Economic Aspects of Advanced Surface Movement Guidance and Control Systems (A-SMGCS)

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Increased incidences of runway incursions and the negative effects of bad weather on airport throughput led to the development of Advanced Surface Movement Guidance and Control Systems (A-SMGCS). The basic levels of A-SMGCS primarily provide aerodrome air traffic controllers (ATCOs) with a weather independent display of the complete traffic situation and a basic runway safety net. Higher-level A-SMGCS will support ATCOs as well as pilots and vehicle drivers in the domains of traffic surveillance and control, routing (planning) and guidance in a holistic way. In 2004 ICAO published the A-SMGCS manual as document 9830 [3], describing operational, functional and performance requirements. Under the umbrella of EUROCONTROL and the European Commission several A-SMGCS projects were launched during the last ten years, such as BETA, EVA, EMMA and EMMA2 (European Airport Management by A-SMGCS). The most important results of those research activities are presented in this paper. Proven benefits are reported, and economic savings are derived and put into relation to the costs of an A-SMGCS for different airport sizes.

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). However, A-SMGCS is also a large investment for both Air Traffic Service Providers (ANSP) and airport operators. So far, only 17 airports in the ECAC area are equipped with at least a level 1 (improved surveillance) A-SMGCS. Cost benefit considerations play an important role for the respective stakeholders. Therefore, such economic aspects will be discussed in this paper.

This paper outlines the concept of an A-SMGCS level 1&2 and its “higher-level” services and compiles operational benefits, which were proven in different airport surface-related research efforts like the European Commission project EMMA and EMMA2 (European Airport Management by A-SMGCS), and the EUROCONTROL A-SMGCS project between 2003 and 2009[1]. In a final step these benefits are transformed into economic savings and put into relation to the monetary costs of an 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

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[1] DLR and NLR were heavily involved in these research projects: DLR had the leadership in both the EMMA and EMMA2 programme and together with NLR were responsible for concept definition and validation activities. In the EUROCONTROL A-SMGCS project DLR and NLR were responsible for the planning, conduction, and evaluation of field trials in Frankfurt, Vienna, and Zurich.

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 [23]. With 18 million movements on the ECAC airports per year, this results in one runway incursion related accident every 3.7 years [23].

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[2] 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

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[2] A-SMGCS levels 1&2 were under investigation in EMMA and the EUROCONTROL A-SMGCS project. EMMA2 dealt with higher-level A-SMGCS services.

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.

A higher-level A-SMGCS was under investigation in the EMMA2 project. Its general system architecture is shown below in Figure 1.

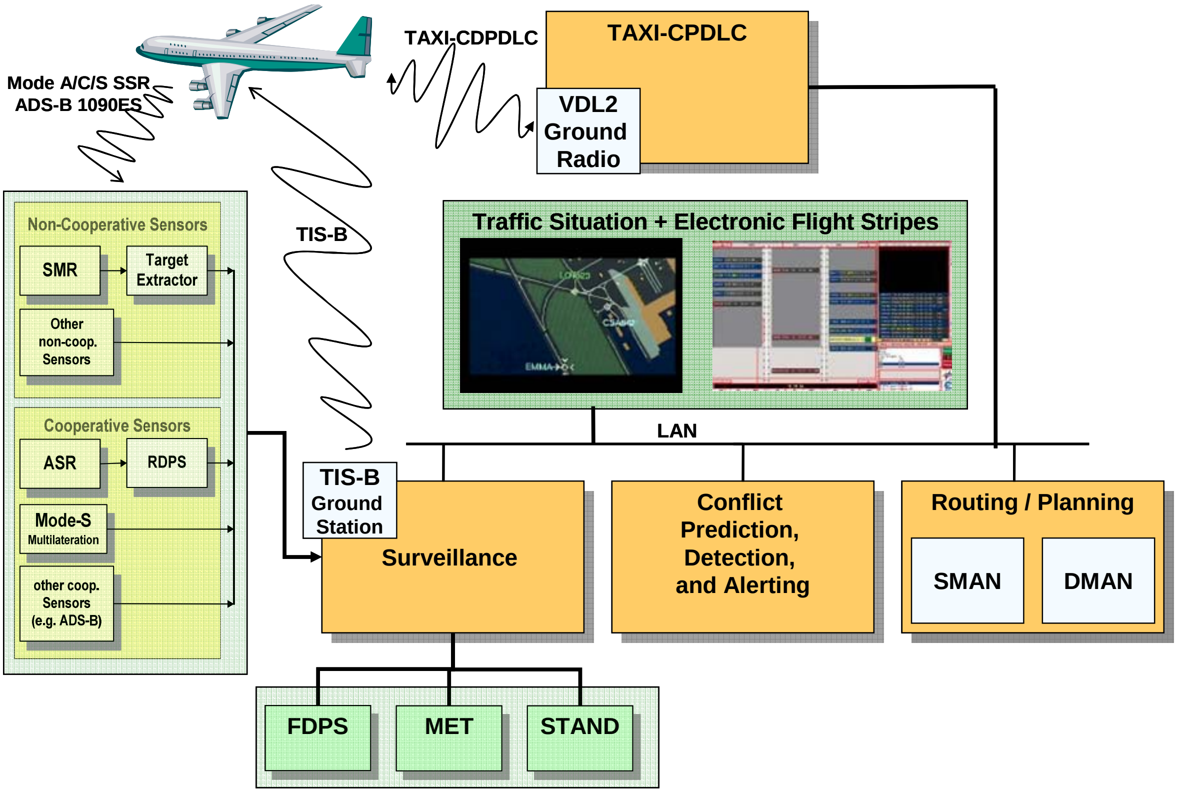

Figure 1: General System Architecture of a "higher-level" A-SMGCS

3 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 A-SMGCS 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.

The benefits reported in this paper are mainly based on research done in the EU projects EMMA (2004 – 2006) [28] and EMMA2 (2006 – 2009) [29] focussing on the trials performed by DLR. Additionally, EMMA results are accompanied by references to results of other projects, like the EUROCONTROL A-SMGCS project [5] [9] or TARMAC [31]. Although field tests were performed in all projects, they mainly served to test the technical and operational feasibility. For gathering convincing quantitative results, real experimental conditions are needed as provided in real-time simulations. Therefore, all results reported in this paper originate from such kind of simulation platforms.

3.1 Experimental Design

In EMMA (A-SMGCS level 1&2) as well as in EMMA2 (higher-level A-SMGCS) 11 respectively six ANS CR ATCOs from Prague Tower worked as test subjects in the DLR Tower simulator. EMMA dealt with two independent variables: IV-A = “Visibility” (3 factors: CAVOK, CAT I, and CATII/III) and IV-B “System” (2 factors: Baseline (SMR only) vs. A-SMGCS level 1&2).

As higher-level services support the users in terms of planning, information access/exchange and communication, different visibility conditions were neglected as independent variables in EMMA2. Thus, in EMMA2, IV-A “Systems” investigates effects of the different new services. IV-A was composed of three levels (Baseline (A-SMGCS level 1&2), EFS, and DMAN).

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.

3.2 Results

3.2.1 Throughput and Capacity

According to the A-SMGCS concept (e.g. EUROCONTROL [1] or EMMA2 [25]) one of the main expected benefits from implementation of A-SMGCS will be the maintenance of airport throughput in reduced visibility conditions and at night.

Simulations from the EUROCONTROL A-SMGCS project indicated an increase in movement rates in all conditions between **5% and 15%** with A-SMGCS level 1&2 [5]. Supporting evidence for this comes from field trials data. ATCOs at Vienna, Heathrow and Zurich confirm that A-SMGCS level 1&2 allows throughput to be maintained in visibility 2 conditions [9]. The impact in these conditions depends on the complexity of the ground layout (complexity of airport tracks, taxiways and runways) and on local LVP implementations. However, for a given traffic demand, an increase in available airport throughput brings about a reduction in total delay, assuming the airport is limited in capacity.

Within EMMA and EMMA2 such an effect could not be measured. The traffic scenarios used in the EMMA simulation runs were not that demanding that they caused capacity problems at Prague airport, not even in low visibility conditions. In EMMA2 those traffic scenarios were improved to this respect but new A-SMGCS planning tools were mainly designed to improve efficiency, to equalise outbound peaks in order to avoid stop and go manoeuvres and excessively long runway queues. Therefore EMMA and EMMA2 cannot provide a conclusion to the A-SMGCS effect on throughput.

3.2.2 Efficiency

Reduced Taxi Time

An A-SMGCS level 1&2 provides the ATCO with an excellent picture of the traffic situation with accurate position, call-sign labels, speed and heading. Movements on the ground can thus be better monitored, anticipated and co-ordinated, which shortens taxi time as an overall effect. This effect seems to be independent on the visibility conditions. In reduced visibility, the ATCO seems to be benefit from the effect that, through A-SMGCS level 1&2, the traffic situation is still present. Instead, in good visibility usually more aircraft are taxiing and beneficial co-ordination effects of A-SMGCS level 1&2 cause shorter taxi times.

In EMMA and in EMMA2 the taxi time was measured automatically for each aircraft starting from the parking position (velocity > 0 kts) until the wheels left the ground (take-off) for outbound movements. For inbound movements, the time measurement started when the wheels touched the ground (touch down) until the velocity was 0 at the final parking position. In EMMA, pairs of “taxi times” (with and without A-SMGCS level 1&2) were added up for each scenario A, B, and C dependent on in- and outbound traffic. The pairs were tested via a t-test with repeated measurements. The results showed significant differences in the taxi times between A-SMGCS and the baseline condition: M_{Total} = -30 seconds, $T_{(178)} = 1.973$, $p < .05$. This mean value corresponds to an effect of 5.5%.

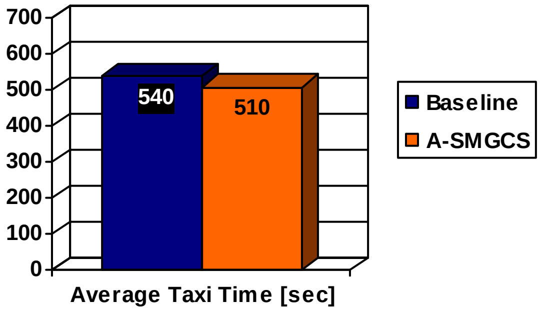

Figure 2: Reduced Taxi Times (EMMA project)

Simulation campaigns for the EUROCONTROL A-SMGCS project even showed a 15% reduction in taxi time caused by an A-SMGCS level 1&2 [5].

With higher-level A-SMGCS services, additional reduction of taxi time compared to level 1&2 could be proven. During the cockpit simulation trials in the project TARMAC, pilots taxied faster in low visibility conditions when they were supported by an electronic moving map (EMM) showing their own ship position and the cleared taxi route to be followed. With support of an EMM they taxied with an average speed of 14.2 knots, without EMM they only taxied with an average speed of 12.1 knots, which would result in a 15% reduction of taxi times [31].

In EMMA2 [29], the effect of a DMAN on the stop times during taxiing was investigated. Stop times are the times during taxiing, when the aircraft is not moving. A significant positive effect for the DMAN was measured. Taxiing traffic in the DMAN test conditions had 24 seconds (26%) less stop time than in the baseline conditions (one-way repeated measures ANOVA, $F_{(2,10)} = 4.24$; $p = .046$*). There seemed to be less waiting time at the runway entry points and less stop and go manoeuvres during taxiing due to the effect that DMAN equalises outbound traffic. Compared to an A-SMGCS level 1&2, reduced stop times would further contribute to shorten the taxi time: In the EMMA2 Prague airport setting by 4,5%. This result also corresponds to the answers given by the ATCOs after the trials in the debriefing session:

Questions / Statements	M	N	SD	p
The DMAN calculated times (TSAT, TTOT) and the recommended time until the next clearance (RTUC) helped me to perform my control task more efficiently.	4.33	6	0.52	.03*
The DMAN calculations help me to avoid excessive departure queue length at the runway entry point.	5.00	6	0.89	.03*
The new A-SMGCS services (EFS + DMAN) support me to reduce the average stop time of the aircraft.	5.00	6	0.89	.03*
The new A-SMGCS services (EFS + DMAN) support me to reduce the average taxi time of the aircraft.	4.17	6	0.41	.03*

Figure 3: Debriefing Answers of the ATCOs to their perceived Efficiency of the higher-level A-SMGCS services (EMMA2) [3]

Radio Communication Load

An overall improved ATCO situational awareness and new procedures that make pilot position reports unnecessary, reduces the need of communication between ATCO and pilot. Data link communication (TAXI-CPDLC), as a higher-level A-SMGCS service, further reduced the time spent on communication via radio when taxi clearances are requested, transmitted and acknowledged by data link. For the pilots, waiting times to talk with the ATCO can be reduced to a minimum and traffic can be handled more efficiently during peak hours. Both anticipated effects could be proven in EMMA and in EMMA2. In EMMA, a two-way 2x3 ANOVA shows a significant result for A-SMGCS level 1&2 with a significant mean difference of 237 (12.5%) seconds per hour less R/T load ($F_{(1,30)} = 12.2$, $p < .05$).

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[3]. Answers from “strongly disagree” (1) to “strongly agree” (6); Binominal tests; Test value 3.5; A star (*) attached to the p-value indicates a significant result ($p \leq .05$).

The EUROCONTROL A-SMGCS projects revealed an effect of 20% R/T reduction caused by an A-SMGCS level 1&2 [5].

In EMMA2, a descriptive analysis comparing the times needed for radio telephony communication in a test run with and without the use of TAXI-CPDLC was performed for the ground controller position (GEC). The results are based on 15 TAXI-CPDLC test runs, and 18 test runs with A-SMGCS level 1&2 but with R/T communication only. In the TAXI-CPDLC traffic scenario, 50% of the flights were data link equipped and, with the exception of the initial call to assume the flight and provision of additional traffic information, all communication[4] was performed by TAXI-CPDLC. This resulted in 40% less radio communication time.

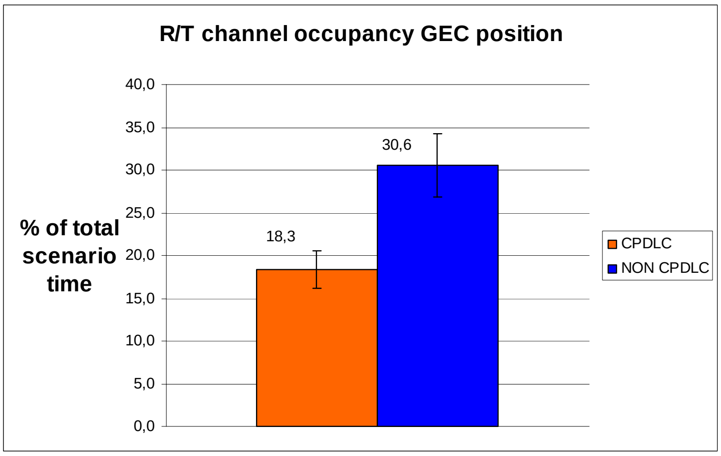

Figure 4: Percentage of time needed for R/T Communication with and without TAXI-CPDLC

3.2.3 Safety

Safety benefits from A-SMGCS level 1&2 are mainly caused by an increased situational awareness for the controller. As a result, controllers are working more ahead of the traffic, are able to better anticipate conflict situations, and better detect real conflict situations, thus reducing the likelihood of real accidents.

Situational Awareness

In EMMA after each test run the ATCO's situational awareness was measured with a simple five-point Likert scale. These ratings were merged to two scores per controller, one for the A-SMGCS level 1&2 and one for the baseline condition. A t-test with repeated measurements revealed a t-value of $T_{(10)} = 2.965$ with a p-value of .007, which expresses statistical significance.

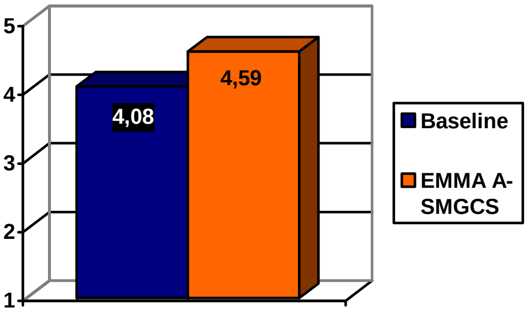

Figure 5: Debriefing Answers of the ATCOs to their perceived situational Awareness (EMMA)

Conflict detection

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[4]. Requests by the pilots, Pushback, Taxi-Out, Taxi-In, Revised Taxi, handover instruction

In EMMA controller reaction time was assessed by an observer who measured the time between the initiation of a conflict and the reaction of the ATCO in charge. The reaction of an ATCO was defined by the time when the ATCO contacted the pilots to resolve the conflict. Pilots in the simulation were not real pilots but pseudo-pilots. They were instructed to cause conflict situations. The results showed an improvement of 11.5% in the 'reaction time' of the runway controller between A-SMGCS and the baseline condition even if statistical significance ($M = -0.69$ seconds, $T_{(12)} = -0.560$, $p > 0.05$) could not be achieved. However, an important trend was discovered that showed that ATCOs react faster in the A-SMGCS level 1&2 condition (cf. [28]).

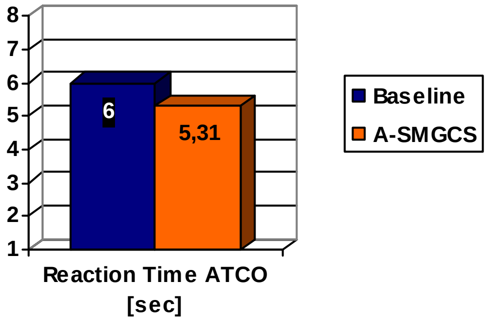

Figure 6: ATCO's reaction time in case of conflict situations

The EUROCONTROL A-SMGCS project simulated runway, closed taxiway, and protected area incursions. In the baseline (no A-SMGCS) 30% of the simulated incursions were detected by controllers. With A-SMGCS level 1, 40% of the incursions were detected (an increase of 10% with respect to the baseline). With A-SMGCS level 2, 80% of the incursions were detected (an increase of 50% with respect to the baseline.) [5].

3.2.4 Environmental Benefits

A reduction in taxi times does not only lead to efficiency benefits to an airspace user. The burning of aviation fuel causes the emission of carbon dioxide, oxides of nitrogen, oxides of sulphur, water vapour, hydrocarbons, particles - the particles consist mainly of sulphate from sulphur oxides - and soot. The reduction in fuel burnt also results in a reduction in emissions at the airport, which has an environmental benefit.

Based on a medium WVC aircraft type, such as the Boeing 737-400, and an average saving of 5% taxi time at airports with 350,000 movements per annum, this would result in savings of:

- 1,470,000 kg fuel burn,
- 4,630,000 kg CO_2, and
- 1,230 kg SO_2 [17].

4 ECONOMIC ASPECTS OF AN A-SMGCS

Knowledge about the expected benefits of an A-SMGCS leads only to one parameter for calculating economic savings. Also, the costs for A-SMGCS equipment and the maintenance of that equipment must be taken into account, as well as specific airport and traffic characteristics. In the end, each stakeholder must perform his own cost-benefit analysis applying the exact local values. Nevertheless, this paper attempts to provide a general analysis based on two general airport types and average costs for equipment. Numbers provided here are mainly based on EUROCONTROL data and reports from 2005 and 2006 [22] [23] [24]. Since higher-level services are still rather complex and immature, exact costs are hardly known so far, and benefits have not been proven exhaustively, this study focuses on A-SMGCS level 1&2 economic savings only.

4.1 Types of Airports

For analysis, two typical airport types were chosen. Airport A is a typical European midsize airport like Prague Ruzyne or Milano Malpensa with at least 175,000 annual movements and 50,000 minutes of weather delay. Airport B is a typical large European Airport like Frankfurt International Airport (Rhein-Main) or Paris Roissy Charles-de-Gaulle with at least 350,000 annual movements and 100,000 minutes of weather delay.

4.2 Costs

All costs refer to the EUROCONTROL 'Final Report on the generic cost benefit analysis of A-SMGCS' [23]. It is assumed that one surface movement radar (SMR) is already available. Main equipment for level 1 would then result in a multi-lateration system (receivers + transmitters), a sensor data fusion, an update of the controller working position, and the equipage of vehicles with Mode-S transponders or similar technologies. For level 2 two additional SMRs would be needed to reduce the probability of false detection (false targets). For both system levels operating costs were calculated. The following concluding cost table was produced:

	Stakeholder	one-off capital costs	one-off implementation costs	TOTAL one off costs	operating costs per annum
Airport A	ANSPs (10 receivers + 2 transmitter, 5 CWP)	2.6M€	0.593M€	3.3M€	0.274M€
	Airports (75 vehicles)	0.150M€	0.019M€	0.169M€	0.019M€
Airport B	ANSPs (20 receivers + 3 transmitters, 10 CWPs)	3.4M€	0.653M€	4.2M€	0.342M€
	Airports (150 vehicles)	0.3 M€	0.038 M€	0.338 M€	0.038 M€
	Airlines	Costs for airlines derive entirely from the service charge passed on by ANSPs and Airport Operators.			

Figure 7: Total Costs of A-SMGCS level 1&2 at a large and a medium size airport

Costs for medium size airports are a bit higher as compared to large airports, since investments for a sensor data fusion or the implementation costs are always the same.

4.3 Economic Savings

4.3.1 Throughput and Capacity

According to §3.2.1 of this paper, simulations have shown a 5% average increase in throughput in all visibility conditions using A-SMGCS level 1&2. According to the APR business case [11], a 5% increase in throughput would lead to a 25% decrease in delays. It is assumed that, on average, 60% of all delays are caused by bad weather (cross winds, snow, thunderstorms, low visibility, etc). It is further assumed that among those 60% of bad weather delays 40% are generally caused by low visibility where A-SMGCS is expected to have a positive influence (which is a rather conservative estimate). In a nutshell, 25% less delays out of the 40% of delay caused by low visibility would result in a 10% reduction in all weather-related delays (cf. Figure 8)

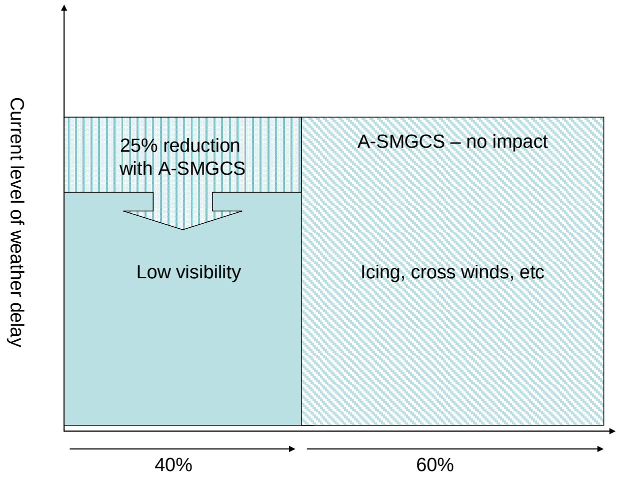

Figure 8: 10% Delays Reduction by A-SMGCS level 1&2 of all Weather related Delays[5]

In accordance to EUROCONTROL [16], with delays being longer than 15 minutes, one minute of delay is assumed to cost 72 EUR. For a medium size airport with 50,000 minutes of weather delay per annum, this would result in savings of 10% * 50,000 minutes * 72 EUR = 360,000 EUR. For large airports with 100,000 delay minutes, this would even lead to savings of 720,000 EUR.

4.3.2 Efficiency

In this report, efficiency was mainly looked at as reduced taxi times. Simulations in EMMA and the EUROCONTROL A-SMGCS project proved an effect of at least 5% for A-SMGCS level 1&2. With higher level A-SMGCS, this effect is certainly further improved: departure planning (DMAN) as well as onboard guidance (EMM + cleared route) could (independently from each other) further reduce taxi times by an additional 5%.

The Westminster Report [12] estimates the costs of delay during taxiing (delays lower than 15 minutes and without additional network effects) at 5 EUR per minute. Assuming the rather conservative delay reduction of 5% of taxi time by an A-SMGCS this would result in 5% * 13 minutes of taxiing in average * 87,500 departures * 5 Euro = 284,000 EUR per annum. For a large Airport 569,000 EUR could be saved per annum. With higher level A-SMGCS services such savings are expected to be doubled or even tripled.

4.3.3 Safety

Simulations in the EUROCONTROL A-SMGCS project proved that the detection of an incursion is 50% more likely with support of an A-SMGCS level 1&2 (§3.2.3).

In 2006, the accident rate as a result of runway incursion at ECAC airports was calculated to be 1 in every 66,600,000 movements ($1.5*10^{-8}$), which would mean that, with 18,000,000 movements per annum within the ECAC area, one runway related accident occurs in every 3.7 years. With 50% better detection by an A-SMGCS, this figure would be halved to 1 accident in every 7.5 years [23].

Obviously, runway incursions and particularly accidents are rather costly. For example, only the mere cost for the hull loss of two aircraft caused by the Milan Linate accident in 2001 was about 52,000,000 EUR (Boeing 47M€ + Cessna 5M€). The Flight Safety Foundation also takes into account the indirect costs associated with an accident (passenger losses, ground damage, airline and airport image lost), which results in three times the direct costs, thus 156M€. In the EUROCONTROL cost-benefit analysis an average and more conservative value of 104M€ has been assumed.

According to the 'SRC Annual Safety Report' [22] there is one severe runway incursion in every 350,000 movements. For all ECAC airports this would mean one severe runway incursion occurring every 14 days, or once a year for a large airport. One of 100 incursions will result in a runway

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[5]. Source of figure: EUROCONTROL, 2006, *Final Report on the Generic Cost Benefit Analysis of A-SMGCS*, Version 1.0, 13 Oct 2006.

incursion accident, meaning that large airports can expect an accident every 100 years, and medium size airports can expect one accident in every 200 years. Assuming the costs of such an accident to be about 104M€ and the reduction of risk by A-SMGCS to be about 50% (i.e. one accident less within 200 years for large airport), this would save 0.52M€ per annum. For medium sized airports with half the movements per year, savings would also be halved and be about 0.26M€.

4.3.4 Summery of Economic Savings

The following Table summarises the economic savings reported above:

AIRLINE OPERATORS	**Airport A** (175K movements) **€ per annum**	**Airport B** (350K movements) **€ per annum**
Weather delays	0.360M	0.720M
Flight efficiency (all visibilities)	0.284M	0.569M
Safety	0.260M	0.520M
TOTAL	0.904M	1.809M

Figure 9: Total Savings of an A-SMGCS level 1&2[6]

4.4 Cost Benefit Analysis

The previous sections outlined the expected benefits and costs of an A-SMGCS level 1&2 for two representative types of airports. Since costs are mainly on the ANSP and airport operator side and benefits are mainly received by the airspace users, a net present value has been calculated. The NVP assumes that when all costs are borne by the ANSPs or the airport operators and are passed on to the airlines by means of appropriate charging mechanism, benefits can be seen as network benefits. When calculating the net present value and the benefit to cost ratio, it will be possible to deduce the number of years it will take for amortisation. This has been calculated and can be seen in the following table:

	Airport A (175K movements)	**Airport B** (350K movements)
Total Costs	3,47M (+ 0.29M yearly operating costs)	4.59M (+ 0.38M yearly operating costs)
Total Savings	0.904M	1.81M
Payback Years	5 years	3 years

Figure 10: Total Savings of an A-SMGCS level 1&2[7] (all values in Euro)

5 CONCLUSIONS

The present paper summarises A-SMGCS research activities of the last 10 years. Benefits of A-SMGCS level 1&2 are proven and are known rather well, with the concept having been validated and 17 European airports having at least a level 1 A-SMGCS in operation as of 2009. According to its concept of operations, an A-SMGCS mainly contributes to safety and efficiency. In terms of safety, the risk of a runway incursion could be halved by support of an A-SMGCS, weather dependent delays could be reduced by 10% and the average taxi time would at least be reduced by 5%. In EMMA2 it could also be shown that higher-level A-SMGCS services have the potentials to further increase those benefits. Departure manager systems, improved onboard guidance by electronic moving maps, and taxi routes transmitted to the cockpit by data link (TAXI-CPDLC) could show a further improvement of flight efficiency. However, so far have only the potential of higher-level services could be shown.

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[6]. Source of figure: EUROCONTROL, 2006 [23]

[7]. Source of figure: EUROCONTROL, 2006 [23]

In EMMA2 there was proof of their technical and operational feasibility. Yet, not all procedures were validated as of now and the final proof of the benefits must still be provided.

Having compiled the A-SMGCS level 1&2 benefits they can be put into relation to incurred costs, and the years of return of investment can be calculated by a cost-benefit analysis. For airports with more than 175,000 movements per year, overall costs of an A-SMGCS would result in 3.47M€. With a total annual saving of 0.9M€, it would take 5 years for the investment to pay off. For large airports with at least 350,000 movements per year, the cost-benefit ratio is slightly better since several costs are fix costs which are independent of the size of the airport. Here, it can be expected that the investment pays off after three years.

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7 ABBREVIATIONS

ANOVA	Analysis of Variance
A-SMGCS	Advanced Surface Movement Guidance and Control System
ATC	Air Traffic Control
ATCO	Air Traffic Controller
ATM	Air Traffic Management
ATN	Aeronautical Telecommunication Network
CDG	Paris Charles de Gaulle Airport
CFMU	Central Flow Management Unit
CTOT	Calculated Take Off Time (CFMU)
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	European airport Movement Management by A-SMGCS
ETD	Estimated Time of Departure
GEC	Ground Executive Controller
ICAO	International Civil Aviation Organisation
PRG	Prague Ruzyne Airport
QE-OF	Operational Feasibility Questionnaire
QE-OI	Operational Improvement Questionnaire
R/T	Radiotelephony
RTS	Real Time Simulations
RWY	Runway
SA	Situational Awareness
SPOR	A-SMGCS Services, Procedures, and Operational Requirements document
TAXI-CPDLC	Controller Pilot Data Link Communication with Taxi operations
TIS-B	Traffic Information System Broadcast
TSAT	Target Start-up Approval Time
TSD	Traffic Situation Display
TTOT	Target Take-Off Time
VHF	Very High Frequency
WVC	Wake Vortex Category

8 BIOGRAPHIES

Jörn Jakobi was born in Heiligenstadt, Germany, in 1974.received his diploma in psychology from the University of Göttingen in the year 1999. Since 2000 he is as a human factors expert with DLR institute of flight guidance where he worked in the domain of airport airside traffic management with the focus on A-SMGCS concept operations and validation. He was coordinating operational trials and performance analyses at diverse European airports in multi-national research projects, like TARMAC or BETA. With EMMA & EMMA2 between 2004 and 2009 he was the project manager of the subproject “concept”, where 18 European partners from the industry, R&D organisations, airlines and ANSPs worked together on higher-level A-SMGCS services. He was also responsible for all EMMA2 related validation activities that were performed in Braunschweig and at Prague Airport. Since 2009 Jörn Jakobi is working in national-funded projects dealing with the concept of 'Total Airport Management'.

Michael Röder was born in Hamburg, Germany, in 1964. He studied Mechanical Engineering and received his diploma in from the Technical University of Braunschweig in the year 1994. During and after his study Michael worked as a scientific engineer with DLR institute of flight guidance. In 1999 he took over the ‘simulation group’ as a team leader. At 2000 he moved to the department operations control’, where he took over the department lead in 2009. From 1999 till 2009 he was the project manager of BETA, EMMA, and EMMA2.

Marcus Biella received his diploma in psychology from the Technical University of Braunschweig in the year 1999. Since 2000 he is as a human factors expert with DLR institute of flight guidance where he worked in the domain of concept operations and validation of new onboard guidance systems like electronic moving maps, enhanced vision system or flight management systems. He was coordinating operational trials and performance analyses in many different onboard related research activities and projects, like MOSES, EMMA2, OPTIMAL, or in EUROCONTROL project. With EMMA2 between 2006 and 2009 he was the project manager of the subproject “validation”. Since 2007 Marcus Biella is working in the FP6 funded project HUMAN dealing with the development of ‘Pilot Models’ to predict human errors during the design phase of new onboard guidance means.

Jürgen Teutsch was born in Cologne, Germany, in 1969. He studied Mechanical Engineering with a major in Aerospace Engineering at the Technical University of Aachen (RWTH), Germany, and obtained his academic degree with a final examination on GPS-data post-processing carried out at the Faculty of Aerospace Engineering of Delft University of Technology (TUD), the Netherlands, in 1995.

After his studies Jürgen was involved in a research programme on computer simulation studies of re-entry space-vehicles at TUD. He later worked as a computer consultant for LogicaCMG in Amstelveen, the Netherlands, and as software engineer at the Structural Dynamics department of EADS Airbus in Hamburg, Germany, before joining the National Aerospace Laboratory of the Netherlands (NLR) in 2000 as manager for air traffic management (ATM) simulation projects.

Since then Jürgen has been involved in several multi-national research initiatives in the area of ATM and airport technologies, among which the most prominent are AFAS, Gate-to-Gate, C-ATM, EMMA and the currently active Single European Sky initiative called SESAR. As validation specialist for the NLR ATC Research Simulator (NARSIM), he has also been involved in the development of the European Operational Concept Validation Methodology (E-OCVM).