Head-Up Display
ICAO	International Civil Aviation Organisation
IMM	Integrated Moving Map
LACK	Logical Acknowledgement
MCDU	Multifunctional Control and Display Unit
MLAT	Multilateration
MOBT	Managed Off-Block Time
MOPS	Minimum Operational Performance Specifications
MSSR	Monopulse Secondary Surveillance Radar
MXP	Milan Malpensa Airport (IATA Code)
NAC	Navigation Accuracy Category

Acronym	Meaning
NASA TLX	NASA Task Load Index
NM	Nautical Miles
ODIR	Opposite Direction Conflict
OFZ	Obstacle Free Zone
OST	On-Site Trial
PF	Pilot Flying
PFD	Primary Flight Display
PNF	Pilot Not Flying
POBT	Proposed Off-Block Time
PRG	Prague Ruzyně Airport (IATA Code)
PRIMA	Basic Runway Safety Net (no abbreviation)
PSR	Primary Surveillance Radar
R&D	Research and Development
RP	Route Planner
RPA	Runway Protection Area
RTCA	Radio Technical Commission for Aeronautics
RTS	Real-time Simulation
RTUC	Recommended Time Until Next Clearance
RWY	Runway
SASHA	Situational Awareness Rating Scale for SHAPE
SCA	Surface Conflict Alerting
SDF	Sensor Data Fusion
SES	Single European Sky
SESAR	Single European Sky ATM Research Programme
SGS	Surface Guidance System
SHAPE	Solutions for Human Automation Partnership in European ATM
SID	Standard Instrument Departure
SMA	Surface Movement Alerting
SMGCS	Surface Movement Guidance and Control System
SMR	Surface Movement Radar
SMT	Surface Movement Tracker
SP	Sub-Project
SPOR	Services, Procedures, and Operational Requirements (SPOR)
SSR	Secondary Surveillance Radar

Acronym	Meaning
SUS	System Usability Scale
TCAS	Traffic Alert and Collision-Avoidance System
TCD	Traffic Conflict Detection
TEC	Tower Executive Controller
TIS-B	Traffic Information Service-Broadcast
TLS	Toulouse Blagnac Airport (IATA Code)
TOBT	Target Off-Block Time
TOC	Transfer of Control
TSAT	Target Start-up Approval Time
TSD	Traffic Situation Display
TTOT	Target Take-off Time
TWY	Taxiway
VDL	Very High Frequency Datalink
VHF	Very High Frequency
VIGIESTRIPS	Electronic Flight Strip System for Ground and Runway (no abbreviation)
WP	Work-Package

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