Verification and Validation Results from the Operational A-SMGCS Field Trials of the Project BETA

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Abstract

A-SMGCS is a modular concept defined in the ICAO Manual on A-SMGCS (Doc9830). A-SMGCS 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, ATS providers and flight crews are assisted in terms of surveillance, control, planning and guidance tasks. To facilitate the implementation of A-SMGCS and to mature the necessary technology and operating procedures, the European Commission funded the project BETA (operational Benefit Evaluation by Testing A-SMGCS) within the 5th framework programme. Two sample A-SMGCS systems were installed at the two European mid-size airports Hamburg and Prague using equipment from Industry and R&D labs. The operators were trained in simulation and on-site. The prototype A-SMGCS installations have been used to control the regular airport traffic from a separate BETA controller working position in the Tower. Appropriate testing methodologies concerning functional and operational testing were developed and fed forward to the European MAEVA validation standard. Significant progress was made with the maturation of the technical equipment. Operational issues like proper transponder switching have been tackled. The benefit categories of an A-SMGCS were identified and qualified. The paper presents the BETA approach, the main findings and results as well as the main lessons learnt.

1 Introduction

The Vision 2020 [12] envisages a tripling of the air transport demand compared to the year 2000. Already today airports are considered as one main bottleneck of the ATM-system. Following the EUROCONTROL PRC report [11] airport delays are a growing proportion of the total ATM delays. Nearly all European hubs and already some mid-size airports are on the list of the 25 airports causing 90% of the airport delays.

An extension of existing airport infrastructures, e.g. by building new runways is very difficult. Therefore the optimal usage of existing infrastructure becomes more and more a must. Despite of the importance of optimal resource usage, the operations on the airport airside are more or less managed “manually”. Implementation of modern technology for airport airside management was not as fast as for the “real” flight phases in the last decades.

After touch down pilots have to navigate using paper maps and controllers are performing the surveillance task visually. Radio voice transmission is still used as primary communication means. When the visibility conditions are becoming worse – the pilot can taxi normally but the controller cannot fully see the runways – the controller has to make use of the primary airport radar SMR, that gives him a analogue display with a lot of clutter and false targets. In order to ensure the safety special low visibility procedures are used to handle the poor technology support, compromising airport capacity and increasing delays – with repercussion to the approach areas and finally network effects to the overall air transport system.

A further cause that initiated the A-SMGCS development was the occurrence of runway incursions. It is assumed that each day in the US and in Europe one runway incursion is happening. Runway incursions led already to several bad accidents – e.g. in Milano-Linate in 2001.

2 A-SMGCS concept

A-SMGCS as described in [1] and [10] supports tower controllers, apron controllers or ramp managers, pilots and vehicle drivers in a stakeholder-spanning manner with the following four functions:

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 are as well covered. Vehicles and obstacles shall be as well detected, especially on the manoeuvring area. Currently the surveillance of the aprons is most often limited to track aircraft. It is only possible to fulfil these requirements by multi-sensor-systems. 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.

The difference between the conventional SMR screen and a synthetic A-SMGCS screen is illustrated in Figure 1.

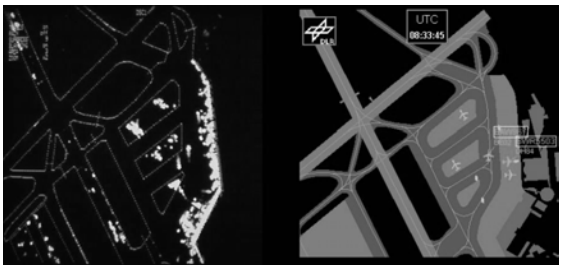

Figure 1: ASDE vs. A-SMGCS Controller HMI

Once the technical and operational feasibility is proven it is intended to allow the controllers to work completely head-down with such systems.

The automatically determined traffic situation is the basis for all further implementation levels and functions.

Control

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

- Taxiing on or crossing of a runway without permission
- Taxiing into prohibited areas (e.g. construction sites)

In a more advanced implementation with planning system support enhancements like conformance monitoring come into consideration:

- Deviations from a pre-planned route
- Deviations from a pre-planned timing

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

Routing / Planning

The Routing/Planning functions is dealing with the support of the controllers w.r.t. spatial and timely planning of the movements with a tactical time horizon of approx. ½ hour. In [1] the term "Routing" is used, putting emphasis on the spatial aspects. In fact the topology of European airports is limiting the possible alternative routes from a specific stand to a specific runway drastically, that there is often only a choice of few alternative standard routes for taxi operations. It seems to be much more important for European airports to get support for the time scheduling of the movements. '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 AMAN, DMAN, SGMAN and SMAN is obvious.

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 functions 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:

<u>Ground Bases Guidance Means</u>, as e.g. switch-able centreline lights, stop-bars or as well runway status lights. Those are often available and should be re-used and integrated. Enhancements to 'follow the greens' are technically feasible today. Finally they can serve as a safety net. They will have their importance for several years, because currently 2/3 of all runway incursions are involving at least one general aviation aircraft – that most probably will not have a onboard guidance system in the short term future.

<u>Onboard Guidance Means</u> as a "Moving Map Display", 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. A sample of such a onboard system – from DLRs TARMAC project – is shown in Figure 2.

Figure 2: Pilot HMI

It shows the own ship position (bright white aircraft symbol in the centre) on the topography of the airport, other traffic with their call-sign, the status of runways the own cleared route in a graphical (green line) and textual mode (at the bottom).

Current Research is indicating that the requirements to the functions (surveillance, control, guidance and planning) are becoming more demanding with increasing implementation level. When using the surveillance as a support tool only displayed false targets might be ignored by the controller due to his cognitive capabilities. Adding a runway incursion detection algorithm would cause frequent false alerts. Therefore e.g. the probability of false detection has to be much lower in this case.

3 BETA Approach

BETA was a major A-SMGCS project funded within the 5th framework programme of the European Commission DG-TREN. The European A-SMGCS situation at the project start was such that the A-SMGCS concept was partly outlined in various documents, that some technological experience was available e.g. from the predecessor project DEFAMM and that those European airports, where A-SMGCS is needed most urgently, started there local attempts to apply the available technology, facing a lot of problems due to pre-mature systems and not available operational procedures. The relationship between technological performance and potential operational usage and the possibly obtained operational benefits was highly uncertain at the project start of BETA.

BETA should improve the knowledge about these issues and especially about the operational benefits. A methodological approach consisting of four main steps as shown in was applied:

As a pre-requisite the following high level benefit expectations to an A-SMGCS were identified:

1. safety gain
2. capacity gain
3. efficiency gain (incl. cost savings)
4. working conditions improvement
5. environmental damage reduction

Obviously these high level objectives are not independent of each other. Therefore it was necessary to break these high level objectives down into low level objectives and measurable indicators.

Step 1: Identify today's Constraints

After definition of top level objectives the limiting factors of today's operations were identified and categorized together with experienced air traffic controllers and pilots. Two samples are given here the full list is reported in [7].

'When active RWYs have to be crossed by landing aircraft, the pilot has to stop before and start moving after the other aircraft passes. Additional delays may arise. The movement has to be co-ordinated in detail and surveyed.'

'The situation awareness decreases during low visibility conditions. Pilots/drivers/controllers may get lost.'

Step 2: Identify potential A-SMGCS Effects

The operational concept of A-SMGCS was described to enable a comparison between a situation with and without A-SMGCS by operational experts. The description in [7] follows the arrival-ground-departure-phases of a flight as shown in Figure 3.

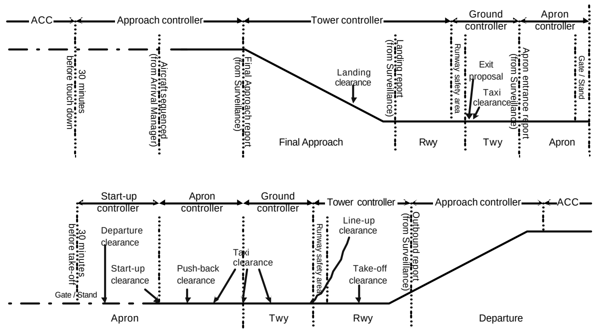

Figure 3: Operational Phases and ATC-Responsibilities

Step 3: Development of Test Concept

The BETA test concept was following a four layer test structure as shown in Figure 4.

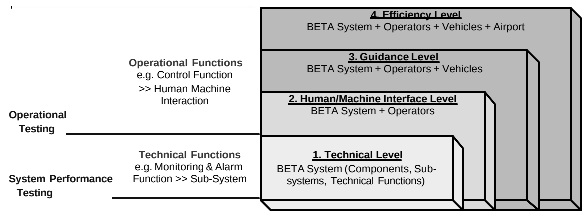

Figure 4: BETA Levels of Testing

It is obvious that only in a combination of simulation and field trials it will be possible to measure the benefits realistically and quantitatively. As BETA was as well aiming at progress of technology and operational feasibility, the focus was put on field trials.

Step 4: Test and Evaluation

The tests took place at two typical European midsize airports, Hamburg and Prague. Some technical pre-tests were carried out at the 'Research Airport Braunschweig' close to DLR premises. The two midsize airports are shown in Figure 5.

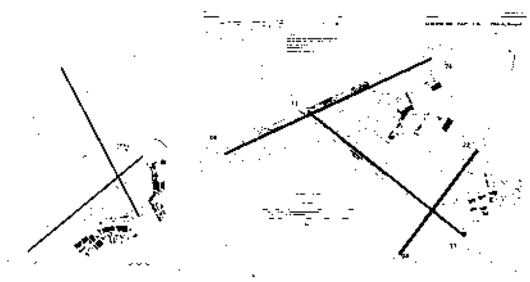

Figure 5: BETA Test-Sites Hamburg and Prague

Multi sensor systems integrating ASR, SMR, MLAT, ADS-B and special gap-fillers were installed and tuned at both sites. Over the whole project time there were two onboard simulations, two tower simulation studies and four on-site trials. With the cockpit simulation 10 Pilots from different airlines took part. With Hamburg nine controllers and three pilots, with Prague six local controllers and four pilots took part as test subjects. For test purposes an additional BETA controller working position (CWP) was set up in the tower cabin, as shown in Figure 6. From this BETA CWP it was possible to take over control as tower, ground, or clearance delivery controller, but supported with BETA A-SMGCS automated functions. Pilots were flying special test aircraft also equipped with A-SMGCS onboard systems.

The BETA CWP was equipped with R/T devices, input devices and two screens, which displayed the actual traffic situation and the list of the electronic flight strips (EFS). Additionally, the BETA CWP provided the controller with several new functions:

- Electronic handover of EFS,
- Routing function,
- Departure Manager function,
- Data link clearances
- Alerts with regard to planning parameter, the clearance delivery status, taxi route deviations and runway incursions.

The test aircraft's cockpit was equipped with a head down electronic moving map (EMM) showing the own position, data link communication and indication of the cleared taxi route.

Per test phase and test location two week of testing was performed. Due to safety restrictions testing was restricted to medium traffic, day light and good visibility conditions.

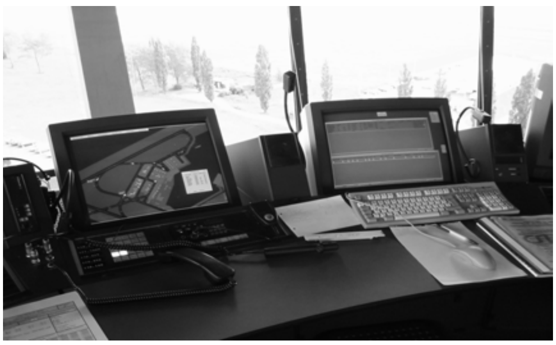

Figure 6: BETA HMI in Prague

Technical system performance was measured objectively and quantitatively using DGPS equipped test cars and DLR test aircraft as a reference.

User acceptance and the operational benefits were assessed subjectively and qualitatively by means of briefing sessions, exercises with the BETA system and de-briefing sessions including questionnaires. Standard methods like NASA TLX and SART were applied.

4 Indicators and Parameters

One outcome of the BETA test planning is a list of measurable indicators. These indicators are linked to the higher level benefit expectations as shown in Figure 7.

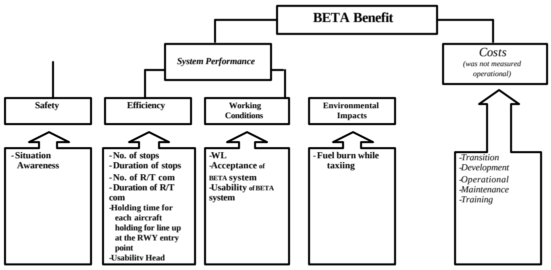

Figure 7: Decomposition of Objectives into Indicators

In order to assess the A-SMGCS technical performance, the following parameters were chosen:

PD	Probability of Detection
PFD	Probability of False Detection
PID	Probability of Identification
PFID	Probability of False Identification
RPA	Reported Position Accuracy
RVA	Reported Velocity Accuracy
PCT	Probability of Continuous Track
UR	Update rate
LT	Latency Time
PDAS	Probability of Detection of Alert Situation
PFDAS	Probability of False Detection of Alert Situation

Definitions of these parameters were initially taken from [8]. These days they are refined in [4].

In order to assess the A-SMGCS benefit, the following objective parameters were finally considered:

a) Situation awareness
b) Number of misunderstandings
c) Number of R/T communication
d) Duration of R/T communication
e) Number of stops during taxiing
f) Duration of stops during taxiing
g) Holding time before line-up
h) Usability head down
i) Workload
j) Usability of the system
k) Acceptance of the system

Additional parameters were identified but were considered as out of the project scope (no effect expected in the realisable test conditions).

5 Results

5.1 Performance Verification

During BETA technical tests were performed at both test-sites in two cycles each. The system performance was assessed during these trials by:

- usage of test vans and test aircraft (see Figure 8) measuring objectively the performance against a reference system
- observation of the system during shadow mode and operational trials and subjective judgements of the operators

The results of the performance assessment were compared with the operational and technical requirements derived from the ICAO document [1] for verification purposes. To limit the scope of this paper only results of the tests concerning the most mature surveillance function are reported here for one specific BETA test "F1A" as an example – further test results can be found in the reports [2] and [3].

Figure 8: Test vans and aircraft

Functional tests concerning the surveillance function were carried out for each individual sensor as well as for the output of the data fusion process.

The DLR test van 'DAZZZ' was driving dynamically on the taxiways and runways following a follow-me car for safety reasons in a distance of 2 to 60m. The test van was simulating a well equipped modern aircraft, equipped with an ADS-B solution (GP&C transponder – predecessor system to the current VDL4 solution) and a SSR Mode S transponder. It was further carrying an geodetically DGPS solution as reference system.

The ADS-B system gave precise information throughout the trial with a good RPA of 2,4m but with a considerable LT of up to 2secs. It is assumed that this latency can be overcome to a certain extent with newer transponder firmware, but the principal characteristic will remain – very accurate and continuous track even on the apron with a higher LT than the ground sensors.

The MLAT (ERA product ASCS) was configured (due to available airport infrastructure constraints) to report the position only in the core area of the airport. The track was quite continuous in this area with only few gaps. The LT of the MLAT was approx. 0,2secs. The RPA of the MLAT was 15m.

The SMR track was not really continuous, showing randomly distributed gaps. The two target were sometimes merged where these two small objects were very close together. The LT of the SMR data was approx. 0,4secs, the RPA 5,2m.

The data fusion was assessing on-line the track using all sensor information (SMR, ADS-B, MLAT) weighting them according to the sensor models but not just giving preference to one of them or switching between them (so it is a 'real data fusion'). The continuous track can be seen in Figure 9. The operational traffic was assessed in parallel, which is not shown here. It was observed that the track of DAZZZ and the follow-me were as well partly merged. This is due to the tuning of the data fusion to avoid track splits in cases where the non-cooperative sensor is reporting e.g. a taking-off aircraft as two tracks, leading to false runway incursion alerts if not corrected by the data fusion.

The LT of the sensors data (see Figure 11) and the LT induced by further processing was compensated in the data fusion by predicting the target movements back to the real time, compromising the accuracy for those moments where manoeuvres occur (all kind of accelerations lead to displayed track overshoot). The data fusion was tested to have an RPA of 12,8m and a LT of 0,1 to 0,2secs (see Figure 12). As the dynamics are of a test van are usually more demanding than those of aircraft this test was showing already some practical lower bound of the performance.

Several of these trials were conducted with different test conditions. The summary of all these performance assessment trials lead to Figure 13, showing the expected values (basically following ICAO) and the measured values for the two test sites Hamburg and Prague.

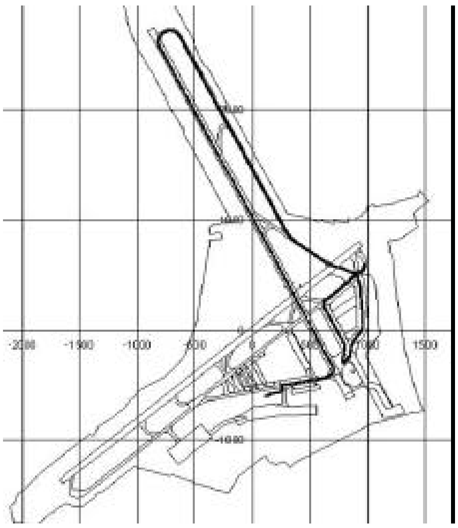

Figure 9: Track of the Data Fusion

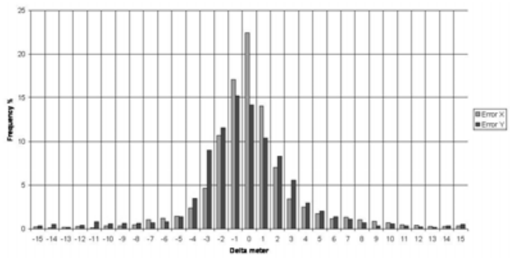

Figure 10: Data Fusion Error Distribution

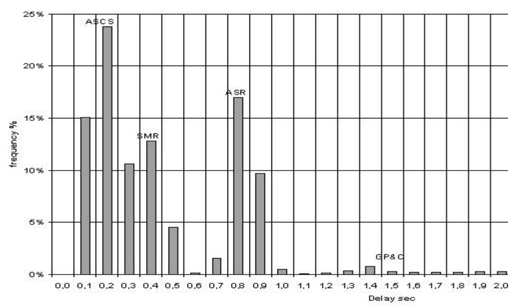

Figure 11: Latency of Sensor Data

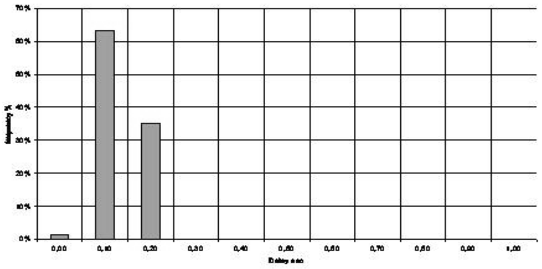

Figure 12: Latency of Data Fusion Data

Item	Expected Value	Measured Value	
		PRG	HAM
RPA	≤ 7.5 m	< 9 m	< 13 m
RVA	≤ 5 m/s	NA	< 3.5 m/s
UR	≤ 1 s	1 s	1 s
LT	unspecified	<0.2 s	<0.4 s

Figure 13: Objective results for functional parameters

The further parameters like PD, PFD, PID, PFID, PCT, PDAS and PFDAS were not measured objectively due to lack of reference for the operational movements. These parameters are currently under investigation in the project EMMA.

Subjective assessments were made together with the operational staff. It was felt that the PD was quite close to 100%. Only in those areas, where the sensor coverage was incomplete (forest shadowing) gaps appeared in the tracks. In a fully operational system a gap-filler or appropriate procedures would have been implemented. PFD was found to be reasonable low, though it was discovered that adding new sensors to the sensor set tends to increase the PFD. The data fusion ‘policy’ in cases of conflicting target features was to suppress the label instead of showing a wrong one. Therefore in those cases, where targets where not resolved anymore (see above) no label was shown. So PID and PFID were sufficiently good.

PDAS and PFDAS were at the same performance level as the underlying surveillance performance.

A special problem was the operational use of the SSR Mode S transponder from touch down to the gate and from push-back to take-off. Pilots are used to switch off transponders after touch down. Sometimes pilots were even unable to manually set the desired transponder mode due to the transponder integration in the aircraft. A NOTAM was issued to the airlines to use the transponders in the desired way, what improved the situation but did not solve it completely. Further the high degree of general aviation – especially at HAM – was leading to a significant number of pure non-cooperative targets.

From the positive feed-back of the controllers (cf. 5.2.4) it is assumed that even a surveillance system with a performance as presented here (slighty worse than the requirements in [1]) would serve the initial wishes of the controllers. Especially controllers were not much irritated by effects like displayed target track overshoots. RPA seems to be less important than PCT and PD. Further PFID seems to be more crucial than PID.

Item	Requirement	PRG	HAM
SR 01	Provide surveillance throughout the aerodrome movement area	√	P
SR 02	Provide surveillance throughout that part of the surrounding airspace where aircraft movements affect surface operations:		
	• For aircraft on approach to each landing runway direction, at such a distance that inbound aircraft can be integrated into the A-SMGCS operation; and	√	√
	• Up to a sufficient altitude that was suitable for covering go-arounds and low-level helicopter operations.	√	P
SR 03	Provide accurate, timely, position information on all movements within the specified coverage volume for the site.	√	√
SR 04	Provide information about the identity of authorised movements.	√	√
SR 05	Provide classification according to size or type (e.g. large, medium, small, aircraft, vehicle, obstacle/unknown) for unidentified or unidentifiable objects detected on the movement area.	√	√
SR 06	Cope with moving and static aircraft, vehicles and obstacles.	√	√
SR 07	Provide all data at an update rate sufficient to meet alerting, guidance and planning requirements both in time and in position.	√	√
SR	Provide a seamless transition between the surveillance of the aerodrome	√	P

08	surface and the surveillance of traffic in the airspace surrounding the aerodrome.		

Figure 14: Surveillance function verification results (P=partial fulfilled)

Comparing the assessed performance with the requirements (see Figure 14) shows the final verification results concerning surveillance function.

5.2 Concept Validation

A large number of results has been gathered by six test campaign, simulation and field trials, pilots and controllers. In order not to get lost in many detailed results this report of results focuses on the last test trials at Prague Ruzyne in 2002 that used probably the most matured system.

The primary aim of the airport operational tests was to obtain relevant measurements that could be used to demonstrate that an A-SMGCS could provide quantitative and qualitative benefits to the current processes for handling surface traffic at an airport.

Indicators and parameters were derived from the high level objectives as explained in chapter 4. A baseline (current systems and procedures) was compared with the BETA system (see chapter 3). The measurements themselves were be performed using either objective or subjective techniques. The objective measurements are principally concerned with the effects of the system on the operational management of the traffic flow at the airport. The objective data is collected by essentially measuring the ease with which the traffic is able to move about the airport surface. The subjective measurements are generally concerned with the user's assessments of the effects of working with the system on, for instance, their situation awareness and workload, this information

5.2.1 Safety

Situation Awareness

Situation Awareness (SA) was measured as an indication of the effect on the safety criterion of the BETA system. It was assessed by operators' subjective ratings in a post run questionnaire (SART), for both the BETA and baseline tests. The SART index comprises a range of –5 (min) to +13 (max), where a rating of 4 corresponds to a medium level of SA.

Figure 15 graphically represents the SART means dependent on the control position and the BETA / Baseline condition. A 2 (BETA) x 3 (Position) repeated-measures analysis of variance (ANOVA) revealed no significant effect, neither for BETA vs. Baseline nor for the Control Positions nor for their interactions.

The measured SART means are distributed nearly equal to one-another, independent of the test conditions, i.e. there is nearly no variance caused by the BETA system nor by different Control Positions. In each test condition the SART means are higher than average. Since the SART questionnaire is usually able to reveal potential differences in a subject's SA, the present test environment does not appear to be sufficient to evoke measurable differences. That is, due to safety reasons, the permitted test conditions had to provide good outside visibility associated with a low/medium traffic load. Such conditions, however, do not place a significant demand on the controller, being independent of which control position or of which system the controller was using. Consequently, differences with respect to the controller's SA are hard to determine, without a more challenging environment.

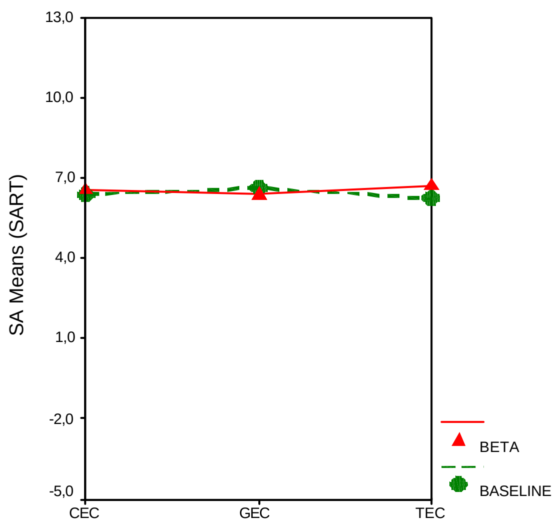

Figure 15: Profile Plots of the SART Means

Number of Misunderstandings

The 'number of misunderstandings' between the controller and the pilot should be measured by observations of the experimenter with support of an appropriate measurement system. Such a specific tool, however, had not been existed nor developed by the time of the trials and could not be provided so that no adequate measure of the 'number of misunderstandings' could be made.

5.2.2 Efficiency

Number and Duration of Stops

Due to very less test validity of these data comprehensive analyses of this parameter were refused, because firstly, Prague Ruzyne is not a highly congested airport, where numerous stops could be expected. Secondly, stops of the taxiing traffic are influenced by numerous permanently changing conditions, external to BETA, e.g. changing runway configurations, dynamic traffic densities with different peaks of either arrival or departures, changing timeliness of the aircraft, altered weather conditions, etc. To cope with those unpredictable conditions, recordings and evaluations over many weeks or even months would be necessary to randomise all the influencing variables to be able to compare effects on the traffic data, which are due solely to the use of the BETA or the BASELINE systems.

Number and Duration of R/T Communication

A second indicator for efficiency was the "Number and Duration of R/T Communication". In order to prove the data for significant differences, an adjustment had to made to ensure that comparison were made relative to the same amount of traffic. That is, one of the two R/T scores, which was to be compared, was extrapolated to the lesser amount of traffic of the two scores.

After this extrapolation the total number and duration of the respective data could be compared by a chi square test, which is well suited for the proof of frequency data.

By a directed hypothesis and $\alpha = 0.05$ a critical Chi square score (?²crit (1; 90%1)) of 2.71 is calculated. Chi square scores that are higher than this critical score are regarded as statistically significant. Since the directed hypothesis expected a lower number and duration of R/T communication within the BETA test condition, only the comparison of the number of communication at the CEC position revealed a significant effect. All other comparisons are either not significant or support the baseline condition.

[1] With a directed hypothesis the critical chi square value correspond to the doubled α-level (5% ? 10%).

Generally, however, it can be stated that controllers using BETA require the same number of communications with the pilot to control the aircraft. On the other hand, the duration of the RT messages per aircraft is systematically longer (constantly 5-6 seconds per control position, approximately 15%) for BETA then for Baseline. This is the case in all positions.

These unexpected results can be explained in that firstly just one aircraft was equipped and controlled via data link. Secondly, a number of communications within the BETA trials very often included the controllers' announcement to the pilots to switch on their transponders whilst pushing back or commencing taxiing, which would have increased the duration of the message. Another reason might be that controllers require more time to find the information they want to communicate to the pilots on their unfamiliar BETA displays while they are speaking with the pilot. This additional "search-time" would extend the duration of the communication.

Holding Time for each Aircraft holding for Line-up at the RWY Entry Point

This efficiency parameter should be mainly influenced by the use of a departure manager. The D-MAN should give the controller the right time of Off-Block and the ETD, as well the best departure sequence when more than one aircraft intents to depart nearly the same time. However, the controller could not use the D-MAN properly because nowadays procedures like "First comes first serves" do overrule the D-MAN's time proposals. In simulation trials the D-MAN was experienced as a very promising tool.

Usability Head Down

The usability of the BETA system whilst working head down exclusively could not be proved. The controllers were requested to work head down but the confidence in the system (the Surveillance function in this case) was still not high enough that controller would trust it blind. The controllers commented that even under low visibility, if using the BETA system they still would ask the pilot whether his/her aircraft had left the runway. Gazes outside the windows are also very influenced by the respective subject themselves as well by the control position, and also the traffic density. A detailed analysis is omitted at this stage because of the obvious result that working with BETA could not yet replace the standard behaviour of 'looking outside the window' when controlling the airport traffic.

5.2.3 Working Conditions

Workload

The NASA-TLX rating scale was used to measure workload. By summing the answers of the six workload dimensions, an overall score ranging from 0 (lower end of the scale) to 120 (higher end of the scale) is attained.

Figure 16 visualises the NASA-TLX workload means depending on the control position and BETA / Baseline condition.

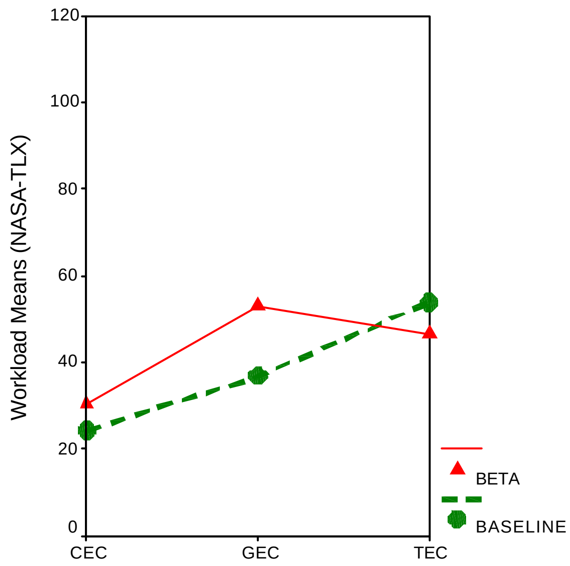

Figure 16: Profile Plots of the NASA-TLX Means

A 2 (BETA) x 3 (Position) repeated-measures analysis of variance (ANOVA) revealed a significant main effect of the 'Control Position', $F(2, 10) = 10.68$, $p < 0,01$. The TEC position had the highest workload mean (50.3 [41.9%]) followed by GEC (45.0 [37.5%]) and the CEC Position (27.5 [22.9%]). This variation in the level of workload between the different controller positions is supported by a contrast-test for proof of linearity, $F(1, 4) = 22.86$, $p < 0.01$, that also shows a statistically significant result.

No significant differences were found between BETA and BASELINE, $F(1, 5) = 2.61$, $p > 0.05$. Both BETA (43.6 [36.3%]) and BASELINE (38.3 [31.9%]) NASA-TLX indices are nearly equal and indicate a low workload. The results is again likely to have been caused by the test environment conditions, with good visual conditions and low/medium traffic load it was usually not very demanding for the controllers to cope with the traffic.

Interesting is the interaction between CEC, GEC and TEC: At the GEC and CEC position working with BETA seems to be harder in comparison with the baseline system whereas working with BETA at the TEC position requires less effort than working with the baseline system. Even though this interaction is not statistically significant ($F(2, 10) = 1.85$, $p > 0.05$), the differences might be caused by different characteristics of the targets' labelling on the surveillance display: The performance of automatic labelling at the Tower position was nearly 100%, no effort was needed to ensure the correct identification. At the CEC and GEC positions, the controllers were often forced to talk to the pilot requesting him/her to switch on the SSR transponder or the controllers would label the targets manually. This additional effort could have evoked an increase in the workload results.

Acceptance of BETA System

On completion of all test runs all six controller were requested to give their opinion on a set of statements, referring to the acceptance of the BETA system. The following table gives an overview of the statements that had to be answered on a scale ranging from 1 (strongly disagree) to 6 (Strongly agree). Additionally within the table, those means marked with an asterisk (*) were determined to be significant according to a 'Binominal Test'. The non-parametric Binominal test proves the probability of the presence of a specific feature, which consists of only two classes, here: Agreement or Disagreement of a specific statement. The answers for the items 1, 9, 10 and 20 are statistically significant with an error probability of 0.05 that is in this case, all controllers had to affirm or refuse a statement. Item 9 expresses the 'good picture of the traffic during the BETA tests'; all controllers affirmed that this was the case. The 'difficulty of the concept of the BETA system' was denied by all controllers. With all other items (except item 10 and 20) only a tendency of the answer can be seen, because there is no statistical significance that can be seen in the mean response.

Statements	Mean
1. The concept of operations for BETA is difficult to understand.	2.00*
2. The BETA procedures were easy to work with.	4.17

3. It is easy to learn to work with BETA.	4.83
4. The BETA system will not fundamentally change the way that controllers work.	3.67
5. The BETA system requires a re-distribution of tasks within the controller team.	2.67
6. Using BETA makes you think differently about the controller tasks.	3.00
7. The BETA system changes routine communication tasks.	2.67
8. This field test changed my attitude towards BETA.	2.17
9. You had a good picture of the traffic under your control during the BETA field tests.	5.00*
10. The BETA system makes the controller's job boring.	1.83*
11. BETA enabled you to handle more traffic.	3.40
12. BETA enabled you to provide the pilots a better level of service.	2.67
13. BETA enabled you to execute your tasks more effectively.	2.67
14. Working with BETA makes you feel safer.	3.50
15. The introduction of BETA will increase the potential of human error.	3.17
16. The types of human error associated with BETA are different than those associated with normal work.	4.00
17. There was enough training to get familiar with the BETA procedures.	4.33
18. There was enough training on the HMI, its rules and its mechanisms.	4.33
19. The work environment (seating, lighting) was comfortable.	4.00
20. There were distractions/disturbances from other activities (e.g. visitors) during the tests.	2.17*
** Marks statistic significance (p < .05)* *# No variance measureable due to no variance of the answers*	

Figure 17: Means of the controllers' acceptance to the BETA System

Usability of BETA System

Usability was measured with use of the 'Standard Usability Scale' by Brooke (1996). All six controllers gave their usability ratings after each test run. The 10 items are answered on a rating scale varying from 1 – 5. Figure 19 shows a graphical representation of the usability means and Figure 18 depicts the strong statistical significance of all three values with $p < .01$.

Position	T-Score	Mean	df	Sig. (1-tailed)
CEC	3.69	3.92	5	0.007*
GEC	4.03	3.57	5	0.005*
TEC	7.50	3.77	5	0.000*
** = Marks statistical significance p < .01* *df = degrees of freedom*				

Figure 18: T-Statistic of the Usability Means of three Control Positions

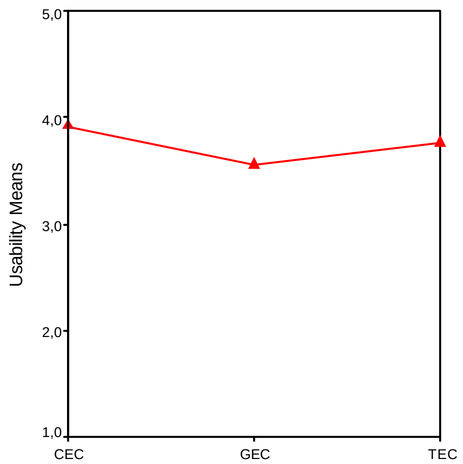

Figure 19: Profile Plots of the Usability Means by each Control Position

Also some Pilots were asked for their perceived usability of BETA. Four pilots could be gained from Czech Airline (CSA). Each of them performed a test run in the test aircraft, which was controlled via data link and equipped with an onboard display, which displayed the current traffic situation, the own position, and the clearances in a graphical form as well alphanumerically to the pilot.

The mean values are put together in the following table. All usability ratings, gained from the pilots, are over-averaged positive. As only three opinions could be assessed a statistical analysis was not considered to be valid.

Position	Pilot Index	Usability index
Co-Pilot	1	4.4 (0.66)
	2	4.4 (0.49)
	3[2]	
	4	4.3 (0.46)

Figure 20: Usability Means of the Pilots (SD)

5.2.4 User Feedback

Controllers

In addition to all the questionnaires and the formal discussion sessions with controllers, the BETA team recorded the feedback from the controllers while they were performing their work. This should be regarded as anecdotal evidence.

[2] No data available.

In general controllers expressed their appreciation for the surveillance part of BETA. It was considered an important improvement over the current radar information. The HMI surveillance part was also liked. Controllers could even imagine working completely head-down if the surveillance data could be proven to be absolutely reliable (a requirement if BETA should bring full advantages under adverse weather conditions).

However, controllers had great difficulty with the Electronic Flight Strips that they felt required too much of their attention and effort. Even after two years of working with them (be it not continuously of course) controllers still preferred paper strips.

Equally critical were the controllers about the routing and guidance functions of the system. It never worked sufficiently well in any of the BETA trials but using their imagination they saw potentially significant problems. According to the controllers there are too many uncertainties and there is too much variability in controlling traffic at an airport that they felt could be currently be incorporated into an automated system. They foresaw even bigger problems if such a system would be applied at a bigger airport with more runways and taxiways and thus more possible uncertainties.

The planning function (as implemented with the departure manager) was regarded as potentially useful, but not in its current implementation. Once again, it could only work if it can deal with uncertainties that are part of airport traffic control (e.g. variability in taxi times, push-back times). Furthermore the departure manager should be able to plan on several runways in parallel and it should take into account arrivals.

During and after the trials comments from the controllers to the different functions of the A-SMGCS were collected. Concerning the most advanced function – the surveillance – the comments were:

Controller	Surveillance Display
APN 1	Nice to have
APN 2	Very often missing labels on the primary targets
APN 3	Ok
APN 4	Doing a good job.
APN 5	Sometimes missing labels, but easy to create afterglow is bad, no identification of cars/bus/ steps and standing aircraft.
GND 1	Working ok Clear – worked fine
GND 2	It is just brilliant, I wish I had one already on my daily duty.
GND 3	Large improvement to last year. It's good.
GND 4	Improved from last year

Figure 21: Comments on surveillance at HAM

Controller	Surveillance Display
CEC 1	-
CEC 2	-
CEC 3	-
CEC 4	-
CEC 5	-
CEC 6	Not needed at CEC position.
GEC 1	Very good surveillance.
GEC 2	Ok – but Mode s must be switched on.
GEC 3	Ok, no comments.
GEC 4	A lot of manual labelling.
GEC 5	I want to have the possibility to rotate the label by the mouse.
GEC 6	Ok.
TEC 1	Surveillance display is ok.
TEC 2	One target disappeared after departure for about 20-30 seconds.
TEC 3	Once label switched from an arrival to departure. More improvements necessary.
TEC 4	S.D. is ok. Better than we have in real traffic.
TEC 5	Not suitable for TEC position, even under low visibility we would ask pilot to report 'Out of RWY', thus not simply trust the display
TEC 6	No comments

Figure 22: Comments to surveillance at PRG

Pilots[3]

Generally, the pilots were very appreciative of such an on-board HMI assisting ground movement operations. They liked the representation of the overall airport showing their own position and including their cleared taxi route, which was transmitted by the controller via data link. They considered that taxiing operations would become safer and more efficient particularly at unfamiliar airports and under adverse weather conditions. But they also proposed some improvements for future use:

In a general, they would prefer to get the most safety critical clearances like "Take-Off clearances" and "Landing clearances" in both ways: via data link and via R/T. That should also help other aircraft

[3] For all original comments see document D22aII [3].

as they can monitor the clearances concerning a runway. Additionally, they would prefer to perform handovers via R/T to guarantee the working of the R/T with the new controller and therefore to ensure the opportunity to fall back to R/T in case of breakdown of the data link. Furthermore, they suggest the provision of an aural warning with an incoming data link clearance. Otherwise a lot of time is consumed by watching the screen.

Another recommendation considers the spatial validity of data link clearances: The pilots would prefer a more segmented taxi instruction in the form of:

1) STAND_B1_TAXI_P//HOLD_04-22;
2) CROSS_04-22;
3) TAXI_P_L_F//HOLD_13-31;
4) CROSS_13-31;
5) TAXI_F_E//HOLD_06
instead of in a single instruction
TAXI_P_L_F E//HOLDRWY_06.

In addition, they wish to have the opportunity to send a "Shut Down" message once they have reached the stand or gate in order to inform the controller that they are leaving the frequency.

However, all in all a ground onboard HMI with a well-integrated data link solution was presented to the pilots, who stated that they would like to see this type of aid in use today rather than sometime in the future.

6 Lessons Learnt

The following summarizing statements are obtained from the final recommendation report of BETA:

a. The A-SMGCS concept has been successfully converted into physical systems by several industrial companies meeting the requirements like modularity, extendibility, etc. (EUROCAE).

b. The airside traffic situation awareness for air traffic controllers and apron management staff can be significantly improved thanks to available A-SMGCS level 1 & 2 systems.

c. A good surveillance sub-system consisting of non co-operative and co-operative sensors is the foundation of all other A-SMGCS functions.

d. Adapted procedures for level 1 & 2 A-SMGCS are immediately acceptable as long as the basic rules for operations are not changed.

e. The main economic benefit of A-SMGCS technology can be expected once confidence in the technical system is improved and adequate safety nets are installed. Then head-down operation becomes possible under all visibility conditions, although this could not be achieved in BETA.

f. The HMI is the key element of this support system. The controllers from the different test sites outlined common requirements. The optimisation of the HMI requires several iteration loops involving users and developers.

g. Pilots are very much in favour of the improved situation awareness that can be provided using a taxi map display, ideally if it includes routing information and identification of other traffic.

h. The onboard guidance function requires an adequate and standardised data link. The STDMA may meet this requirement if it is supplemented with standardised interfaces, and procedures. The performance validation of VDL4 for this application was not part of BETA.

i. The benefit of an A-SMGCS implementation relies upon an optimal management of information from the various data sources.

j. The first step of A-SMGCS level 4 (planning) implementation is the integration of Electronic Flight Strips into the controller working position. Further level 4 assistance tools like Departure-MANager or plan monitoring showed their potential during the BETA testing. Due to their likely affects on the controller's way of working additional evaluation and development is required. It can be expected that additional workload will be avoided if these functions are fully integrated into the overall ATM environment and the HMI has reached a mature level.

k. Tests involving the routing function were too strongly interrelated to other planning function to be efficiently used and assessed. Future tests should allow for a higher interaction with the controller (e.g. manual assignment of route to an aircraft, manual update of route), and thus will require more study on the adequate human-machine interface.

l. Large-scale live trials are essential for proving the operational concept, establishing user acceptance and demonstrating direct and indirect benefits for users. The two phase trials approach showed significant advantages in such exercises. However, the performance level of any developmental system was seen to need to be at a suitably high level before it is likely to be fully accepted by the user in the operational environment.

At the final project presentation day, a retired controller was summarising very well the course of the project:

"My summarizing comments to the second field test at Hamburg are the following: We experienced improvements within many fields, we were able to use the system during all days of the two weeks, some but not all lessons from last year were learnt, criticism could be stabilized and focused onto important aspects, controllers are still distrustful of and reserved against electronic flight data systems and - main expected benefits weren't proved because of safety regulations under operational conditions. However, A-SMGCS is on a good way to improve and replace old methods some day somehow, at least partly and step by step." (Dieter Wilbert, retired ATC controller, BETA Test Co-ordinator Hamburg, Hamburg 2002-10-29)

7 Conclusion and Outlook

During the course of BETA, the first time a consistent operational concept for A-SMGCS was derived. The turn-around of aircraft from final approach to the stand and back until take-off was described with and without A-SMGCS.

BETA has chosen an iterative project approach with two development cycles that were aiming at operational trials each. During the first cycle the technical systems were improved and tuned dramatically making use of in-depth measurements and analysis of the technical performance and of the feed-back of operational staff.

During the second cycle the first time an operational use of the basic A-SMGCS functions surveillance was demonstrated at both test-sites working partly head down from the supervisor position in the tower (with backup controllers for safety reasons).

Higher level functionality's like planning support including electronic flight strips or onboard guidance systems were tested partly in case studies partly operationally. The results are that these functions have to be further developed taking into account the feed-back of the operational staff.

Technical improvements derived from the BETA test experience have been introduced to the pre-operational systems of the manufacturers that were involved in BETA. Partly the test-sites involved in BETA estimated that they saved at least two years towards the operational implementation of A-SMGCS. Feed-Back and results from BETA were taken into account in the ICAO Manual [1] and the EUROCONTROL work [10] leading to improvements to the framework of A-SMGCS implementation. All together this more than justifies the effort spend by the European Commission and the BETA partners.

Looking into the future, what remains as task for further R&D is the consolidation and full validation of the ICAO Manual [1] by additional large scale trials, what is started already in the 6th framework programme with the project EMMA in close coordination with EUROCONTROL's A-SMGCS project. It has to be finally proven that it is possible to work fully head-down with an A-SMGCS. In addition the world-wide mutual understanding of A-SMGCS R&D results is necessary – a FAA-EUROCONTROL-Action Plan on A-SMGCS and CDM is under final preparation to help in this respect. Large implementation programmes like the European SESAME should make best use of the R&D results of BETA and EMMA for their implementation decisions. Last but not least the A-SMGCS R&D community has to start now the technical and especially operational maturing process of the higher A-SMGCS levels.

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9 Abbreviations

ACARE	Advisory Council for Aeronautics Research in Europe
ACC	Area Control Center
ADS-B	Automatic Dependent Surveillance Broadcast
AMAN	Arrival Manager
ANOVA	Analysis of Variance
APN	Apron
ASCS	Airport Surface Control System
A-SMGCS	Advanced Surface Movement Guidance and Control System
ASR	Approach Surveillance Radar
ATM	Air Traffic Management
ATS	Air Traffic Service
BETA	operational Benefit Evaluation by Testing A-SMGCS
CEC	Clearance Executive Controller
CFMU	Central Flow Management Unit
CNS	Communication Navigation Surveillance
CPDLC	Controller Pilot Data Link Communication
CWP	Controller Working Position
DEFAMM	Demonstration Facilities for Airport Movement Management
DG-TREN	Directorate General Transport and Energy
DLR	Deutsches Zentrum für Luft- und Raumfahrt
DMAN	Departure Manager
EFS	Electronic Flight Strips
EMM	Electronic Moving Map
EMMA	European airport Movement Management by A-SMGCS
ETD	Estimated Time of Departure
EVA	Eurocontrol Validation of A-SMGCS
FAA	Federal Aviation Administration
FP	Framework Programme
GEC	Ground Executive Controller
GND	Ground
HAM	Hamburg
HMI	Human Machine Interface
ICAO	International Civil Aviation Organisation
LT	Latency Time
MAEVA	Master European Validation Plan
MLAT	Multilateration
NASA	National Aeronautics and Space Administration
NOTAM	Notice to Air-men
PCT	Probability of Continuous Track
PD	Probability of Detection
PDAS	Probability of Detection of Alert Situation
PFD	Probability of False Detection
PFDAS	Probability of False Detection of Alert Situation
PFID	Probability of False Identification
PID	Probability of Identification
PRC	Performance Review Commission
PRG	Prague
R&D	Research and Development
RPA	Reported Position Accuracy
RVA	Reported Velocity Accuracy
RWY	Runway
SA	Situation Awareness
SART	Situation Awareness Rating Scale
SESAME	Single European Sky Implementation Programme
SGMAN	Stand and Gate Manager
SMAN	Surface Manager
SMR	Surface Movement Radar
SR	Surveillance Requirement
SSR	Secondary Surveillance Radar
STDMA	Self-organising Time Division Multiple Access
TARMAC	Taxi And Ramp Management And Control
TEC	Tower Executive Controller
TIS-B	Traffic Information Service Broadcast
TLX	Task Load Index
TLX	Task Load Index
TWR	Tower
TWY	Taxiway
UR	Update rate
US	United States
VDL-4	Very high Frequency Data Link Mode 4

10 Acknowledgement

The project BETA was funded by the European Commission DG-TREN under Contract 1999-RD.10840. We would like to thank DG-TREN for their support. Further we thank all consortium partners of the BETA team for the fruitful collaboration.

11 Keywords

A-SMGCS, Airport Airside Management, Surface Operations, Operational Trials, Verification, Validation, Human Factors, BETA, FP5, CDM, ATM

12 Biography

Christoph Meier received his diploma in electrical engineering in 1990 and his PhD in 1998 from the Technical University of Braunschweig. Since 1990 he is with DLR Institute of Flight Guidance. He is working in the domain of airport airside traffic management, with focus on A-SMGCS, currently as a department head. He was involved in the A-SMGCS projects of the European Commission DEFAMM, BETA and EMMA and in the EUROCONTROL project EVA. He was managing the CNS part of the DLR A-SMGCS project TARMAC. He was member of the ACARE SRA2 sub-team on ATM, contributing to the European Strategy towards the Vision 2020.

Jörn Jakobi received his diploma in psychology from the University of Göttingen. Since 2000 he is as a human factors expert with DLR Institute of Flight Guidance. He was editor of the BETA operational concept and was coordinating operational A-SMGCS on-site trials at Hamburg, Prague and Zurich. Currently he is managing the sub-project ‘Concept’ of the FP6 integrated project EMMA.