Higher-Level Services of an Advanced Surface Movement Guidance and Control Systems (A-SMGCS)

Results of the Prague Ruzyne Trials in the EMMA / 2 Project

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Under the umbrella of EMMA2 (European Airport Management by A-SMGCS, Part 2), an Integrated Project of the 6th European Framework Programme, a holistic A-SMGCS concept including procedures and requirements was developed and tested in extensive simulation and field trials at four European airports (Prague Ruzyne, Milan Malpensa, Toulouse Blagnac and Paris Charles de Gaulle), using diverse technical solutions and test platforms. The most important results and recommendations are presented in this paper. Even in 2004 ICAO published the A-SMGCS manual as document 9830 [1], describing operational, functional and performance requirements, procedures and operational requirements for the higher levels of A-SMGCS were rather immature at this time or did not exist at all. The present paper addresses those higher level services of an A-SMGCS, like routing, departure management (DMAN), data link communication for ground controlling (TAXI-CPDLC) and onboard guidance services by the example of the technical systems used during the Prague Ruzyne Airport trials.

1 INTRODUCTION

Currently airports are considered as the main bottleneck of the Air Traffic Management (ATM) system. Airport delays are a growing proportion of the total ATM delay. An extension of existing airport infrastructures, e.g., building new runways, is very difficult. Therefore, the optimal usage of existing infrastructure becomes more and more important, particularly in adverse weather conditions. Despite the importance of optimal resource usage, operations on the airport airside are more or less managed "manually". To overcome these problems, a considerable amount of research effort in the last two decades concentrated on the development of Advanced Surface Movement Guidance and Control Systems (A-SMGCS).

2 A-SMGCS Concept

On the airport surface, pilots usually navigate using paper maps, and air traffic controllers (ATCOs) perform the surveillance task, primarily on the "see and be seen" principle. Radio voice transmission is still used as the primary communication means. When visibility conditions degrade, pilots are less capable of following the cleared taxi route and seeing and avoiding each other. The controller cannot see the entire traffic picture by visual observation and must rely on the surface movement radar (SMR) and/or radioed position reports. SMR, however, merely provides an analogue display with clutter, false targets and other limitations in its use. In order to ensure safety, special low visibility procedures are applied to help overcome technological limitations. Yet, these procedures compromise airport capacity and increase delays with negative network effects and repercussions on the overall air transport system.

A further problem on airports is the occurrence of runway incursions. Runway incursions led to several grave accidents (e.g., Milan-Linate in 2001) in recent years. It is estimated that for every 350,000 movements one severe runway incursion occurs and for every 66 million movements one accident is caused by runway incursion [5]. With 18 million movements on the ECAC airports per year, this results in one runway incursion related accident every 3.7 years [2]. The mentioned problems resulted in the development of A-SMGCS levels 1&2. Such a basic A-SMGCS focuses on providing a reliable automatic surveillance of the complete aerodrome traffic and a surveillance-based runway-incursion warning. At level 1, A-SMGCS consists of the introduction of an automated system capable of improving airport traffic situational awareness through the provision of identification and position information of aircraft and vehicles. This is achieved through a labelled display showing position, identification and speed of all co-operative mobiles in the predefined areas of interest. New A-SMGCS procedures allow controllers to monitor traffic and to issue clearances and instructions purely on the basis of such surveillance data. The main benefits from implementation of A-SMGCS level 1 are associated with maintaining safety and airport throughput in low visibility conditions and at night.

A-SMGCS level 2 aims at complementing the surveillance service (level 1) with a control service. It provides ATCOs with a traffic situation picture associated with an automated control service capable of detecting potential conflicts in order to improve safety of runways and restricted areas.

However, comprehensive planning and guidance of flight movements at the aerodrome is still not provided by support of A-SMGCS level 1&2. Local decision making, accompanied by an insufficient flow of information, is still very common. Paper flight strips, most commonly used today, can hardly fulfil the requirements of modern electronic information processing. A major problem with the growth in traffic density is the increase of voice radio communication load. All instructions are given by voice have to be read back by the pilots. Furthermore, if additional information exchange is necessary, voice communication can quickly become a bottleneck of efficiency and safety. Pilots have to check their position and navigate on the aerodrome visually and with the help of paper charts. Low visibility conditions as well as increased traffic volumes make navigation and collision avoidance more complicated and safety critical. Under such adverse conditions, pilots have to rely almost entirely on the information and instructions provided by the controller. All of this led to the development of "higher levels" of an A-SMGCS. Increased support for controllers and pilots through automation is the main characteristic of higher-level A-SMGCS services. New tools like electronic flight strips (EFS) enable faster access to and sharing of relevant information. This again leads to a better planning of airport activities and better monitoring of ground traffic. Overall, communication is made more efficient. Up-to-date information, optimised by planning systems such as a Departure Manager (DMAN), is provided to the controller through EFS. By clicking on the individual strips the controller can easily update and share flight plan data, and pass the flight strip to the next position. In the same way, an optimal taxi route can be calculated for each aircraft by a routing function. When assigned to an aircraft by the controller's click, it is made available electronically within the system. This provides a great safety advantage because, in addition to the aircraft's actual position, the system is now aware of the cleared taxi route. As a consequence a Route Conformance Monitoring function can detect any deviation from the assigned taxi route and warn controllers. A taxi route which is digitally processed by the system has yet another advantage as it can be electronically transmitted to the cockpit. This type of communication with the cockpit is provided by a data link, 'Controller Pilot Data Link Communication', or 'TAXI-CPDLC' for short. Similarly, other instructions, such as start-up and pushback, can be transmitted by data link and acknowledged by the pilot. This will save valuable time on the radio channel, and help avoid misunderstandings by ensuring unambiguous transmission of information to the cockpit. In the future, more and more pilots will be able to determine their position using navigational graphic displays, so-called EMMs (Electronic Moving Map). Technical solutions such as VHF Data Link Mode 2 and TIS-B (Traffic Information Service - Broadcast) could be an enabler for higher-level A-SMGCS on-board services. Pilots will thus be able to see their taxi route, as cleared by the controller via TAXI-CPDLC, and get information about surrounding traffic on the EMM. Automatic onboard conflict recognition, which warns pilots about possible collisions with other aircraft or vehicles, as well as deviations from their cleared taxi route, are very promising new onboard services (e.g.: TCD: Taxi Conflict Display, SMA: Surface Movement Alerting). A higher-level A-SMGCS was under investigation in the EMMA2 project. Its general system architecture is shown in the figure below.

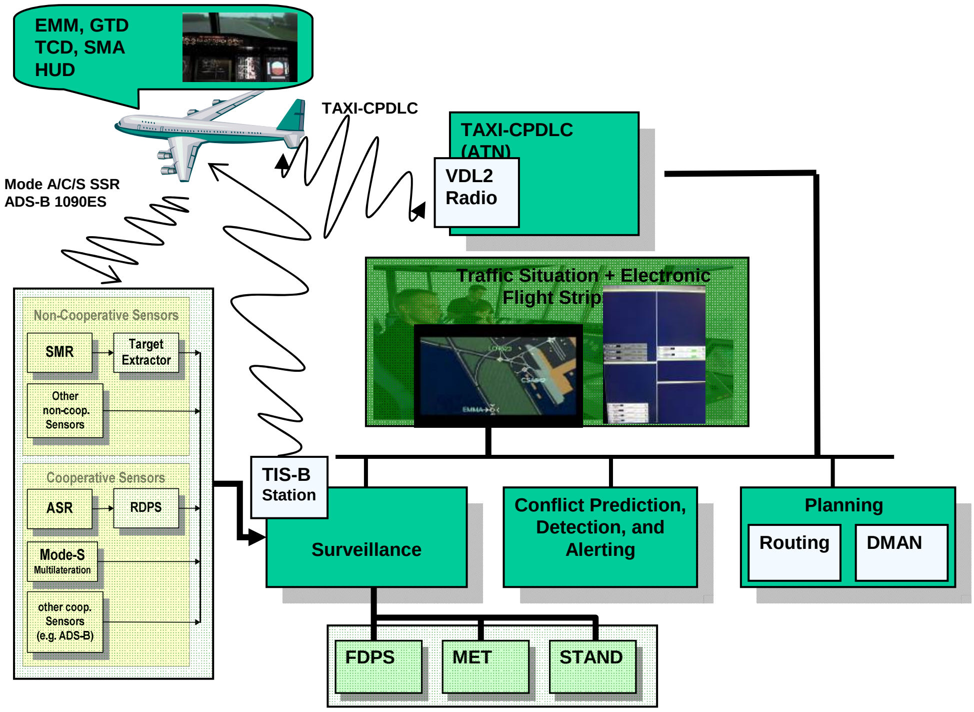

Figure 1: General System Architecture of a "higher level" A-SMGCS

3 Technical A-SMGCS System

The A-SMGCS is a modular concept defined in the ICAO Manual Doc. 9830 on A-SMGCS [1], which systems are aiming to provide adequate capacity and safety in relation to specific weather conditions, traffic density and aerodrome layout. With the complete concept of an A-SMGCS, controllers and flight crews are assisted in terms of surveillance, control, planning and guidance tasks. A-SMGCS will improve capacity, efficiency and safety by maintaining this in different visibility conditions. The environmental impact of fuel consumption and pollution will decrease and the comfort for passengers will increase due to less idle time at the airports.

To follow the ICAO definitions [1] regarding surveillance and control requirements it is expected that more than one type of surveillance sensor is needed to meet the surveillance requirements. In clear words: To ensure the identification and continuous tracking there is the need of a **sensor set** in dependence of the airport layout. This sensor set must be defined in such a way that redundant information sources - fused by a sensor data fusion - are available to survive short term single sensor faults and to confirm the information validity.

3.1 Surveillance

Each individual aircraft is seamlessly tracked and identified from final approach until it reaches the parking position and vice versa from the stand until take-off. Towing operations, other car vehicles and obstacles shall be detected as well, at least on the manoeuvring area but preferably on the whole movement area, which includes aprons. It is only possible to fulfil these requirements by multi-sensor-systems based on cooperative and non cooperative sensors. There are three main types of sensors:

1. non cooperative sensors:
   These sensors are only able to track an object without a clear identification (e.g. SMR). They are installed on the ground site and independent of on-board equipment.

2. cooperative sensors type1:
   These sensors are able to track and identify an object. This prerequisites that the object is equipped with a special transponder. The current objects' position will be calculated by multilateration receiver systems on ground (e.g. Mode-S). These systems can work with broadcast addressing or direct addressing.

3. cooperative sensors type2:
   These sensors are able to track and identify an object. This prerequisites (similar to cooperative sensor type1) that the object is equipped with a special transponder. But in contrast to the sensor type1, the object itself knows its own position and transmits it to the ground sensor (e.g. ADS-B).

The current traffic situation is displayed to the different controllers with a synthetic representation. (Sometimes the analogue SMR information is used as background to the synthetic traffic situation.):

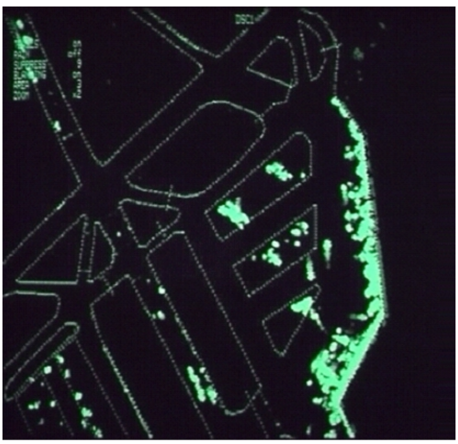

Figure 2: SMR view **A-SMGCS Controller HMI**

3.2 Control

The Control function basically compares the current traffic situation with a pre-planned situation concerning:

- Taxiing on or crossing of a runway with conflicting traffic

- Taxiing into prohibited areas (e.g. construction sites)

In a more advanced implementation with planning system support more advanced safety nets come into consideration:

- Deviations from a taxi route
- Clearance monitoring to show conflicting clearances
- Deviations from a pre-planned timing

The clear advantage of this approach is that it is active and not reactive. Preventing conflicts before they appear is obviously better than solving them under time pressure when they become obvious.

3.3 Routing / Planning

The Routing/Planning functions support the controllers in spatial and timely planning of the movements. In [1] the term "Routing" is used for the spatial aspects, 'Planning' is the more general term that includes routing and scheduling and is therefore used in this paper. It should be pointed out that this planning function of A-SMGCS has to be an integral part of the overall set of planning systems at an airport. The necessity of a good co-ordination between the tactical systems DMAN and Routing is obvious.

3.4 Guidance

The Guidance function supports the implementation of the A-SMGCS plans - either computed by the technical system and approved by the controller or directly created by the controllers. The function supports pilots as well as vehicle drivers in following the correct route and the associated time constraints. Two fundamentally different technical approaches have to be considered:

1. Ground Bases Guidance Means, as e.g. switch-able centreline lights, stop-bars or as well runway status lights. Those are often available and could be used and integrated. Enhancements to 'follow the greens' are technically feasible today.

2. Onboard Guidance Means as a "Moving Map Display" (MMD), presenting the current own-ship-position on a graphical map are the promising future solution. This solution can be extended in modular steps, e.g. to handle clearances and plans transmitted via data-link (CPDLC) or to show other traffic via TIS-B to the pilot. Further this onboard system could integrate warning functions as a safety net, like detection of route deviations, certain timely plan deviations or collision conflict detection.

4 EMMA2 TECHNICAL SYSTEMS

4.1 Surveillance

The installed surveillance systems at Prague Ruzyne Airport are the "well known" sensors described in the following table. Additionally this system was extended by the necessary components for TAXI-CPDLC and the onboard functions based on TIS-B.

ASR stations	1
SMR stations with EXTR-	1
MLAT stations	15
Data Fusion & ATCO HMI (TSD)	3
- Conflict Detection	✓
Gap Filler	Camera
Vehicles equipped	80
Ground based Guidance (Stop bars)	✓
Onboard MMD tested with TCD & SMA	✓
ADS-B (*)	✓
CPDLC by ATN over VDL2	✓
TIS-B	✓
DMAN	✓
EFS with DMAN interface	✓

Table 1: EMMA2 Equipment used in Prague

(*) The results of ADS-B trials showed that due to a poor implementation status in aircraft it is not useful for ground applications (less accuracy, missing time stamp for calculating the latency). In case of vehicles ADS-B can be used because there the ADS-B position data based on GPS navigation data which can be improved by differential GPS stations for increasing the accuracy significantly. For the time being GPS is not certified as a primary navigation aid at aircrafts.

4.2 TAXI-CPDLC

Within EMMA2 the TAXI-CPDLC based on VDL-2 and the ATN stack for the data link communication system. The following figure shows the functional architecture of the EMMA2 TAXI-CPDLC implementation for Prague. The left side describes the airborne system configuration, whilst the right side shows the ground system configuration.

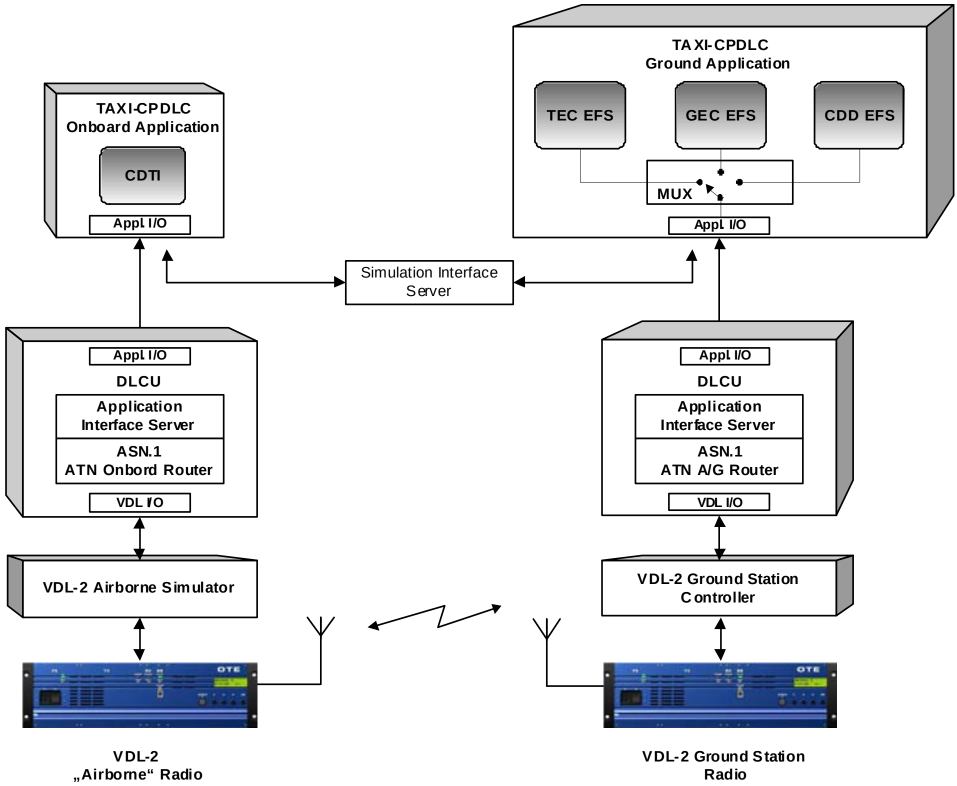

Figure 3: Functional Architecture of the TAXI-CPDLC Implementation

The VDL-2 radios are configurable multimode radios. The ground station radio could be configured and controlled by the ground station controller. Other than in a commercial avionics implementation, also at the onboard side a multimode radio was used, which got its set-up and control by the airborne simulator, and thus behaves like an onboard VDL-2 transponder.

Also at the onboard side no commercial CMU was used, which had the ATN stack and the communication functions implemented. Instead, like on ground, a Data Link Communication Unit (DLCU) was used, which comprised an Application Interface Server and the ATN stack. This configuration provided an open architecture and thus the possibility to implement the TAXI-CPDLC functionality.

At the onboard side the TAXI-CPDLC end application was the Cockpit Display of Traffic Information (CDTI), which served for displaying the traffic situation as well for data link communication.

At the ground side the TAXI-CPDLC end application was integrated with the Electronic Flight Strip System (EFS), which provided HMIs for the Tower/Runway Controller (TEC), the Ground Controller (GEC) and the Clearance Delivery Controller (CDD). The abbreviations TEC, GEC and CDD are Prague-specific.

For simulation purposes the onboard and the ground application were connected via a simulation interface. In the simulation it was not required to use the full communication path via ATN stack and radio transmission.

The following interfaces from an ATN communication stack to an end application were required:

- An onboard interface to the onboard display / CDTI
- A ground interface to the EFS / clearance processing unit

Both interfaces were as similar as possible.

The following figure shows the block diagram of the interfaces. The interface between the ATN communication stack and the TAXI-CPDLC end application consists of an Application Interface Server, which comprises a TCP server for the LAN based data exchange with the TAXI-CPDLC end application client.

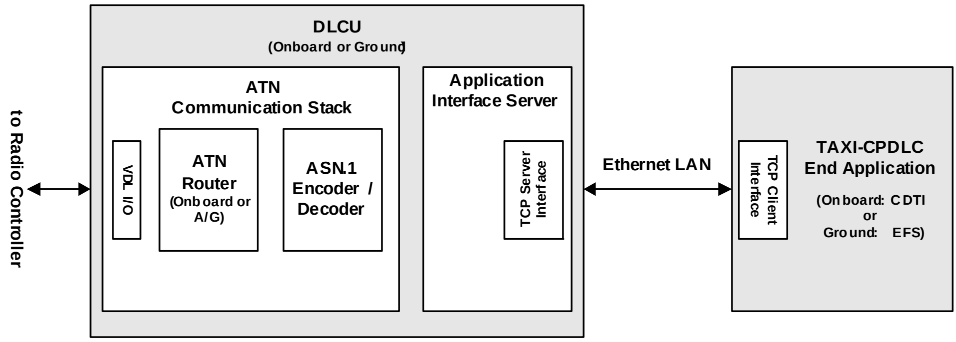

Figure 4: ATN Interface for Onboard and Ground Application

Figure 5: VDL2 Radios for CPDLC

4.3 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.

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.

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.

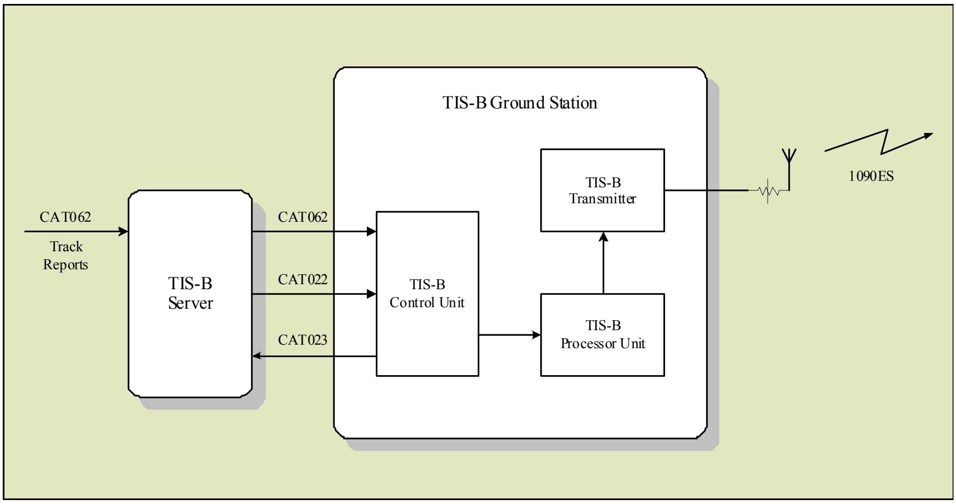

Figure 6: TIS-B Ground System

Figure 7: TIS-B Station

4.4 Controller HMI

The controller HMI (so called CWP: Controller Working Position) consist of a Ground Traffic Display (GTD), the Electronic Flight Strips (EFS) and the regarding functions like planning, routing, guidance and alerting.

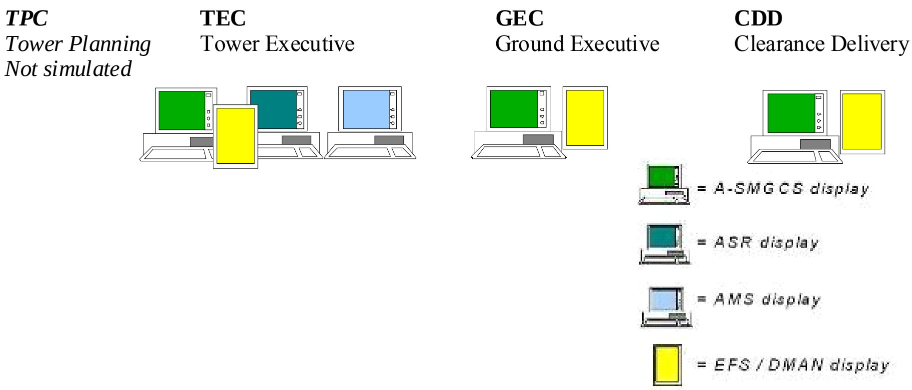

Figure 8: Set-up of the Controller Working Positions of the Experimental System

Figure 9: EFS Screenshot: Test Aircraft (D-ADAM) requests a Taxi-out Clearance by TAXI-CPDLC

4.5 Pilot HMI

The Cockpit Display for Traffic Information (CDTI) consist of the Electronic Moving Map Display (EMM) with the own ship position and the surrounding traffic transmitted by TIS-B. Further on different alerting function could be integrated.

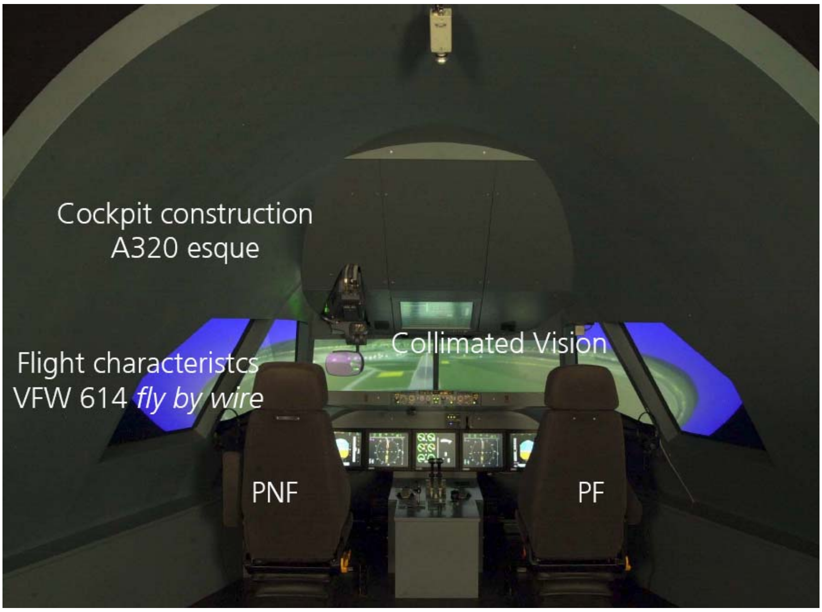

Figure 10: Generic Experimental Cockpit (GECO)

Figure 11: TAXI-CPDLC clearance for TWY H, A after PNF's wilco (NAV mode)

5 BENEFITS OF AN A-SMGCS

Knowing about the benefits that can be expected from A-SMGCS is a key factor in decisions on A-SMGCS implementation. Only if the benefits are identified and quantified, and if the technological and operational feasibility is sufficiently demonstrated, the relevant decision makers will include ASMGCS in their investment plans. A-SMGCS will mainly provide benefits in terms of **safety**, increased **throughput** and **efficiency**. The airport operator and passengers will benefit from a reduction in diversions and cancellations. There may also be some benefits to the airspace user and the airport operator in terms of increased safety, including reduction in loss of life and damage to ground infrastructure, aircraft and vehicles.

5.1 Verification and Validation

Although many tests can be performed in field tests – mainly needed to test the system in real environment in terms of its technical performance and its operational feasibility – some essential benefit criteria can only be validated in simulation runs. Real Time Simulations (RTS) usually offer a good opportunity to measure operational improvements in terms of objective traffic data (e.g. taxi times, R/T load, etc.). They were also used to investigate safety critical situations like low visibility conditions or conflict situations without any danger. A sufficient quality of validation can only be reached if adequate tools and experts are used who are well trained on the new systems / procedures. The real time simulators deserve special attention in this context. They should provide the required performance and flexibility for the envisaged validation. In addition shadow mode trials will support the evaluation: Within shadow mode trials controllers are acting as system observers while the traffic gets controlled in parallel by active operational controllers not involved in system observation. To summarise these three different evaluation methods:

1. Real time simulations:
   Active controllers are operating with new systems / procedures in simulation.
2. Shadow mode trials:
   Passive controllers are observing new systems / procedures on site without interaction with the real traffic.
3. Real operational field trials:
   Active controllers are operating with the new systems / procedures on site, managing the real traffic or only parts of it.

Validation of ATM systems is the last step in the development and integration process before taking these systems in every day operational control. After assuring an adequate performance in the verification phase of the ATM system, validation completes the cycle by including the user's judgement about the right operation of the system. Validation differs from verification in that verification is concerned with testing against requirements, while validation is concerned with finding out whether the defined requirements are appropriate for supporting the users to carry out their tasks.

From these definitions it can be seen that validation is an on-going process which aims to ensure that the overall requirements for the system or subsystems are sufficiently correct and complete, whereas verification is a process which aims to ensure that a particular system implementation meets its specified requirements, at the time of installation and subsequently at pre-defined intervals or whenever changes are made [7].

In summary: Verification is testing against requirements, technical functional testing ("*Did we build the system right*"), validation is operational testing, man-in-the-loop, ATM procedure testing, case studies ("*Did we build the right system?*").

5.2 Experimental Design

The Prague Ruzyne Airport consists of a crossing runway system of two runways, the short one in the south is used for parking positions only.

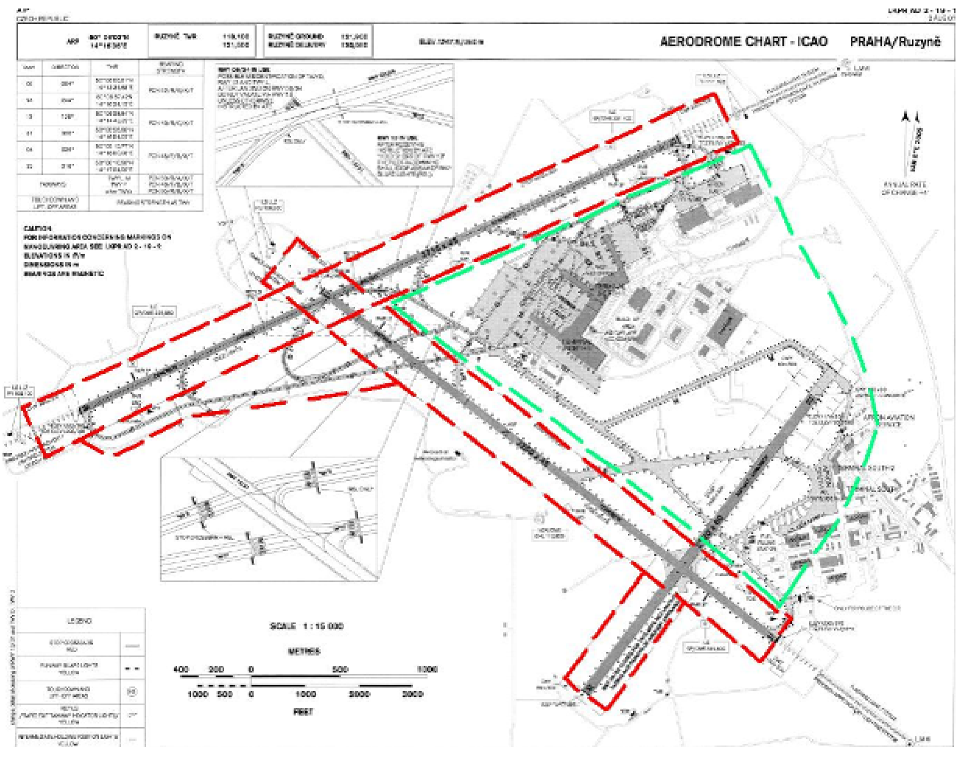

Figure 12: Prague Ruzyne Airport Layout

Even not all technical performance parameters met the ICAO requirements the controllers were satisfied with:

Indicator	Measured	Required
Reported position accuracy	3.2 m – 7.5 m	≤ 7.5 m
Probability of detection	99.65% – 99.98%	≥ 99.9%
Probability of false detection	0% – 0.07%	≤ 0.001%
Probability of identification	99.72% – 100%	≥ 99.9%
Probability of false identification	0%	≤ 0.001%
Target report update rate	0.47s – 1s	≤ 1s
Probability of Detection of an Alert Situation	100%	≥ 99.9%

Table 2: Verification results of the Prague A-SMGCS

During the field test the DLR test aircraft ATTAS (Advanced Technology Testing Aircraft System) was used for TAXI-CPDLC data link applications and the pilot alerting functions like TCD and SMA.

Figure 13: Test Aircraft with Pilot MMD

In EMMA (A-SMGCS level 1&2) as well as in EMMA2 (higher-level A-SMGCS) eleven respectively six ANS CR ATCOs from Prague Tower worked as test subjects in the DLR Tower simulator. With EMMA 33 test runs and with EMMA2 18 test runs were performed. A test run usually lasted 60 minutes with a realistic mix of Prague arrival and departure traffic in a high density traffic scenario. Aircraft were operated by pseudo-pilots. Clearance delivery, ground controller, as well as runway controller positions were always manned by ANS CR ATCOs. Base line scenarios (today status of work) were compared against the different/full A-SMGCS services.

Figure 14: Tower-Simulator (ATS) and Cockpit-Simulator (GECO)

5.3 Analysis of Results [8]

In the upcoming sections, each of the A-SMGCS functions tested in EMMA2 will be analysed by presenting the results of the verification or validation activity carried out.

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

Although ADS-B Out transmissions from aircraft and vehicles were successfully received and all A-SMGCS interoperability requirements were met, performance requirements for accuracy and timeliness of the information could not be met. 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 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 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.

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.

5.3.2 Electronic Flight Strips

In the simulations that took place the Electronic Flight Strip (EFS) Systems were used as enabler for a number of different A-SMGCS services.

The EFS was very advanced regarding HMI design and functionality, so that both systems were well accepted by controllers. 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.

5.3.3 TAXI-CPDLC (Ground and On-board)

Extensive TAXI-CPDLC trials, including both simulations and field trials, were performed. Feedback was mainly received on TAXI-CPDLC operations with start-up, push-back, taxi-in and taxi-out clearances, and handover operations. 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 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.

The 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.

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.

Pilots highlighted the EMM as a very effective HMI presenting the needed graphical information. They highly appreciated the display of taxi routes and clearances. The used terminology and symbology were easy to interpret.

5.3.4 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.

5.3.5 Departure Management

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).

5.3.6 Onboard Electronic Moving Map

In the previous phase of the EMMA project the moving map display was already evaluated. In EMMA2, the EMM functionality incorporated own-ship position, surrounding traffic information, and route and clearance information for navigation purposes. 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 EMM and suggested that it was more comfortable than the workload for handling a paper map.

5.3.7 Onboard Surface Movement Alerting Function

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.

5.3.8 Onboard Ground Traffic Display

Generally, the HMI design 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. It 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).

5.3.9 Onboard Traffic Conflict Detection Function

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.

6 CONCLUSION

The present paper summarises A-SMGCS research activities in EMMA and EMMA2. It shows the technical benefits of A-SMGCS and according to its concept of operations, an A-SMGCS mainly contributes to safety and efficiency.

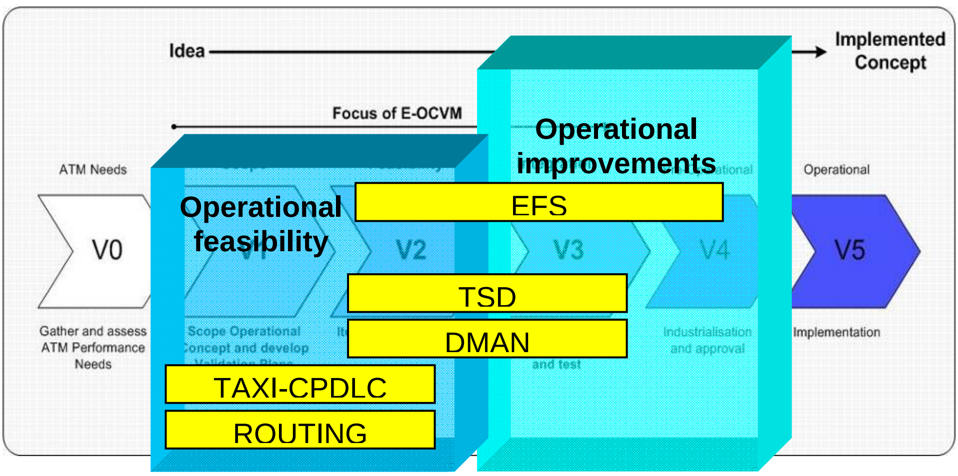

Figure 15: Today A-SMGCS Status of higher services mapped on the E-OCVM

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 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 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 EMM, 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 EMM and GTD in EMMA2 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.

7 REFERENCES

[1] ICAO, Advanced Surface Movement Guidance and Control Systems (A-SMGCS) Manual, Doc 9830 AN/452, First Edition 2004.

[2] EUROCONTROL, 2006, Final Report on the Generic Cost Benefit Analysis of A-SMGCS, Version 1.0, 13 Oct 2006.

[3] EMMA, 2006, Test Results Prague, Jakobi, J. et al, Version 1.0, D6.3.1, EMMA, www.dlr.de/emma

[4] EMMA2, 2008, Prague – A-SMGCS Test Results, Jakobi, J. et al, Version 1.0, 2-D6.3.1, EMMA2, www.dlr.de/emma2

[5] Jakobi, J., Lorenz, B., & Biella, M. (2004). Evaluation of an Onboard Taxi Guidance System. Presented at the Human performance, situation awareness and automation technology conference, HPSAA II, Daytona Beach, 22.-25.03.2004, Embry-Riddle Aeronautical University, FL.

[6] EMMA2, 2008, A-SMGCS Services, Procedures and Operational Requirements (SPOR), Jakobi, J. et al, Version 1.0, 2-D671, EMMA2, www.dlr.de/emma2

[7] EUROCAE Doc. ED-87A (2001), Minimum Aviation System Performance Specification for A-SMGCS, EUROCAE, Paris, France

[8] EMMA2, 2010, Analysis Report, J. Teutsch et al, Version 1.0, 2-D671, EMMA2, www.dlr.de/emma2

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8 Abbreviations

ADS-B	Automatic Dependent Surveillance Broadcast
A-SMGCS	Advanced Surface Movement Guidance and Control System
ASR	Approach Surveillance Radar
ATC	Air Traffic Control
ATCO	Air Traffic Controller
ATM	Air Traffic Management
ATN	Aeronautical Telecommunication Network
CDTI	Cockpit Display for Traffic Information
CFMU	Central Flow Management Unit
CWP	Controller Working Position
DLR	Deutsche Zentrum fuer Luft-und Raumfahrt – German Aerospace Center
DMAN	Departure Manager
EC	European Commission
EFS	Electronic Flight Strips
EMM	Electronic Moving Map
EMMA 2	European airport Movement Management by A-SMGCS, Part 2
E-OCVM	European Operational Concept Validation Methodology
ETD	Estimated Time of Departure
FDPS	Flight Data Processing System
GEC	Ground Executive Controller
HUD	Head Up Display
ICAO	International Civil Aviation Organisation
PRG	Prague Ruzyne Airport
MET	Meteorological Data System

R/T	Radiotelephony
RTS	Real Time Simulations
RWY	Runway
SA	Situational Awareness
SDF	Sensor Data Fusion
SMA	On Boar Surface Movement Alerting
SMR	Surface Movement Radar
SPOR	EMMA A-SMGCS Services, Procedures, and Operational Requirements document
STAND	STAND Allocation System
TAXI-CPDLC	Controller Pilot Data Link Communication with Taxi operations
TCD	On board Traffic Conflict Display
TIS-B	Traffic Information System Broadcast
TSD	Traffic Situation Display
VDL2	VHF Data Link Mode 2
VHF	Very High Frequency

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