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AUTHOR'S SUMMARY	The ATOPS project is led under the DGVII/ 12.1 European Programme. The goal of ATOPS is to let key end-users (controllers, pilots, Airport ATC authorities,etc.) define and evaluate relevant A-SMGCS procedures using the real time A-SMGCS simulation platform developed by the SAMS project (Project DGVII no AI-97-SC.2097). This report describes the entire project in detail including the objectives, means used to achieve objectives, scientific and technical description of the project, conclusions and recommendations for future work.	

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Executive Summary

To cope with the continuous growth in air traffic and to avoid airports becoming the bottleneck of air traffic management, it is essential to improve the efficiency of ground movements at airports. A-SMGCS (Advanced Surface Movement, Guidance and Control Systems) is a concept that has been developed by ICAO (International Civil Aviation Organisation) and it encompasses the introduction of new technologies and new operational procedures to improve the efficiency of operations on airport runways, taxiways and apron areas.

Prior to the ATOPS Project, the European Commission Transport Directorate had been strongly stimulating the necessary A-SMGCS developments through Research and Technological Development programmes such as DEFAMM and SAMS. Through these projects the technological means by which candidate A-SMGCS solutions can be assured were demonstrated. The SAMS project was aimed at designing and developing a real-time, man-in-the-loop simulation platform capable of testing and demonstrating new support tools and new A-SMGCS procedures in all weather conditions. It linked together a cockpit simulator, control tower simulator and a core A-SMGCS simulator for the first time.

To take benefit from these technological developments and evaluations, new procedures using A-SMGCS technologies needed to be developed. It is the operational procedures that were the subject of study in the ATOPS project.

The main objectives of the ATOPS (A-SMGCS Testing of Operational Procedures by Simulation) project, sponsored by the Directorate Generale VII of the European Commission, were to identify operational procedures that were expected to enhance efficiency and capacity of ground movements; to conduct evaluations by Air Traffic Controllers and pilots of selected procedures on the SAMS platform; to analyse and report the results and finally to disseminate the results of the project through fora.

The first phase of the Project was dedicated to the definition and selection of operational procedures. This task was broken down into three sub-tasks, namely Airport ATC (Air Traffic Control) Consultations, Selection of Procedures and Procedure Descriptions. The Airport ATC Consultations involved four major European airports (Heathrow, Charles De Gaulle, Schiphol and Frankfurt). Through the use of comprehensive questionnaires and interviews the ATC authorities provided information on their airport’s present SMGCS, future planned A-SMGCS, perceived business benefits of A-SMGCS and possible operational procedure topics for A-SMGCS. The interview subjects agreed with a set of ‘basic’ or ‘core’ procedures for A-SMGCS that were put forward by the ATOPS team. The ‘core’ procedures were defined as enablers that give Controllers the basic skills, initially to exploit enhanced surveillance and eventually to use other advanced tools. Examples of the ‘core’ procedures used in ATOPS were ‘Identification of an SMR (Surface Movement Radar) labelled aircraft’, ‘Conflict Detection and Alert by an Air Controller’(for runways), ‘Tactical Ground Movement Control Instructions’, ‘Line up after an arrival or departure’ and ‘Cross the Runway after an arrival or departure’. ‘Advanced’ Procedure topics that were also suggested in the ATOPS project encompassed the automatic Routeing/ planning (taxi and departure), Guidance (automated switching of lighting and signage, free taxi) and the Control functions (runway/ taxiway conflict alert including incident management and missed approach management). In preparing the description of procedures, ICAO documentation was taken into consideration and the process used by Heathrow ATC procedure designers was used.

The second phase of the project started with the preparation of test scenarios for the simulation of selected procedures. A set of ‘management objectives’ was defined for the two airports considered for simulation (Heathrow and Schiphol). For example, for the identification sub-system, do the Controllers carry out correct procedures to cope with system misidentification of wrong labels for an aircraft? Representative traffic samples were built for all the scenarios that were envisaged. Scripts were also prepared for the cockpit pilot and the ‘pseudo-pilots’ involved in creating a realistic (and interactive) traffic set-up. Five weeks of simulation took place in January and February 2000 and involved six Controllers from Heathrow airport and two Controllers with experience of Schiphol airport.

There were a number of problems encountered with the SAMS platform, with certain sub-systems not functioning correctly. Although most of the ‘core’ procedures were addressed in the simulation, the ‘Advanced’ procedures were not evaluated due to the limitations of the SAMS platform (i.e. the Guidance and Planning functions not performing as required).

General feedback from the Controllers who took part in the simulations indicated that they were able to use the labelled SMR HMI to guide the traffic on the airport. Although no quantitative data was collected, the use of the HMI appeared to improve the amount of traffic that could be moved in reduced visibility conditions. Subjective observation indicated that ATCO workload decreased. This was apparent in the reduction of Radio/ Telephony communications. It seemed as though the Controllers using the HMI needed fewer checks to form a mental picture of the traffic situation on the airport and to keep this picture updated. Unfortunately no more than an indication could be found due to the technical problems encountered.

The ATOPS project was successful in identifying candidate operational procedures for simulation and conducting simulation tests of ‘core’ procedures using the SAMS platform. It was a good example of a project where the dialogue between researchers, technology providers and ‘end-users’ such as Air Traffic Controllers necessary for providing a practicable A-SMGCS was achieved. The Project was partially successful in preparing ‘advanced’ operational procedures for A-SMGCS functions. Due to technical difficulties during the simulation, it was not possible to record performance data.

The evaluation phase of the ATOPS project provided significant feedback from the participating Controllers on the usability of the A-SMGCS HMI and the areas that need further development both in terms of A-SMGCS sub-systems and also operational procedures.

It is recommended that

- Research is continued to optimise the function and format of the Controller and Pilot HMIs to provide a useable interface for these ‘end-users’ to the A-SMGCS.
- Work is carried out for Conflict Detection and Alert systems particularly as Controllers stated that they would find such systems very useful.
- Further investigation of ‘Advanced’ procedures and ‘end-user’ interaction with advanced A-SMGCS tools for Routeing, Guidance and Control functions is undertaken.
- A-SMGCS sub-systems performance specifications continue to be developed.
- Future dependent projects such as SAMS and ATOPS should be planned with less overlap and therefore with more certainty about what the first project is going to deliver.
- ‘End-users’ should be involved in the design of A-SMGCS sub-systems and operational procedures from an early stage.
- Further testing of A-SMGCS and associated new procedures should be carried out in simulation as it allows new concepts to be well tested under all conditions before expensive airport installations.
- Future A-SMGCS platform development, whether based on SAMS or otherwise, should take account of the technical and management findings.

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GLOSSARY

ACI	Airports Council International
AOPG	Airport Operations Project Group
ATC	Air Traffic Control
ATCO	Air Traffic Controller
ATIS	Automatic Terminal Information System
ATM	Air Traffic Management
ATOPS	A-SMGCS Testing of Operational Procedures by Simulation
A-SMGCS	Advanced-Surface Movement Guidance and Control System
CFMU	Central Flow Management Unit
CORBA	Common Object Request Broker Architecture
DEFAMM	Demonstration Facilities for Airport Movement Management
DERA	Defence Evaluation and Research Agency
DFTI	Distance From Touchdown Indicator
EANPG	European Air Navigation Project Group
EC	European Commission
GMC	Ground Movement Control
HDD	Head Down Display
HMI	Human Machine Interface
HUD	Head Up Display
ICAO	International Civil Aviation Organization

IFATCA	International Federation of Air Traffic Controllers Associations
Kts	knots
LVP	Low Visibility Procedures
NATS	National Air Traffic Services Ltd
NLR	Stichting National Lucht-En Ruimtevaartlaboratium
PANS	Procedures for Air Navigation Services
PDC	Pre Departure Clearance
PT/2	Project Team/2
R&D	Research and Development
R/T	Radio Telephony
RTD	Research and Technological Development
SAMS	SMGCS Airport Movement Simulator
SMGCS	Surface Movement Guidance and Control System
SMR	Surface Movement Radar
WP	Work Package

1. INTRODUCTION

This document is the major document in the series of final reports that are provided for the ATOPS project. ATOPS (A-SMGCS Testing of Operational Procedures by Simulation) is one of the contracts awarded by the European Commission - DG VII in the 4th R&D Framework Programme.

The structure of the report is as indicated in the EC ‘Guidelines for the preparation of reports’ [1]. This section (Section 1) gives an introduction to the report. Section 2, states the objectives of the project. Section 3 describes the means used to achieve the objectives. Section 4 gives a scientific and technical description of the project. Section 5 presents the results and analysis of the results. Finally section 6 presents the conclusions of the project and makes recommendations for further work.

This report describes a simulation of airport ground movement operations using new technologies and procedures to improve the efficiency and safety of aircraft and vehicle movements.

2. RECAP OF ATOPS PROJECT OBJECTIVES

2.1. BACKGROUND

The volume of air traffic continues to grow year after year and economic studies clearly show that this trend will continue for the foreseeable future.

Within the air transport industry, there is now a widespread acceptance that in order to support this predicted increased volume of traffic and to solve current capacity problems, it is essential that a ‘gate-to gate’ concept of air traffic management (ATM) be implemented. The efficiency and safety of ground movements at airports within this overall ATM concept is a key element that needs particular and urgent attention.

In this respect, an Operational Requirement for Advanced Surface Movement Guidance and Control System (A-SMGCS) has been developed and recently approved for publication by ICAO [2]. This baseline document provides the framework for future developments matching the necessary and safe improvements of airport efficiency.

However, it is important to recognise that these developments cannot be based solely on new technology. Indeed, they will only be realised by combining new technologies and techniques with new A-SMGCS procedures.

The European Commission Transport Directorate has been strongly stimulating the necessary A-SMGCS developments through a number of RTD projects, particularly DEFAMM and SAMS. Through these projects the technological means by which candidate A-SMGCS solutions can be assured were demonstrated.

To take benefit from these technological developments and evaluations, new procedures using A-SMGCS technologies must be now developed.

2.2. A-SMGCS CONTEXT

Currently, operational procedures on the surface of an aerodrome depend on pilots, air traffic controllers, and vehicle drivers using visual observation of the location of the aircraft and vehicles in order to estimate their respective relative positions and avoid the risk of collision. Pilots and vehicle drivers rely on visual aids (lighting, signage, and markings) to guide them along their assigned routes and to identify intersections and holding points. Pilots and drivers are subject to clearance-to-proceed instructions issued by the controller based on these visual references. During periods of low visibility, controllers must rely on the pilot’s RTF reports and surface movement radar to monitor separation and to identify conflicts. In these conditions, pilots, and vehicle drivers find that their ability to operate in the “see and be seen” mode is severely impaired.

Within the framework of the ICAO Operational Requirement, A-SMGCS is divided in the following functional areas:

- Surveillance
- Control
- Routeing/ Planning
- Guidance

Currently the human operators are helped in their tasks by some technological tools but these have rather limited capabilities.

For instance, in the surveillance function, a surface movement radar (SMR) partially, replaces the eyes of a controller: the SMR gives the position of the objects on the airport platform but not their identity. The controller has to mentally correlate the reported positions with identities gathered by other procedures and constantly keep in mind these associations.

Similarly in the control function, the controller has to visually monitor the position of objects and evaluate all this data to ensure that aircraft and vehicles are properly separated and do not enter restricted or prohibited zones.

In the field of routeing/planning, the controller must know which runway will be used for each flight, when it will be used, and which taxiways are available for use at any given time in order to route an aircraft on the manoeuvring area.

In the guidance function, the controller (or an assistant) has to manually select the guidance means (lights, signs, stop bars…) to guide the aircraft along the designated taxi route.

2.3. THE SAMS PROJECT

The “SAMS” project [3] was commissioned by the EC in the 4th Framework Programme to design and develop a platform for real-time, man-in-the-loop A-SMGCS simulation. It included simulation of the air/ground environment and a platform that simulates A-SMGCS tools and technologies. Thus, SAMS was capable of testing and demonstrating new support tools and/or new A-SMGCS procedures in all weather conditions.

As in real life, both pilots and controllers operating the SAMS simulation derived the major part of the necessary information from visual observation, but this was supplemented by automated information processing tools (such as radar displays). The SAMS platform was connected to simulation tools that offer highly realistic outside views and working environments. A pilot working environment, a Boeing 747 cockpit, located in Bedford (UK) and a controller working environment including an outside view projection system of a Control Tower, located in Braunschweig (D) were integrated and connected to the A-SMGCS simulator, located in Amsterdam (NL).

The SAMS project simulated the A-SMGCS environment including visuals to allow the testing of enhanced procedures for Amsterdam Airport Schiphol and London Heathrow.

2.4. ATOPS PROJECT OBJECTIVES

The ATOPS project objectives [4] were to:

- Identify operational procedures using A-SMGCS that are expected to enhance the efficiency and capacity of airport ground movements in a safe manner.
- Collate these candidate procedures together with the comments of end-users and facility providers and then select some procedures for testing that could provide significant operational benefits.
- Conduct simulation tests using the SAMS platform to enable pilots and controllers to evaluate the chosen procedures and record performance data.
- Analyse the recorded data, develop conclusions and make recommendations for future work in the Fifth Framework R & D Programme.
- Inform interested parties of the conduct and results of the project and to take account of their comments in the final reporting, using fora and internal consultations.

In addition to the project objectives listed above, the results of the ATOPS simulations were expected to provide:

- An operational emphasis to complement the technological emphasis of previous A-SMGCS research, e.g. DEFAMM [5].
- Initial evidence for business cases for implementing A-SMGCS.
- An input into the ICAO Manual of A-SMGCS for which PT/2 of the AOPG of the ICAO EANPG is responsible.

The project duration was 18 months, for collating procedures, conducting simulation tests of Heathrow and Schiphol airports and analysing results. A three-month extension period was used for completing the final reports and dissemination activities.

2.5. ATOPS PARTNERSHIP

The ATOPS consortium is composed of industry and research establishments, as well as end users. The consortium consists of seven partners and one associate partner from four European countries.

The following companies participated:

- DERA (United Kingdom) – project co-ordinator.
- ANS (Germany) – contractor.
- Thomson/Detexis (France) –contractor.
- Thomson/ISR (France) – contractor.
- delair ATS (Germany) – contractor.
- NATS (United Kingdom) – contractor.
- NLR (The Netherlands) – contractor.
- Sofréavia (France) – associated partner.

The consortium was chosen to include organisations deeply involved in the field of A-SMGCS. Four industrial companies, three research organisations and one ATC Service provider made up the consortium. In addition to this, airline pilots and additional Air Traffic Controllers were drafted in for the evaluation phase.

3. MEANS USED TO ACHIEVE THE OBJECTIVES

The main means used to achieve the objectives of the ATOPS project were simulators, a procedure design method, a forum, consultation rounds, real-time man-in-the-loop simulations and briefings. The project partners agreed a technical approach that were divided into four main phases or work packages. The availability of the SAMS platform and the knowledge and experiences of the consortium partners were prerequisites for the ATOPS project.

3.1. TECHNICAL APPROACH

The ATOPS project was broken into four main phases to be executed within an 18-month timeframe:

- Definition and selection of procedures.
- Simulation.
- Analysis and synthesis of simulation results.
- Dissemination of results.

At the core of the ATOPS project was a test programme of approximately 5 weeks using the SAMS simulation platform.

3.2. WORK DESCRIPTION

The work performed in the ATOPS project was structured into 5 Work Packages (WP), which were:

WP 1000: Definition of A-SMGCS procedures. This work package dealt with the definition of A-SMGCS procedures. This activity relied on the ICAO draft A-SMGCS manual as well as the architecture documentation of the SAMS platform. Selection and preparation of procedures were carried out directly by professional end-user (controllers) with the support of official bodies such as IFATCA and ACI.

WP 2000: Simulation Testing. This work package dealt with the effective testing of procedures selected in WP 1000 as well as the definition test scenarios. Operational testing was carried out with real end-users in the loop (controllers and pilots), with the technical support of the SAMS platform providers.

WP 3000: Analysis and Review. This work package dealt with analysis and review of test results.

WP 4000: Dissemination. This work package was dedicated to disseminating and discussing the results.

WP 5000: Management. This project-long work package was devoted to the management of the overall project. It encompassed the set-up of a management structure, project co-ordination, tracking of work progress, periodic project and technical meetings, preparation of periodic EC reviewing, administrative and financial reporting to the EC.

3.3. SAMS PLATFORM AND ITS CAPABILITIES

Figure 1 describes the global architecture of SAMS and its capabilities. Not all of these capabilities were used in the ATOPS project. In SAMS each facility has been substituted with a simulator. SAMS consists of the following major components:

- The LATCH cockpit simulator, located in Bedford (UK).
- The DLR TOWER VISUAL SIMULATOR , located in Braunschweig (D).
- An A-SMGCS simulator, located in Amsterdam (NL).
- A datalink facility, between the A-SMGCS simulator and LATCH.
- A voice channel, between LATCH and the DLR TOWER VISUAL SIMULATOR.

In Figure 1 we also find:

- An HMI for the pilot, in the cockpit simulator.
- HMI for the controller, at the controller working position.
- Additional functionality needed to perform simulations such as an environment generator, simulation command and control, logging, and analysis.

In Figure 1, displayed in yellow/italics are the actual simulation facilities. For LATCH and the DLR TOWER VISUAL SIMULATOR, additional hardware and software were required to enable their simulation function, e.g. aircraft performance models. The functions displayed in red/underlined show additional facilities necessary to the SAMS platform to connect the simulators and to enable evaluations with the platform.

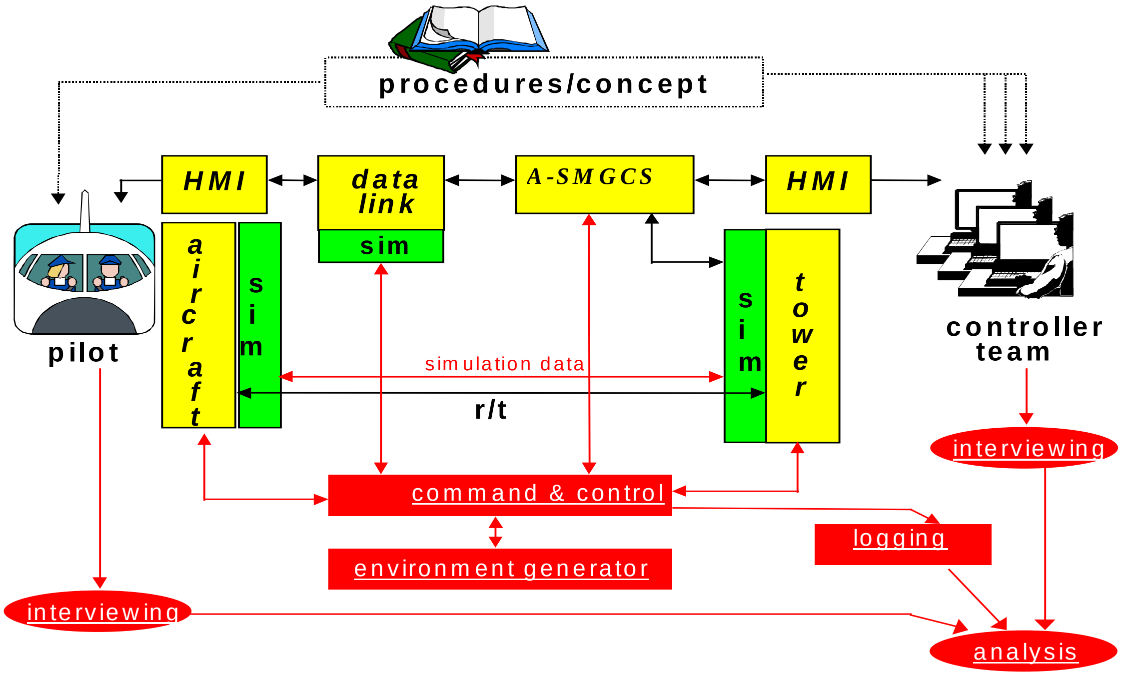

Figure 1 Global architecture of SAMS

The procedures and operational concepts were the subject of study in the ATOPS project.
Although not part of the SAMS project, it was intended that the system be configurable for different procedures and concepts.

The information flow between the different SAMS simulators and within each facility is depicted in Figure 2. The same colour coding/text format as in the previous figure is used. Figure 2 also shows that the A-SMGCS simulator is sub-divided into four functions: surveillance, planning (runway and taxiway), control and guidance.

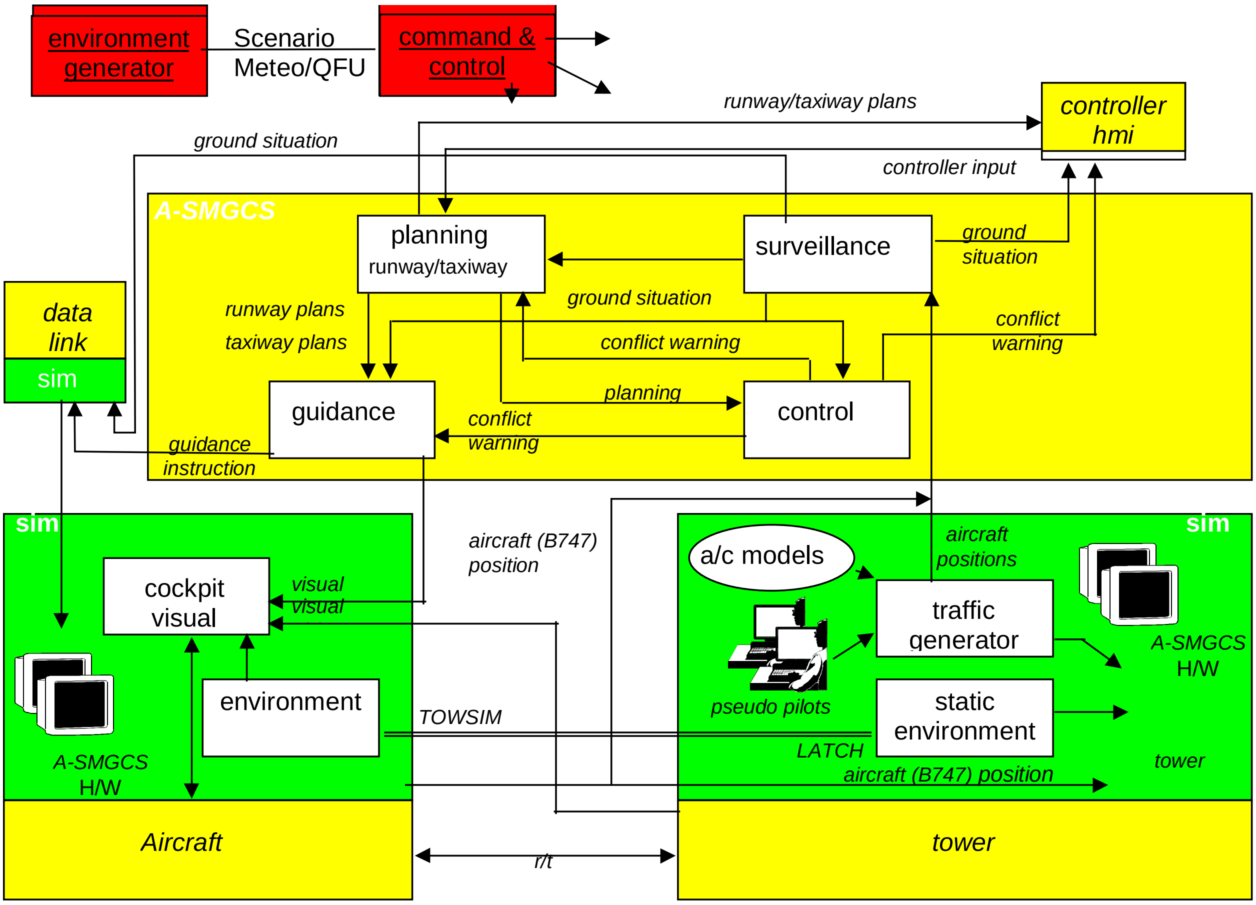

Figure 2 SAMS information flow.

3.3.1. Surveillance

The surveillance subsystem of the SAMS platform was composed of a multi-sensor data fusion and labelling system responsible for the elaboration of the ground situation in terms of kinematic information (position, velocity, heading) and mobile (aircraft or vehicle) identification. The output data (enhanced airport ground situation) of the surveillance subsystem was forwarded to the routeing subsystem, the guidance subsystem, the control subsystem and the controller HMI. A reduced traffic situation describing the traffic in the vicinity of the DERA LATCH aircraft was sent to the data-link and from thereon to the pilot HMI.

The labelling was done, either automatically by associating the elements received from the sensor simulator and the elements received from the Flight Plan Server, or manually by controller assignment of identification to tracks from the Controller HMI.

Additional « touch down » information, was calculated based on the altitude information. This was delivered to the guidance subsystem to initiate the guidance processing of arriving aircraft.

3.3.2. Control

The goal of the control subsystem was to detect possible conflicts on the airport surface with regard to the enhanced airport ground situation, to detect route deviations of aircraft with regards to their assigned routes, and to generate associated warning messages (alerts) to the concerned subsystems. The input data of the control subsystem was composed of the enhanced airport ground situation delivered by the surveillance subsystem and the aircraft assigned routes delivered by the routeing subsystem. The warning messages (alerts) were delivered to the routeing subsystem, the guidance subsystem and the controller HMI whenever a conflict was detected.

Conflicts between two or more tracks were subdivided into a taxiway alerting function which checked for wingtip clearances and intrusions into localizer sensitive areas, and a runway incursion alert to safeguard the open runways.

3.3.3. Guidance

The Guidance Processor was responsible for the facilities, information, and advice necessary to provide continuous, unambiguous and reliable information to pilots and vehicle drivers to keep aircraft and vehicles on their assigned surface routes. This included the automated control of the ground guidance aids and the transmission of guidance messages to suitable on board pilot/driver assistant systems.

Ground guidance aids used were taxiway centreline lights and stop bars. Both of these could be switched on and off in front of the aircraft or vehicle. The guidance processor also generated onboard messages (displayed in the aircraft cockpit). These messages were generated in accordance with the routes assigned for each mobile by the Planning function or the Controller, taking the enhanced ground situation information into account.

3.3.4. Planning

3.3.4.1. Runway Planning

The goal of the runway planning was to maximise the number of departing aircraft per hour giving priority to slotted flights and complying with separation criteria as well as runway operating rules. The runway departure planning was implemented only for Heathrow Airport. The departure sequence could include multiple line-up departures. The planning horizon was 20 minutes.

Re-planning, triggered by changes in flight status, can occur if:

- The sequence was rejected by the taxi planning because one or more of the aircraft could not achieve the assigned take-off time. In this case, the taxi planning gives the new expected take-off times of the aircraft so that a new sequence can be computed.

- A taxiing aircraft deviates from its taxi plan: the runway planning is informed of this by the taxi planning which gives a new expected take-off time.

The departure sequence was sent to the Controller HMI. The controller can change the order of or give priorities to flights through the Controller HMI. Such a request can be sent by the controller along with call signs of concerned aircraft and their new position in the sequence.

The Runway planning used a list of active runways supplied by the Airport Topology component and a list of flight plans of departing aircraft, supplied by the Flight Plan Server, to which it allocated a take-off time within the CFMU time slot or close to the estimated take-off time. The flight status (inactive, pending, active, live, terminated) was included in the flight plan. Only pending flights were input to the Runway Planning.

The runway planning also checks that the aircraft can take off with the current cross and tail wind. Meteorological data consists essentially of air and visibility conditions as separation criteria and runway operating rules depended on this information.

3.3.4.2. Taxiway Planning

The main objectives of the taxiway planning subsystem were:

- To define a route for each aircraft in order to reach its destination on the airport with respect to its flight plan constraints, taking into account other airport traffic.

- To allow for re-planning, minimising the impact on the rest of the traffic in case of non-respect of the first established plan or in case of conflict.

In order to provide the controller with a quite realistic plan and to avoid disturbing him with useless validation actions, the taxiway planning subsystem provided the plan during push back time for outbound aircraft and during landing time for inbound aircraft.

During both London Heathrow and Amsterdam Airport Schiphol session paper strips were used. The use of paper strips was preferred by all controllers and allowed stepwise change in operations from complete visual tower operations to the advanced procedures needed for using A-SMGCS. The SAMS platform provided an electronic version of the flight strips, but this was only used and commented during the last days of the ATOPS simulations.

The starting and ending location and times of aircraft movements were extracted by the Taxiway Planning from the flight data supplied by the Flight Plan Server. The best departure times of outbound aircraft were extracted from the runway sequences supplied by the Runway Planning component. The airport tarmac possibilities were extracted from topology data supplied by the Airport Topology component and the airport movement regulations from the Airport Procedures component. The influence of meteorological conditions on routeing regulations were computed with the meteorological data supplied by the Meteo component.

The aircraft performances and characteristics were extracted from the aircraft performance data supplied by the Aircraft Performance component and checked that an aircraft can use a given taxiway block because of its size or weight.

The deviations of the actual path followed by an aircraft from its cleared route were known from the conflict warnings supplied by the Control component. In this case, the current position of the aircraft was extracted from the enhanced ground situation supplied by the Surveillance component (the taxiway route origins will be computed from these positions).

The controller could make changes to the taxiway routes through the Controller HMI. A notification was sent to the Controller HMI to inform the controller when the Taxiway Planning did not find a feasible routeing for the aircraft.

The assigned routes were sent to the Guidance function to enable the latter to guide the aircraft, to the Control Aids component to enable the latter to check for deviations, and to the Controller HMI for display allowing the controller to make route modifications.

3.3.5. Datalink

The data link simulator module provided the communication of advisory and ground situation information from the A-SMGCS guidance module to the aircraft (LATCH cockpit). The transfer of these messages by data link allowed remote guidance to be carried out, even in low visibility conditions, whilst contributing to a reduction in controller and pilot workload. The module provided consistent system behaviour as if data link equipment and infrastructure were actually in place.

3.3.6. Platform Interfaces

CORBA (Common Object Request Broker Architecture) middleware was used to enable communication between the different A-SMGCS components. Communication between the different simulators was achieved through the DIS (Distributed Interactive Simulation) and UDP (User Defined Protocol) protocols. All communication was via dedicated ISDN lines to Bedford and Braunschweig. A special filter program was necessary to translate DIS to UDP and vice versa.

3.3.7. Controller HMI

The controller HMI supplied the controller with information regarding the planning of traffic at the airport (e.g. arrivals and departures lists), airport status, current traffic situation, conflict situations, assigned routes etc. The HMI also allowed the controller to interact with the A-SMGCS platform and access the advanced features.

The main inputs of the controller HMI server were:

- Flight data, received from the Flight management, including changes in the status of the flight plans and modification of the estimated times computed by the runway planning component.

- Ground topology, received from the Airport topology component, in order to display an airport map over which on overlay was made with assigned routes, taxiway segments and gate locations.

- Enhanced ground situation, also overlaid over the airport map, received from Surveillance, in order to display the labelled traffic on the airport.

- Air traffic, received from Surveillance, which was dedicated for the tower controller in order to manage air arrival and departure traffic.

- Runway sequences, received from the Runway Planning function.

- Conflict warnings, received from the Control component, in order to display the taxiway/runway/plan conflicts.

- Stop bar statuses, received from Guidance.

- Meteorological data received from the meteorological server.

Through use of the HMI, the controller was able to:

- Change the stop bar status to stop or start aircraft in case of a conflict.

- Change the runway or taxiway status, when the controller opens or closes a runway or taxiway.

- Change runway sequences.

- Change routes, when the controller manually wants to assign a route or when the provided one is not deemed correct.

- Estimate distance to touch down (Distance to Touch Down Indicator, one for each active runway)

- (If preferred) make use of the electronic flight strip for arrivals and departures

- Observe weather parameters and active runways

Figure 3 shows the Controller HMI.

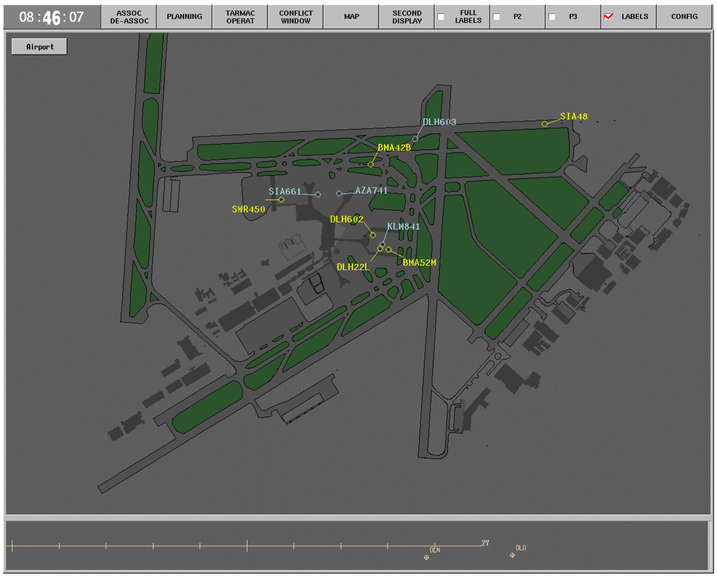

Figure 3 Controller HMI

3.3.8. Pilot HMI

The Pilot HMI enabled the pilot to receive messages from the controller and the A-SMGCS platform. It showed a map of the airport in the direct vicinity of the aircraft itself, enhanced with the positions of other aircraft, routeing information, and the status of airfield lighting and stop bars.

3.3.9. LATCH

The SAMS project made use of the DERA B747 ‘LATCH’ flight simulator to include pilots in the loop (Figure 4). The flight simulator featured a realistic view of the world outside of the cockpit as well as all the instrument panels found in an actual B747. The cockpit was based on a generic Boeing 747 with two pilot positions, representative cockpit controls/instrumentation including Primary Flight Head Down Display (HDD) and simulated out-of-cockpit visuals. Furthermore, it was equipped with a SAMS pilot HMI, which relays A-SMGCS messages (e.g. taxiing instructions and runway incursion warnings) from the SAMS platform to the pilots and vice versa.

The LATCH position was sent back to the A-SMGCS modules in Amsterdam and through them to the DLR Tower Visual Simulator. There the LATCH B747 could be observed from the tower position on his actual position, and via the Surveillance function on the radar screens.

The LATCH operator communicated with the LATCH pilot(s) via a headset intercom system, which was capable of being connected to operators of the other SAMS subsystems via a standard telephone link. The LATCH simulator provided the capability to video record simulation trials, with superimposed out-of-cockpit visuals and moving map view, and a sound track of the headset communications.

The SAMS simulation scenarios were based on realistic traffic situations at Heathrow and Schiphol airports. Visual databases of both airports, along with aircraft models representing simulated aircraft generated by pseudo-pilots based at the DLR TOWER VISUAL SIMULATOR platform at DLR in Braunschweig, were used to simulate out-of-cockpit views. The Heathrow visual database incorporated airport lighting patterns (runway, taxiway and apron lights, and taxiway stop bars) which were capable of being controlled by the A-SMGCS guidance and control subsystems, although the functionality to do this had not been envisaged or realised in the SAMS platform.

The LATCH HDD displayed a “moving map” plan view of the airport in use, provided in the cockpit. Superimposed on the moving map were symbols representing the other simulated aircraft taking part in the simulation. It was possible to display on the moving map the status of taxiway stop bars, but also the functionality to do this had not been envisaged or realised in the SAMS platform.

Pilot requests for pushback or taxi clearance were initiated via a data link button panel installed in the cockpit. A “clearance granted” message, issued by ground controllers based at the DLR Tower Visual Simulator, could be displayed in the moving map message area. Followed by a “clearance granted” message, the pilot could issue an acknowledgement via the button panel, although the functionality to respond to acknowledgements was not implemented in the SAMS platform.

Following the granting of a clearance to taxi, LATCH provided the possibility to display a taxi plan, issued by ground controllers based at the DLR TOWER VISUAL SIMULATOR, on the moving map as a series of connected taxiway segments.

Figure 4 LATCH cockpit at DERA

3.3.10. DLR TOWER VISUAL SIMULATOR

The SAMS platform used the DLR TOWER VISUAL SIMULATOR, to include air traffic controllers in the simulations. The Tower Simulator featured a simulated outside view and realistic controller working positions. The SAMS controller HMI allowed the controllers to interact with the A-SMGCS features of the SAMS platform and enhanced the working positions. Figure 5 gives an impression of the outside view quality of DLR TOWER VISUAL SIMULATOR.

Figure 5 300° Tower Simulator at DLR

The DLR TOWER VISUAL SIMULATOR is used by DLR for research and development purposes for vision-based air traffic control in the vicinity of airports, i.e. for tower, apron, and ground control.

ATS consisted of a dynamic module that generated aircraft movements according to aircraft dynamic models and a visual system that generates the synthetic vision. The simulated aircraft were controlled by pseudo pilots in a separate control room, who communicated with the controllers via a simulated radio transmission line. The DLR TOWER VISUAL SIMULATOR supervisor used a master station to control the simulation.

The quality of the outside visuals (both for pilot and controllers) was improved during the SAMs project. When starting ATOPS the controllers and pilots passed familiarisation sessions, at the end of which they were asked about the quality of the visuals. As they commented the visuals to be acceptable for the ATPS simulations, no more effort was put into improvements.

3.3.11. Pseudo-pilot Workstations

Up to six pseudo pilots participated in the simulations entering the control clearance to a terminal via mouse and keyboard and reading back the clearances. Each pseudo pilot could in theory control up to 30 aircraft (in SAMS the maximum was 10 due to intensive VHF communication and taxi work load). The association between pseudo pilots and controller working positions was arbitrary with respect to the different number of aircraft that may be under each controller's responsibility. Figure 6 shows a typical pseudo pilot position. The map for Heathrow and Schiphol came from the same source as the outside visuals.

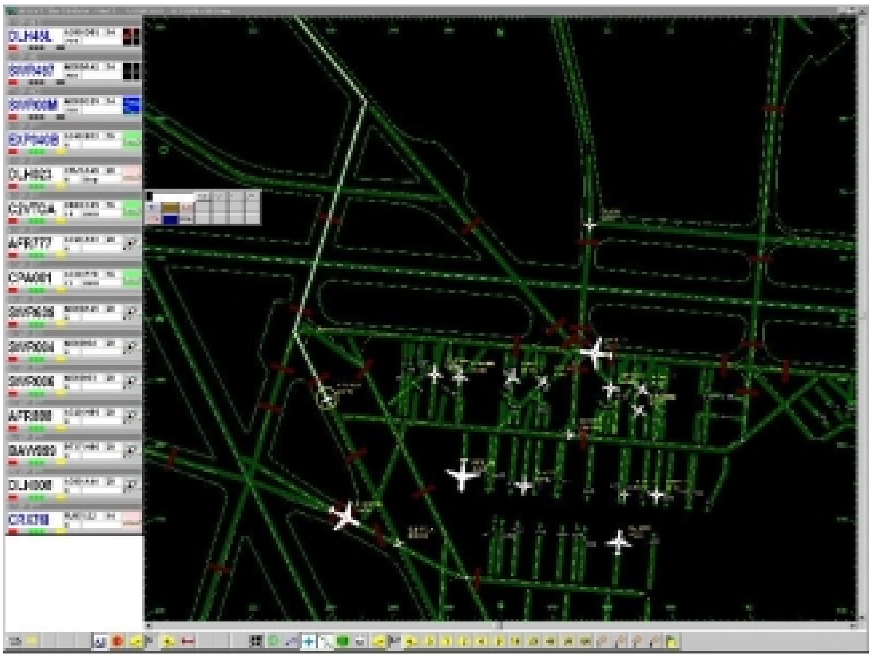

Figure 6 Pseudo pilot station

4. SCIENTIFIC AND TECHNICAL DESCRIPTION OF THE PROJECT

This chapter covers the work performed in the ATOPS project by describing the consecutive work packages. The project consisted of work packages for definition and selection of procedures; simulation; analysis and synthesis of simulation results and dissemination of results.

4.1. WP 1000 DEFINITION OF A-SMGCS PROCEDURES

This work package dealt with the definition of A-SMGCS procedures. The overall task was broken down into three main areas: airport ATC Consultation; selection of Procedures and Procedure descriptions.

4.1.1. *Airport ATC Consultations*

The Airport ATC consultation process was divided into two parts, namely a questionnaire phase and an interview phase. Four major European airports were consulted: London Heathrow; Paris Charles De Gaulle; Amsterdam Schiphol and Frankfurt airports. The full details of the consultations are given in reports produced during the course of the project [6,7]

The purpose of the consultation process was to:

- Find out the state of local A-SMGCS development/strategy at each airport.
- Establish what local ATC management expected from A-SMGCS.
- Identify local constraints at each airport which were seen as potentially being relieved by A-SMGCS.
- Gain an indication of the potential benefits arising from relieving these constraints.
- Establish what A-SMGCS procedures each airport thought ATOPS should test and reasons for this choice.
- Identify any resources airports could provide to support simulations.

4.1.1.1. *Questionnaire Phase*

The questionnaire was aimed at the airport ATC managers and was divided into four sections: subject’s professional background; the SMGCS used at the airport; the forecast A-SMGCS initiatives and possible procedures for simulation in the ATOPS project. As far as possible, the questionnaire referred to the terminology and functions stated in the ICAO Manual [2].

4.1.1.2. *Interview Phase*

After the completed questionnaires were received and evaluated, interviews of the ATC managers were performed. This was undertaken to allow additional information on the ATOPS project to be explained and to clarify and elaborate on areas of the responses.

4.1.2. *Results of the Consultation Process*

Table 1 summarises the responses for the airports’ present SMGCS.

Table 2 summarises the responses for the airports’ future planned A-SMGCS.

Table 3 summarises the responses for airports’ perceived business benefits.

Table 4 lists the airports’ suggested procedure topics for consideration in ATOPS and beyond.

	Airport			
Function/ item	**Heathrow**	**CDG**	**Schiphol**	**Frankfurt**
Surveillance				
SMR	✔	✔	✔	✔
ICAO Procedures for surveillance	✔	✔	✔	✔
Multiple coloured displays for ATCO	✔	✔		
Vehicle tracking system		✔		
Labelled SMR for arrivals		✔		
Routeing/Planning				
Advisory system (environment/weather) for runway use			✔	
Electronic Data Display (flight plan)			✔	
Closed Circuit Information (ATIS/CTOT/runway use) system			✔	
Gate management tool (arrival/departure times)				✔
Guidance				
Standard landing/ navigation aids and panels/displays	✔	✔	✔	✔
Mixture of marshallers and docking guidance systems	✔	✔	✔	✔
ATCO HMI airfield lighting display	✔			
Control				
ICAO procedures for Control	✔	✔	✔	✔
Selectable red/green lighting system operated by lighting operator	✔			
Communications				
VHF/UHF R/T	✔	✔	✔	✔
ICAO procedures for Communication	✔	✔	✔	✔
Datalink for ATIS and PDC information		✔	PDC trial	✔

Table 1 Present SMGCS at airports

	Airport			
Function/ item	**Heathrow**	**CDG**	**Schiphol**	**Frankfurt**
Surveillance				
Multilateration and Data Fusion	✔	✔	✔	
Labelled ground radar for arrivals and departures	✔	✔	✔	✔
Second SMR aided by infra-red camera			✔	
Integrate output of vehicle reporting system			✔	
Terminal Area Radar to send identification data to SMR for arrivals			✔	
Mode-S to supplement ground identification	✔			
Labels to provide positive identification	✔		✔	
Routeing/Planning				
Transmit routeing information via datalinks		✔		
Various slots (CFMU, airport etc.) integrated		✔		
No plans for implementation in next five years			✔	
Growing requirement but unsure of form of system	✔			
Guidance				
Addressable lighting system for new taxiways			✔	
Addressable signs for taxiway entrances		✔		
Control				
Runway Conflict Alert	✔		✔	
Taxiway Conflict Alert	✔			
Communications				
Datalink for PDC	✔		✔	
Digital ATIS			✔	
Datalink for repetitive messages		✔		
Procedures for combining R/T and datalink communications.			✔	

Table 2 Future planned A-SMGCS

	Airport			
Benefit/ item	**Heathrow**	**CDG**	**Schiphol**	**Frankfurt**
Runway Capacity				
Low visibility capacity to be brought up to normal day levels			✔	
Capacity enhancements by use of MLS	✔			
GMC Capacity				
Better punctuality, reduced controller workload, more efficient use of stands, reduced delays in low visibility conditions			✔	
Possible increase in capacity at night with use of labelled SMR	✔			
Labelled SMR would permit capacity enhancements to match those produced by MLS	✔			
Optimised taxitimes in all conditions		✔		
Efficiency				
Decreased controller workload due to less position reporting			✔	
Optimised taxitimes		✔	✔	
Reduction in queue size at holding point (day/night); reduced emissions	✔			
Improved stand planning due to better data exchange	✔			
Greater number of towing movements (night/low vis)	✔			
Safety				
Conflict alert would maintain or increase safety in all conditions	✔	✔	✔	✔
Improvements on taxiways during low visibility conditions	✔	✔	✔	✔
Other				
Benefits in sharing information with airport authority	✔			
Monetary saving if A-SMGCS allows relaxation of lighting regulations		✔		

Table 3 Perceived business benefits

	Airport			
Procedure topic	**Heathrow**	**CDG**	**Schiphol**	**Frankfurt**
Identification of A-SMGCS derived radar return	✔	✔	✔	✔
Runway Conflict Alert using A-SMGCS	✔	✔	✔	✔
Sequencing and Planning / GMC tactical instructions using A-SMGCS	✔	✔	✔	✔
Conditional clearances using A-SMGCS	✔	✔	✔	✔
System degradation			✔	
Assisting emergency vehicles in low visibility			✔	
Transition from visual to other surveillance means			✔	
Sequencing departures prior to arrival at runway holding areas	✔			
Optimising taxi routes	✔			
Planning to reduce queue size at runway holding area	✔			
Optimising planning area and routeing of towed traffic	✔			
Ground routeing and taxi clearances		✔		
Managing stop and clearance bars		✔		
Decreasing voice communications				✔
Incorporating vehicle traffic				✔
Increase emergency vehicles efficiency				✔

Table 4 Suggested Procedure topics

4.1.3. Additional Procedure Topics

The list of procedure topics shown in Table 4 was augmented through a secondary process in which parts of the airport consultation questionnaire were sent to representatives of the following “stakeholders” in the ATOPS project:

- EC-DG VII - the customer for ATOPS.
- Eurocontrol.
- IFATCA.
- IATA.
- ACI Europe.

A written response was received from Eurocontrol. Similar input was also received from the PT/2 working group of the AOPG of the ICAO EANPG, and from some ATOPS partners. Table 5 lists the suggested topics.

Procedure	Proposed by
Planning departures	ICAO PT/2
Planning arrivals	ICAO PT/2
Automatic routeing	ICAO PT/2
Free taxi	ICAO PT/2
Flexible use of taxiways	ICAO PT/2
Automatic runway line-up clearance	ICAO PT/2
Runway direction change management	ICAO PT/2
Automatic alerts	ICAO PT/2
Parallel taxiway / taxiway-runway management	ICAO PT/2
Multiple runway line-ups	ICAO PT/2
Missed approach management	ICAO PT/2
Incident management	ICAO PT/2
Gate management	Eurocontrol
Runway management	Eurocontrol

Table 5 Procedure topics suggested by Stakeholders.

4.1.4. Procedure Selection

The process carried out in the ATOPS project for the selection of procedures is illustrated in Figure 7 below.

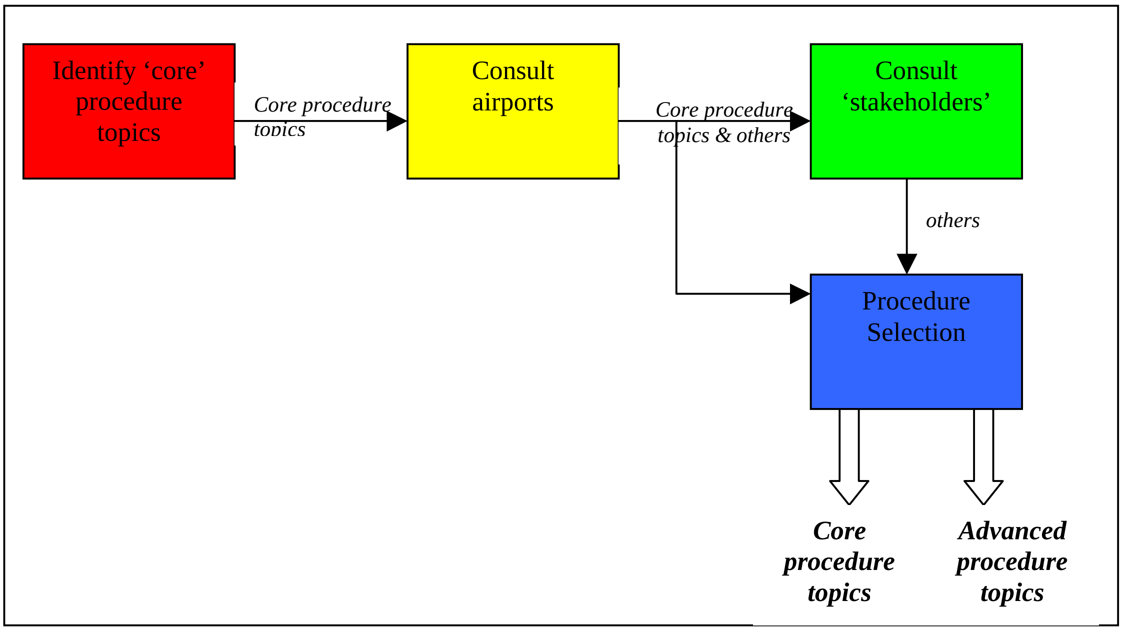

Figure 7 ATOPS Procedure selection process

4.1.4.1. Core and Advanced Procedure Topics

The two sorts of procedure topics that were defined in the ATOPS project were referred to as *basic* or '*core*' and *advanced* procedures.

For the controller to be able actually to control the traffic at an airport, a set of *basic* procedures is mandatory. These basic procedures are presented here:

1. First of all the controller needs to know whether there are any objects (aircraft or vehicles) within his area of responsibility and, if so, where they are (**surveillance - localisation**).

2. Secondly, the controller needs to know the identity of each object in order to be able to correlate it with (e.g.) flight plan information and exercise executive control (**surveillance - identification**).

3. Expeditious and safe movement of objects across the airport will be controlled through the use of instructions provided to the pilots/drivers (**control - tactical instructions** and **conditional clearances**).

4. Possible conflicts between objects will have to be detected. They can be solved through instructions from the controller to the pilots/drivers (**control - conflict alert/detection, tactical instructions** and **conditional clearances**).

These procedures were not new. Every controller employs skills in these areas every day. The difference is that with the use of A-SMGCS, these procedures no longer have to be a largely mental co-ordination and data handling task based on visual perception. Systems can be provided to support the controller in these tasks. With the help of A-SMGCS, normal procedures can be applied to low visibility conditions. The need to reduce the throughput of traffic that results from the application of special low-visibility procedures, may thus be avoided.

The A-SMGCS 'core' procedures that were identified in WP 1000 for further investigation were:

CP1 Identification of an SMR-labelled aircraft by a Ground Movement Controller.

CP2 Identification of an SMR-labelled aircraft by an Air Controller.

CP3 Conflict Detection/Alert by an Air Controller.

CP4 Conflict Detection/Alert by a Ground Movement Controller. *(Note: Not fully implemented in SAMS platform)*

CP5 Tactical Ground Movement Control Instructions.

CP6 Line up after an arrival or departure (Air Controller).

CP7 Cross the runway after an arrival or departure (Air Controller).

The *advanced* topics suggested in the ATOPS project encompassed automatic routeing/planning, guidance functions and special control functions. The use of these functions required the *basic*, or core, procedures, because they could not be employed without the surveillance and basic control functions of A-SMGCS being in place. Figure 8 refers.

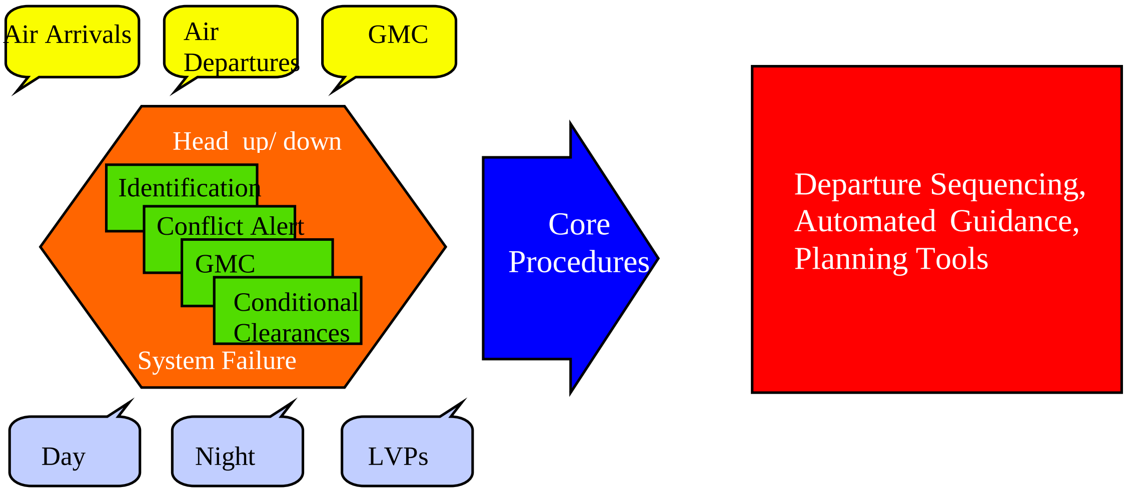

Figure 8 Core and advanced procedure topics

The 'A-SMGCS' advanced procedures that were identified for further investigation were :

AP1a Procedure describing the use of asimple departure planning tool, with no connection to taxiway routeing/planning and control tools. Departure sequence is calculated on the basis of, inter alia, CFMU slots, performance and SID. *(Note: SAMS platform not configured to implement this procedure)*

AP1b Procedure describing the use of an advanced departure planning tool, interfacing with both control and taxiway routeing/planning tools. The departure sequence is calculated on the basis of, inter alia, CFMU slot, performance, SID, and actual traffic situation (e.g. can aircraft be at the runway in time, or are runway crossings required?)

AP2a Procedure describing the use of a simple taxiway routeing/planning tool. The tool would be working in a more or less stand-alone mode. CFMU slots would be used to calculate an “optimal” pushback time and the aircraft would be routed via standard routes.

AP2b Procedure describing the use of a more advanced taxiway routeing/planning tool. Such a tool would be integrated with a tool for departure planning, and would use the resultant takeoff time to calculate an “optimal” pushback time.

AP2c Procedure describing the use of a very advanced taxiway routeing/planning tool. The tool would be integrated in a full-scale A-SMGCS. Pushback times would be calculated based on the actual traffic situation and the takeoff time (from departure planning). Standard routeing would no longer be used, taxiways would be used flexibly to optimise airport capacity and reduce taxi delays, ideally by use of conflict-free taxi plans. The tool would interact with control, calculating new taxi plans for aircraft deviating from the plan, and guidance.

AP3a Guidance is used to switch the taxiway centreline lighting and/or automatic signs along the route of aircraft simulating the behaviour of a follow-me vehicle. The pilot would employ a follow-the-greens strategy. The switching of the lights would be based solely on the route to be followed and the position of the aircraft itself. The taxi plan would only describe the waypoints. This means of guidance could be used for Visibility Conditions 1, 2 and 3 <Ref.2>.

AP3b Guidance is used to switch the taxiway centreline lighting, stopbars and/or automatic signs along the route of aircraft simulating the behaviour of a follow-me vehicle. The pilot would employ a follow-the-greens / hold for the reds strategy. The switching of the lights would be based on the position of the aircraft, the route to be followed and the time at which the aircraft was to arrive at the next waypoint. If the aircraft were taxiing too fast, the lights would slow down or a stopbar would be switched on to slow the aircraft down. The taxi plan would describe waypoints and the time to arrive at these waypoints. This means of guidance could be used for Visibility Conditions 1, 2 and 3.

AP3c Guidance is used in the same way as described above. Added to this functionality is the possibility to uplink guidance information to onboard systems. Up-linked information would be displayed on a display in the cockpit or HUD, showing the airport lay-out, the route to be followed, lit stopbars, positions of other traffic, etc. This means of guidance could be used for Visibility Conditions 1, 2, 3 and 4.

AP4 Aircraft would be guided over the airport the same way as they are today. The difference is that these practices could be used up to and including Visibility Condition 4. Pilots would be responsible for their own navigation and separation. Situational awareness would no longer be provided by the view out of the cockpit window alone, but by information provided by onboard and external lighting and signage guidance systems, such as:

- position of objects and other traffic
- position of own aircraft
- Layout of the airport etc.

AP5 A procedure to deal with incidents when using an A-SMGCS. *(Note: The SAMS control function implemented in the SAMS platform was not equipped to deal with incidents (e.g. collisions on taxiways/aprons and emergency landings).*

AP6 A procedure to deal with runway configuration changes when using an A-SMGCS. *(Note: The SAMS platformwas not equipped to deal with changing weather conditions and the corresponding changes in runway configurations)*

AP7 A procedure to deal with missed approaches when using an A-SMGCS. *(Note: The SAMS platform was not equipped to deal with missed approaches and the corresponding changes in runway configurations)*

4.1.4.2. Procedures Selected For Simulation

Taking into consideration the limitations of the SAMS platform as noted above, the list of procedures that were selected for simulation was as follows:

CP1 Surveillance: identification of labelled aircraft by a Ground Movement Controller;

CP2 Surveillance: identification of labelled aircraft by an Air Controller;

CP3 Control: conflict detection/alert by an Air Controller;

CP5 Control: tactical Ground Movement Control Instructions;

CP6 Control: line up after an arrival or departure (Air Controller);

CP7 Control: cross the runway after an arrival or departure (Air Controller);

AP1b Planning: departure planning (Air Controller);

AP2b Planning: automatic generation of taxi routes (Ground Movement Controller);

AP3c Guidance: automatic routeing (Pilot).

Reference [8] provides further details on the procedures selected for simulation and documents the rationale for proposing these topics for simulation within the ATOPS project.

It should be noted here, that during the course of the ATOPS project, a methodology was produced to allow selection of procedures for simulation and documented in a working paper [9]. This methodology was produced because it was anticipated that there would be more procedures to choose from. However, a natural down selection of procedures for simulation was made due to the non-availability of some SAMS functions as stated above.

4.1.4.3. ATOPS Procedures As Part Of The Overall ATC Procedures

Management of aerodrome movements by air traffic controllers (ATCOs) is a highly complex task that comprises

- Guidance of aircraft and vehicles according to their mission plans with respect to the actual traffic situation
- Co-ordination with other control units and controllers to ensure an overall safe and efficient traffic flow

To perform this complex and challenging task, the interaction between controllers and pilots is directed by officially published procedures that are based on ICAO regulations. The details of the procedures depend on the support of the controller by technical systems that provide the controller situation awareness and support them in Surveillance, Control (conflict avoidance), Routeing and Guidance for Pilots and Drivers.

The aerodrome control units are embedded into the overall Air Traffic Control chain, which manages the Gate-to-Gate movements of aircraft. The number of control units involved and the related areas of responsibility depend on the local organisation at the dedicated airport. The distribution of the areas of responsibility and the number of control positions involved may further depend on the expected traffic load or the time of the day (day, night).

Figure 9 presents these control units and their areas of responsibility for inbound and outbound movements. It depends on the type of operation for the runways (mixed mode, segregated mode) whether the duties of the Tower and Ground Controller for inbound and outbound are dedicated to the same or different persons.

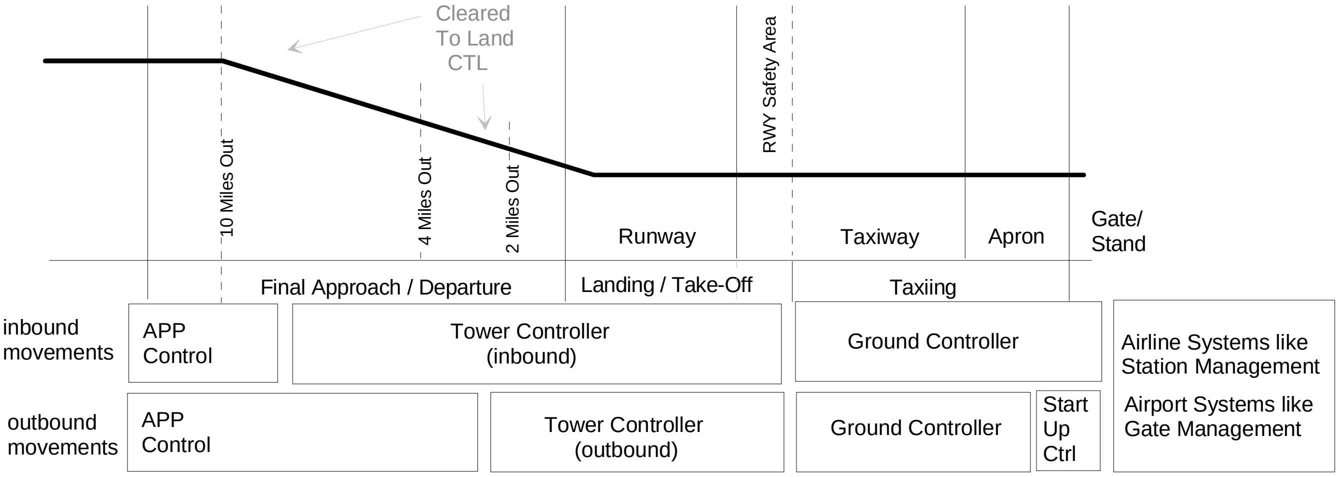

Figure 9 'Co-ordination between different control units and related areas of responsibility'

This example of the organisation of an aerodrome control shows that the control procedures for each control unit comprises the following basic actions:

- Receive responsibility of the controlled mobile (aircraft, vehicle) from previous control unit or the starting position of the movement,
- Control the mobile (aircraft or vehicle) by surveillance, conflict avoidance and guidance according to efficient movement plans,
- Release the responsibility of the mobile by handing over the responsibility to the next control unit or by stopping the movement in a destination position.

Figure 10 shows how the main activities of the Overall Procedure (Receive Responsibility, Control Mobile and Release Responsibility) can be split into nine generic activities, placed roughly in time order.

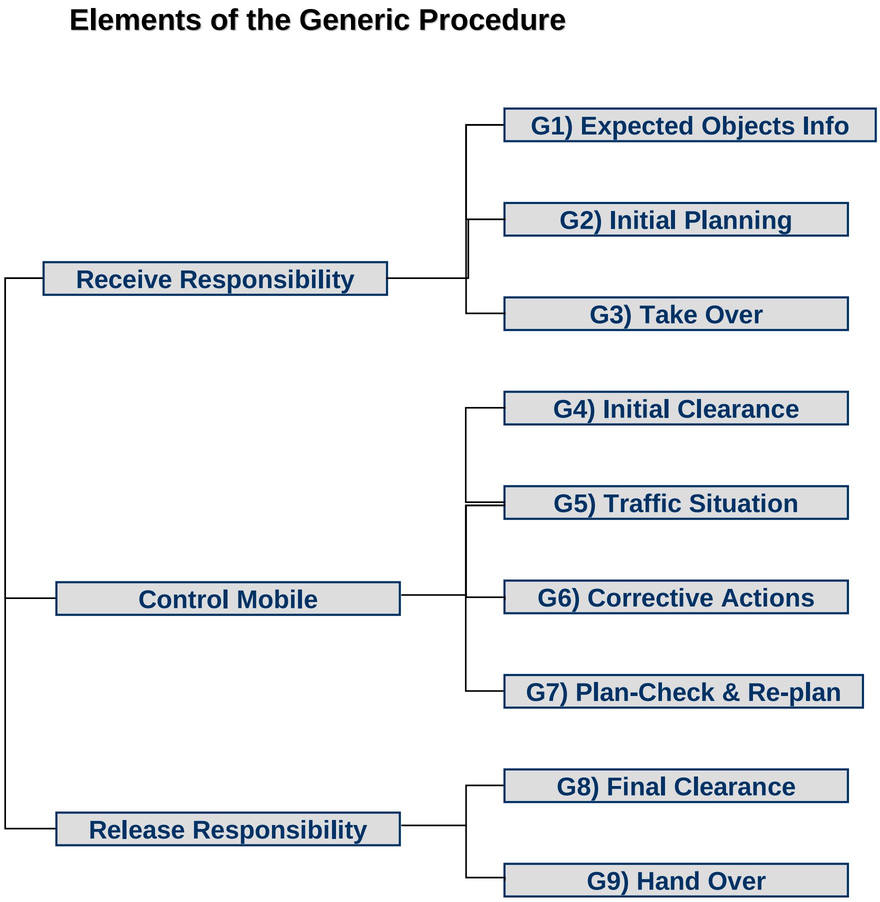

Figure 10 Decomposition of the Generic Procedure into nine Elements

The relevance of the selected ATOPS core procedures and the advanced procedures becomes evident, when their embedding into the overall procedure is shown as demonstrated in Figure 11.

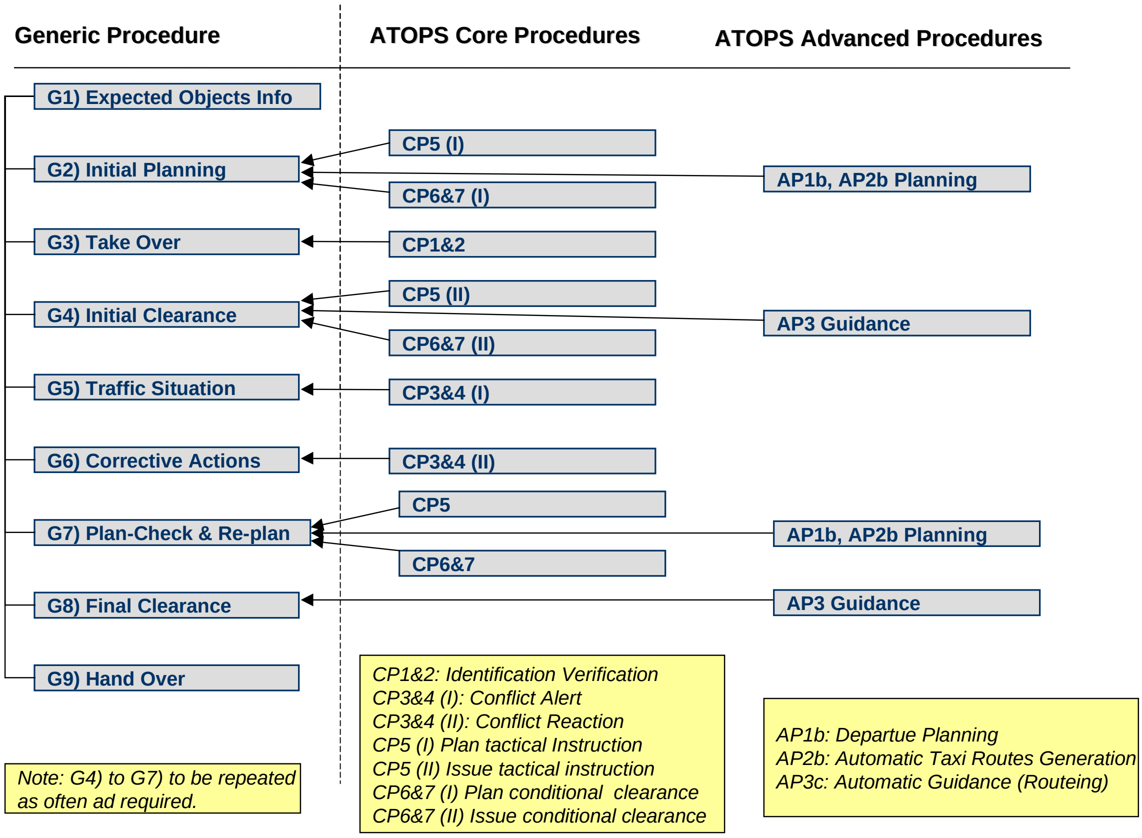

Figure 11 Embedding the selected ATOPS Procedures into the Generic Procedure

The ATOPS Core Procedures

Identification Verification: the procedures CP1 and CP2 are usually applied when the take over of the mobile into the actual control segment is performed, therefore they are related to G3 the Take Over Procedure.

Conflict Alert: the Conflict Alert is a result of the evaluation of the traffic situation by the system, therefore the core procedures CP3 and CP4 are related to G5, Traffic Situation. This is closely related to the required corrective actions procedures G6 by the controller.

Tactical instructions CP5 and conditional clearances (CP6 and CP7) can be split into two activities, the planning of the movement relative to an other movement which is related to the initial planning (G2) and the plan check and re-planning procedure. The second activity is the issue of the instruction or clearance itself which is related to G4 (Clearance) and G8 (Final Clearance).

The ATOPS Advanced Procedures

The **Advanced Planning Procedure** for Departure Planning (AP1b) and Taxi Routes Generation (AP2b) are related to the initial planning procedure G2 as well as to the Plan Check and Re-Planning procedure G7.

The automated guidance procedure AP3c is related to the procedural elements where clearances and instructions are issued either by the controller or the system, these are G4 (Initial Clearance) and G8 (Final Clearance).

4.1.5. Procedure Descriptions

The ‘Core’ Procedures (CP1 – CP7 above) were described in detail in Reference [10]. In preparing the procedures, the ICAO Doc. 4444 [11] and the UK procedures [12] were taken into consideration. Also, the Process used by Heathrow ATC Procedure designers was used to construct the ATOPS procedures. This process, known as the ATC Procedure Safety Analysis (APSA), has 9 steps:

1. Hierarchical Task Analysis

2. Procedure Design
3. Talkthrough and Filter questions
4. Preliminary Hazard Analysis Utilising a Focus Agenda
5. Construct Incident Sequence
6. Severity Category Assessment
7. Safety Requirements
8. Resolution
9. Sign Off by the Responsible Manager

The first four elements are undertaken to all ATC procedure changes and the other steps are undertaken when the filter questions (step 3) indicate that a change has safety significance.

It was intended to prepare the ‘Advanced A-SMGCS’ procedures in WP 1000 of the project. . The ‘Advanced concepts’ related to the advanced procedures stated in section 4.1.4.1 were outlined in reference [13]. However, the ‘advanced’ procedures were not drafted. This is due to insufficient knowledge about the advanced A-SMGCS functions actually implemented in the SAMS simulation platform when the procedures were being written. It was decided that because the ATCOs taking part in ATOPS would get the opportunity to use the tools once the platform was complete and they could still create ideas for advanced A-SMGCS procedures for future evaluation.

4.2. SIMULATION TESTING

This work package dealt with the preparation and execution of the simulation activity. The overall task was broken down into two main areas: simulation support and simulation runs. Reference [14] contains details of the simulation organisation.

4.2.1. *Simulation Support*

The main activity undertaken in this part of the project were the preparation of the required test scenarios and the final adjustments to the SAMS platform before the simulation started.

4.2.1.1. Statement of Management objectives

For both Schiphol and Heathrow simulations, a set of ‘management objectives’ were defined. These objectives formed the basis of the qualitative evaluation of the procedures. Table 6 summarises the objectives for the Schiphol simulation and Table 7 summarises the objectives for the Heathrow simulation.

Procedure/ sub-system	**Objective**
Identification	• Are the ATCOs able to work with the labelled SMR? • Do the ATCOs feel the procedure with respect to the identification of traffic on the airport has operational significance? • Can the ATCOs dispense with the paper flightstrips? • Is there an indication of an increase in capacity or reduction of ATCO workload during low visibility conditions due to the labelled SMR? • What kind of system deficiencies can the controller accept with respect to: Label swap, label drop, system misidentification, loss of track, positional inaccuracy, and detection probability?
Conflict detection/ alert on the arrival runway	• Do the ATCOs feel that the procedure with respect to Runway incursions has operational significance? • Do the ATCOs think that the Runway Incursion Alert (RIA) is triggered at the correct moment and under the right circumstances? • If the RIA is not triggered at the right moment, then how can the applicable user parameters be adjusted? • If the RIA is triggered correctly, does the ATCO react in an expeditious and safe manner? • Is there enough time left for both controller and pilot to respond and prevent an accident after a RIA is

	triggered? • Is the procedure correctly applied? • Are correct priorities applied in multiple conflict situations? • What is the impact of surveillance positional accuracy on conflict detection/ alert? • What is the impact of positional accuracy? Can track jitter cause false alerts?
Conditional clearances	• Do the ATCOs feel that the applicable procedure has operational significance? • Do the ATCOs feel comfortable to employ such a procedure during low visibility operations? • Is there an indication of a positive effect on the capacity of the airport or the ATCO workload?
Tactical GMC Instructions	• Do the ATCOs feel that the procedure has operational significance? • Do the ATCOs feel comfortable to employ such a procedure during low visibility operations? • Is there an indication of a positive effect on the capacity of the airport or the ATCO workload?

Table 6 Schiphol objectives

Procedure	**Objective**
Identification	Does the ATCO carry out correct procedures to cope with: • System misidentification of an aircraft – wrong labels, or right aircraft/wrong strip, at pushback request? • Track loss? • Loss of label, start-up without label, etc?
Conflict detection/ alert on the arrival runway	• Does the ATCO react correctly to a single conflict alert? • Is the procedure correctly applied, are go-around decisions correctly judged? • Are correct priorities applied in multiple conflict situations? E.g. when a vehicle enters the runway in front of aircraft A on finals which in turn is being caught up by aircraft B? • What is the impact of surveillance positional accuracy on conflict detection/ alert?
Conflict detection / alert on the departure runway	Frequent level 1 warnings occur when aircraft are lining up one behind another; does the ATCO identify and act on real vehicle conflicts in the event of a level 1 warning?
Conflict alert - general	• Should pop up windows be used? • Are colour changes sufficient? • Are audible warnings necessary? • Are time parameters for levels 1 and 2 correctly set for normal and low visibility? • What is impact of positional accuracy? Can track jitter cause false alerts?
Conditional clearances	Are they safe, based on surveillance information?
Tactical GMC Instructions	Applied in Visibility conditions 2 and 3, do they expedite traffic movement rates above the baseline rates without such instructions?
Tactical GMC	In response to a direction to follow, an aircraft follows the wrong leader. How does the ATCO react?
Conditional clearances	An aircraft lines up in the wrong place. How does the ATCO react?

Table 7 Heathrow objectives

4.2.1.2. Preparation of Test Scenarios

After listing the management objectives for each airport, a test scenario was generated for each objective with an associated success criterion. An example of this is as follows:

Management Objective: In A-SGMCS Visibility Condition 2, the GMC ATCO is able to consistently apply the identification procedure to outbound aircraft.

Test Scenario: During a continuously busy GMC simulation the ATCO should be presented with an aircraft pushing back using a callsign that agrees with the FPS and visuals but does not agree with the HMI.

Success Criterion: The controller – if applying the procedure – will notice the error and identification will fail. The controller will inform the aircraft that his SSR is unreliable and that it is not identified.

To create the test scenario, the traffic samples had to be built and the scenario compiled with flight plan information. Four hours of recorded Heathrow traffic data (runway logs plus strip information) from 4th June 1999 were used to generate representative scenarios. The recorded data was divided into operations of shorter length to provide a variety of arrival and departure scenarios for the various Controllers. The building of traffic samples included preparation of the DLR TOWER VISUAL SIMULATOR traffic data, preparation and checking of trial strips and preparing scripts for the pseudo pilots and LATCH pilot. Similar recorded data was collected and used for the Schiphol simulation.

4.2.1.3. Status of SAMS Platform For Simulation

The Tower Simulator supported at least two controller working positions. For each Heathrow or Schiphol scenario, the controller positions were configured as required. In the case of Heathrow simulations, the positions could be used by a GMC controller, Arrival or Departure Controller. For Schiphol simulations, the two positions were occupied by two Ground Controllers, one Tower Controller and one Ground Controller or two Tower Controllers. *(Note: In the second week of the Schiphol simulation only one controller was available).*

The Tower Simulator had a number of aircraft type/ livery combinations available. These were originally designed for simulations for Frankfurt and Zurich airports. Therefore, not all the aircraft/ livery combinations that could be expected at Heathrow/ Schiphol airports were available. A working solution was set up which included the use of similar or comparable aircraft.

One of the goals of the ATOPS project was to acquire information about system parameters for an A-SMGCS (e.g. what kind of inaccuracies controllers can cope with related to the surveillance system such as positional errors). The SAMS platform had been set up in such a way that parameters like this could be configured by the user and their effects can be studied. It was therefore not possible to prepare the platform with sets of parameters determined long before. Instead these were decided with controller and pilot interaction shortly before the start of the simulation runs.

A technical and operational validation of the SAMS platform took place in December 1999. During this validation, shortcomings of the simulation platform were found (see Section 5 of this report).

Up to five pseudo pilots provided by delair ATS were used during the simulations controlling up to 60 moving aircraft.

The meteorological parameters were set to correspond with the runway use and the information displayed on the controller HMI. The visibility settings of the Tower Visual Simulator were deemed not to correspond with reality. The Dutch controllers calibrated the Tower visuals as indicated in Table 8 below. It can be seen that in low visibility the reported visibility was significantly less than the perceived value. In other cases the reported visibility seemed to be optimistic.

Tower Visual Simulator Value	**Compared to Schiphol reality**	**Simulation Category**
100m	Less than 400m	Low
6km	About 2km	Medium
200km	Better than 10km	Good

Table 8 Tower Meterological conditions

4.2.2. Simulation Runs

4.2.2.1. Simulation 'Work Up'

A 'work up' period took place between 20 and 23 December 1999. This activity involved final installation checks of the SAMS platform, installation of Schiphol and Heathrow scenarios and 'rehearsals' of the Schiphol and Heathrow scenarios. The personnel involved included the simulation providers, Dutch and UK Controllers, pseudo pilot drivers and a simulation co-ordinator.

4.2.2.2. Timetable For Simulation Runs

The simulations ran over a five week period (10 January – 10 February 2000). The first two weeks were set up for Schiphol simulations using Dutch controllers and the latter three weeks for Heathrow simulations using Heathrow controllers. For most weeks there was three complete days of simulation following half a day for training and familiarisation. Each simulation day started with a briefing for the day. Typical simulation 'slots' ran for around an hour followed by a thorough de-briefing session. *(Note: some part of the Schiphol simulation time was used in attempting to address SAMS platform problems).*

4.2.2.3. Operating Procedures

All manoeuvres conducted by aircraft and vehicles under the control of the pseudo/ LATCH pilots were in accordance with instructions received from Air Traffic Control. Exceptions to this were (i) specified in the Scenario Specific Procedures provided to the pseudo-pilots or (ii) unless instructed otherwise by the simulation supervisor for the purpose of investigating specific SAMS functionality, e.g. Runway Conflict Alert.

When the GMC position was manned for the simulation exercise, the controller issued taxi instructions to aircraft and vehicles under his responsibility, i.e. on the Manoeuvring Area. The taxi instructions specified the route to be followed in order to proceed from the runway entry/ exit point to the stand and vice-versa. Taxi instructions were also issued to aircraft under tow and ground vehicles proceeding from one part of the airport to another.

When the GMC position was not manned for an exercise, the pseudo-pilots taxied their aircraft to the holding point of their assigned runway (for departures) or to the designated stand (for arrivals) by the most direct route. However, aircraft did not enter or cross either of the active runways, without first obtaining the authorisation of the appropriate Tower controller.

4.3. ANALYSIS AND REVIEW

This work package was concerned with analysing the results of the simulation. The overall task was broken down into two main areas: simulation reporting and future research activities.

4.3.1. Simulation Reporting

Reference [15] details the results of the simulation and provides an analysis of results. For ease of reading, Section 5 of this report repeats the main results and analysis of the results.

4.3.2. Future Research Activities

Section 6 of this report contains the conclusions of the ATOPS project and includes recommendations for future research activities.

4.4. DISSEMINATION

This work package was concerned with exposing the ATOPS progress and results to relevant and interested parties. The overall task was broken down into two main activities: Procedure Selection meeting and final presentation.

4.4.1. Procedure Selection Meeting

During WP 1000 a meeting was held between the EC, Eurocontrol, ATOPS partners and representatives of IFATCA, ACI Europe and AOPG PT/2. The purpose of this meeting was to present the ATOPS project to the 'stakeholders' and to inform them of the results of the Airport Consultation process. A further reason for the meeting was to discuss and select procedures for simulation.

4.4.2. *Final Presentation*

It has been agreed with the EC that the results and lessons learnt from the ATOPS project should be presented to the Eurocontrol Airport Operations Team (AOT) in December 2000 and the AOPG PT/2 in October 2000.

5. RESULTS AND ANALYSIS OF RESULTS

5.1. RESULTS

Six Controllers from Heathrow airport and three Controllers from Schiphol airport took part in the simulations that took place over a period of five weeks.

Figure 12 below is a pictorial representation of the procedures and sub-systems involved in the ATOPS project. The colour /text format coding represents whether an item was available for simulation. A green box/ bold text indicates that the procedure/ function was available and a red box/ italic text indicates that the procedure/ function was not available for the ATOPS simulation. The pink box/ regular text indicates that the procedure was only partly available. It can be seen from this that the SAMS platform was not fully functional for the ATOPS simulations, and this obviously had an impact on the results obtained. The 'Advanced' procedures were not evaluated due to the limitations of the SAMS platform (i.e. the Guidance and Planning functions not performing as required).

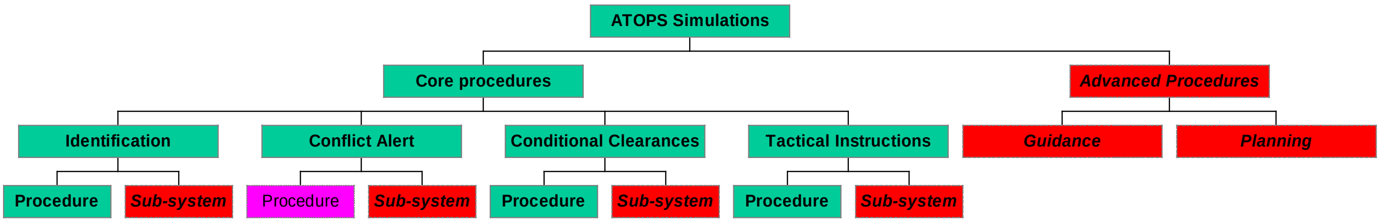

Figure 12 Availability of ATOPS procedures/ sub-systems

5.1.1. Core Procedures For Use Of An A-SMGCS

Only the Core Procedures were eventually addressed during the ATOPS simulation. The following sections provide information on the quantitative and qualitative results of the simulation for each core procedure.

5.1.2. Identification

During the testing the ATCOs were exposed to scenarios with low, medium and high traffic densities. Each of these scenarios were used in good, medium and low visibility conditions to identify what the effect would be on ATCO task performance of using a labelled SMR display in a variety of operational conditions. Initially the controllers needed to familiarise themselves with the display (including labelling).This was expected and was managed through the use of training exercises.

5.1.2.1. Quantitative Results

Once the ATCOs indicated that they were used to the labelled SMR, the data gathering started. During and after each run observers checked whether aircraft were delayed while taxiing on the airport and determined whether those situations when delays occurred were any different in any way than what would have occurred in real-life. No discrepancies between the simulation and real airport operations were identified in this aspect of the trial scenarios.

5.1.2.2. Qualitative Results

In order to test the procedure with respect to the identification of aircraft on the manoeuvring area, several strategies were used:

- Some aircraft were initialised with labels that did not correspond to their flightplan. This had the effect that the callsign used by the pilot was in correspondence to the one on the flightstrip, but the labelled SMR showed a different callsign,

- Pseudo-pilots were sometimes instructed to call the ATCO with a callsign that differed slightly from the callsign on the labelled SMR and the flightstrip,

- Some of the aircraft labels were purposefully initialised with a wrong type of aircraft (e.g. B747 instead of B737)

During the controller familiarisation period (the first 2 or 3 exercises) wrong callsigns generated as described above were missed. As the ATCOs became familiar with the HMI it became second nature to check the data on the HMI with the flight progress strip and the pilot read-back. Wrong callsigns were inserted in various situations and weather conditions for Arrival, Departure and GMC scenarios. Each time the controllers noticed the error and clarified the situation by checking the flightstrip, labelled SMR and contacting the pilot.

The wrong aircraft type information posed a slightly different problem. The detail of the aircraft type was only on the extended label and not on the default label (callsign only) which was normally used. Usually the ATCOs would be monitoring both the labelled SMR display and the paper flightstrips and would still notice the difference in aircraft type. However, once some of the ATCOs started to experiment with using the labelled SMR display without the paper flightstrips, they were more than likely to miss the error. Unless the ATCOs intentionally used the extended label the occurrences of wrong aircraft type information were not detected.

The test objective associated with track loss (and the ATCOs reaction to this) could not be evaluated easily, as there was no facility in the simulator to remove individual aircraft tracks. A work-around was established by turning off all HMI labels and instructing the controller to re-identify particular aircraft. Positive identification was re-established in this situation using the HMI. This technique seemed to work effectively.

During the testing other more general comments related to aircraft identification were made by the ATCOs as follows:

- The label de-conflicting and leader lines in the HMI caused a number of problems. More display development work is needed to clear these problems:
  - Labels appear to swap targets due to the length of the leader lines,
  - Labels, when de-conflicting, lie over the runway suggesting there is a runway incursion,
  - A suggestion was made that the current ATM label de-conflicting could be used in this simulator,
  - Duplicate labels appeared at random causing confusion as to which was the correct target, especially in Visibility conditions 2 & 3.

- A procedure is needed for total loss of aircraft identification, assuming you will lose the equivalent to the current “squawk ident.”

- The colours on labels need more thought, the yellow inbound labelling had insufficient contrast on a grey background and was therefore difficult to see.

- The labels attached to arrivals should clear from the display when the aircraft has parked on stand or a manual option to clear the label should be available. The labels in the exercises remained active for too long and created clutter on the screen, making the identification of targets on the aprons rather difficult.

- The labels attached to departures should be activated shortly before the aircraft becomes active and the pilot calls for Start-up, Push or Taxi. As long as the aircraft is parked on stand the label should not be visible. This would help to prevent clutter on the screen and make it easier for the ATCOs to identify targets on the aprons.

- The GMC HMI display should incorporate data on occupied stands. The digitised and labelled SMR does give this kind of information implicitly by showing a target at the gate, a characteristic which the controllers really liked. However, they wondered about the possibility of connecting the HMI with the gate management system and showing whether a gate is occupied, will be occupied in the near future, or is available to an arrival if needed.

- The HMI labelling information should be limited:
  - Arrival labels should only show callsign, aircraft type and gate/stand,
  - Departure labels should show callsign, SID, aircraft type and assigned runway.

- The Distance From Touchdown Indicator (DFTI) should have an option to be rotated such that it represents the actual runway orientation. Furthermore, the arrivals did not clear from the DFTI once they had landed. Thus the area around the runway threshold was cluttered in the display.

- The Dutch ATCOs were of the opinion that the procedure with respect to identification as drafted in the ATOPS project was not really a procedure. In their opinion a procedure description should have a lot more detail, instructing them what to do in various cases, such as how to continue if suddenly all of the labels disappear from the display (as happened during the trials due to technical problems). However, the basics for a useable HMI display were there in what was provided for ATOPS. They felt that the way they identify an aircraft in the current situation is very similar to the way they could do it with use of the labelled SMR. Naturally a prerequisite would be to have a reliable surveillance system.

  An extra remark made by the observers was that it seemed as though once the controllers started to use the labelled SMR display extensively there was a reduction in R/T communications. No hard data has been recorded, but the simulation room seemed quieter when the ATCOs used the display instead of the outside view.

5.1.3. *Conflict Detection And Alert*

The ATCOs have been exposed to traffic scenarios with low, medium and high intensities of traffic. Each of the scenarios was used in good, medium and low visibility conditions. In some of the runs the ATCOs intentionally created Runway Incursion Alerts (RIAs) to see how the RIA-function would respond, in other cases the Pseudo-pilots created them intentionally to test the response of the controllers to RIAs. Initially the controllers had to get used to the display showing the traffic situation and the RIA warnings, but this was expected and managed through the use of familiarisation runs.

Once the ATCOs were used to the display, the data gathering started. During the runs observers checked whether RIAs were presented and whether or not the controllers noticed them and responded accordingly.

5.1.3.1. Quantitative Results

- The first attempt at using the RIA function was unsuccessful. The controllers or the test team did not expect a lot of the alerts presented, since none of the RIA rules applied [15]. In other cases, when the rules did apply, no RIA was given.

- RIAs were generated for aircraft on final approach when another aircraft infringed on the runway, but the alert immediately disappeared once the arriving aircraft passed the runway threshold. It only appeared again when the landing aircraft had passed the aircraft intruding on the runway.

- Initially during good visibility runs, the ATCOs missed some of the alerts. Their performance improved as their experience with the A-SMGCS grew.

- During the Schiphol trials the RIA function generated incorrect alerts for aircraft which were not in conflict with one another and on completely different runways.

- A large number of the arrivals had to be given a go-around either because they came in for landing too close behind one another or because a RIA was generated. Especially in low visibility condition exercises 60% of arrivals were given a go-around even when the usual increased spacing applicable to these conditions was applied.

- Due to an insufficient command of the English language, R/T skills and unfamiliarity with the tower simulator’s pseudo-pilot software and problems with the software itself and the database driving it, the pseudo-pilot input was not always quick enough to accurately react to the ATC instructions. Over time this improved considerably, despite the problems with the software and especially the Heathrow database.

- The ATCOs regularly did not notice the change in status of RIA alerts. Warnings were signalled in pink, whilst critical alerts were signalled in red. During the trials yellow and orange alert labels were used for the warning stage to assess whether or not this would improve the visibility of the change in alert status. It was thought that a yellow warning stage alert was a great improvement.

- Multiple line-ups generated warning RIAs, distracting the controllers and sometimes lead them to miss a critical RIA. If more than one RIA was generated simultaneously, the controllers were warned by the RIA, but did not always notice all of the conflicting aircraft.

5.1.3.2. Qualitative Results

- The controllers were of the opinion that the applicable procedure did not really reflect a complete procedure. It does not give them a handle on how to respond in certain situations when a RIA was generated. Consequently the controllers put their operational experience to use, coping with the simulator's characteristics as best as they could. No incidents or accidents occurred other than those that were intentional.

- The ATCOs remarked that Conflict Alert & Detection should be runway specific, so the ATCO would only see the RIAs that are being generated for the runway under his/her responsibility. To show the RIAs generated for traffic on other runways is very distracting, since they cannot react upon it.

- Alerts caused by multiple line-ups on departures are a distraction to the ATCOs. A multiple line-up consists of two aircraft lined-up behind one another on the runway. No RIA is needed unless the rear aircraft starts to move while the other aircraft is still on the runway.

- Critical RIAs should have some audible warning as in good visibility conditions the ATCOs may not even be using the HMI screen and may miss the alert.

- The labelled SMR display usually was zoomed in on the airport. Due to this fact, the aircraft on approach to the airport were not visible in this display. They could be seen on the Distance From Touchdown Indicator (DFTI), an extended runway centreline overlaid with the approaching aircraft positions and identification. Aircraft in conflict were marked with a coloured label on the SMR display, but not on the DFTI. It was therefore not always immediately obvious to the controller which aircraft was causing the alert. ATCOs remarked that RIAs should also be displayed on the DFTI/approach monitor.

- The ATCOs felt that even though the functionality of the RIA as implemented in the SAMS platform was not optimal, testing and evaluating such a tool in a tower simulator is a good idea. It gives the opportunity to quickly test the system with respect to situations that will not regularly happen at any actual airport.

5.1.4. Tactical Ground Movement Control Instructions

5.1.4.1. Quantitative Results

No quantitative results were obtained for tactical ground movement control instructions.

5.1.4.2. Qualitative Results

ATCOs remarked that GMC seems an easier task with the labelled SMR display (for both Head down only and combination of Head up/ down operations). Traffic loads taken from samples with good weather (High traffic density) were comfortably handled in medium and low visibility conditions with the improved surveillance from the labelled SMR.

5.1.5. Conditional Clearances

5.1.5.1. Quantitative Results

No quantitative results have been obtained for use of conditional clearances.

5.1.5.2. Qualitative Results

The controllers involved in the trials were able to use the HMIs in good, medium and low visibility conditions to execute conditional crossing and line-up clearances. Compliance of instructions was successfully monitored on the labelled SMR display. The indications were that the labelled SMR display was allowing the controllers to perform their task during good visibility without impedance but it was provided an enhanced capability during medium and low visibility A-SMGCS performance Parameters

5.1.5.3. Surveillance Performance

5.1.5.3.1.Positional Accuracy

5.1.5.3.1.1.Quantitative Results

Tests to check what kind of surveillance inaccuracy could be acceptable to controllers when using an A-SMGCS in good and low-visibility conditions failed. No quantitative results were obtained for reasons described in the section below.

5.1.5.3.1.2.Qualitative Results

Some traffic scenarios were run, with the accuracy of the surveillance system degraded to realistic values for particular technologies. In practice this meant that only the SMR was assumed to be operational (neither Heathrow nor Schiphol had any other sensors available for ground surveillance at the time of the trial). The accuracy of the SMR position information was set to 25 meters, which is a more or less realistic value depending on the type of radar used.

In theory, if the positional error for the SMR was configured correctly, this should have led to the plots on the ATCOs HMI 'jumping' or 'jittering' around the actual position of the aircraft within a circle whose radius was equal to the positional error.

The ATCOs immediately responded that the error modelling was not realistic. The magnitude of the error was greater than what had been set (25 m) and the so-called track-jitter did not look random as it should have, but occurred along a line from SW to NE (Figure 13). Due to the difficulties encountered with the error modelling, it was impossible to find out what the ATCOs required with respect to positional accuracy for the surveillance function.

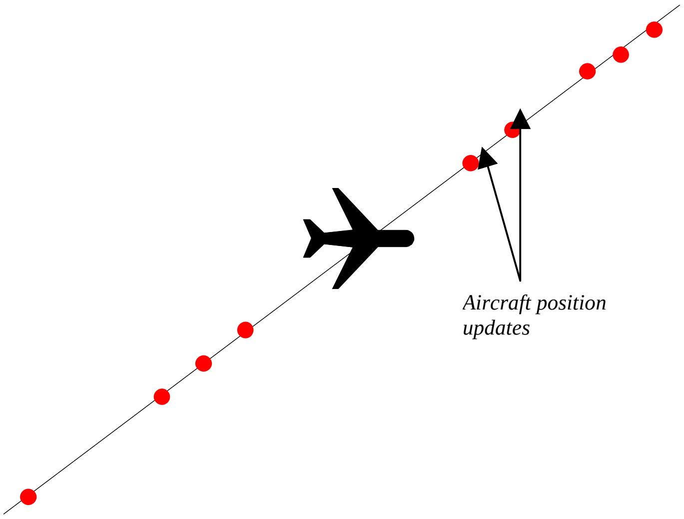

Figure 13 Track jitter

5.1.5.3.2.Detection Probability

Due to the instability of some of the SAMS components and the lack of a sufficient level of realism of the error modelling , it was decided not to investigate requirements for detection probability with respect to the surveillance function. Neither qualitative nor quantitative results were obtained with respect to subsystem performance.

5.1.5.3.3.Wrong Initialisation of Label

Due to the instability of some of the SAMS components and the lack of a sufficient level of realism of the error modelling, it was decided not to investigate requirements for wrong label initialisation with respect to the surveillance function. Neither qualitative nor quantitative results were obtained with respect to surveillance subsystem performance.

5.1.5.4. Control Performance

5.1.5.4.1.Parameters for Triggering Runway Conflicts

The team was not able to investigate what the optimal parameters would be for triggering runway incursion alerts. Here more tuning of the Runway Incursion function is needed.

5.2. ANALYSIS OF RESULTS

This chapter is an analysis of the results obtained during the simulations.

5.2.1. Analysis Of Core Procedures For Use Of An A-SMGCS

5.2.1.1. Identification

The ATCOs were able to use the labelled SMR to guide the traffic on the airport without any significant changes to the usual operations of the airport. Even in the low visibility scenarios the ATCOs were able to cope with high traffic densities. It should be noted that due to the difficulties with modelling the behaviour of actual sensors with respect to parameters such as positional accuracy, the ATCOs were working with a system that had no errors or delays in the data used. . In the view of the test ATCOs it is to be expected that even a less than perfect system would be beneficial during medium and low visibility conditions.

Intentional data errors were introduced into the system, leading to wrong combinations of flight strip, label on the SMR display and the R/T identification used by the pilot. Mixing up types of aircraft, leading to a mismatch in the visual presentation of the aircraft on the outside view and the data on the flight strip and the labelled SMR display produced a similar scenario. In the majority of cases, after getting acquainted to using the labelled SMR, the ATCOs had no trouble identifying the various data errors introduced by the ATOPS test team.

However, in a limited number of cases, the mismatch in the type of aircraft was missed by the ATCO when the flight strip and the SMR label presented the same information. This was due to the low resolution of the simulated outside visuals (low compared to what the human eye is capable of), the fact that the type of aircraft was not shown in the default label on the SMR display and the ATCO not checking the flight strip when using the labelled SMR extensively. It is likely that in a real tower the ATCOs eyes would have picked up the details of aircraft types and liveries etc. that were missed in the simulator.

It can be concluded that a labelled SMR is extremely helpful to ATCOs, because it helps them to identify and guide traffic on the airport surface especially during low visibility conditions. Subjective observation indicated that ATCO workload decreased. This was apparent in the observed reduction in R/T communications. It would seem as though the controllers using the HMI needed fewer checks to form a mental picture of the traffic situation on the airport and to keep this picture updated. Unfortunately no more than an indication could be found due to all the technical problems encountered. In order to find quantitative evidence of these indications, more and better tests will have to be done.

The procedure with respect to identification of traffic as drafted in this project is a good start to the task of developing new procedures for A-SMGCS. The ATCOs were able to apply it to the situations they were exposed to with success. Any failure in identifying traffic or spotting system errors (e.g. wrong label) were not due to the procedure itself, but were caused by the limitations of the simulation and lack of proper knowledge of the simulation platform when the procedures were designed. A good example of this is the absence of the type of aircraft in the default label on the SMR display. Procedures and the systems used by ATCOs should be designed in close co-operation in order to prevent things like these from happening in actual A-SMGCS implementation projects.

5.2.2. Conflict Detection And Alert

Initially the ATOPS trials for Schiphol started with the RIA function switched on. However, this created a lot of nuisance alerts which the controllers considered distracting and of no real value. For the remainder of the first week of testing, the RIA function was switched off and the attention was on the use of the labelled SMR surveillance. The second week, the team focussed on the RIA function as well as during the three weeks of the Heathrow simulations. For the Heathrow simulations, fewer problems were apparent , since most of the technical problems had been ironed out during the Schiphol trials and as a reflection of the less complicated runway configuration used (2 parallel runways) at Heathrow.

A lot of initial problems with the RIA function, or other A-SMGCS sub-systems that supply information to the RIA function, had to be fixed. Once this had been done, it became apparent that the implementation of the RIA function was such that the Schiphol ATCOs could not work effectively with it. This was less the case for the Heathrow ATCOs due to the less complicated layout of the runways at Heathrow, but they were also not content with the RIA function.

Initially a lot of RIAs were never generated in situations when they should have been. After some investigation, it was found that the RIA function was being supplied with wrong heading and speed information.

Aircraft entering the runway when another aircraft was on final approach did generate RIAs, but these disappeared once the landing aircraft passed the runway threshold. This discontinuity was caused by the change of algorithm at that point because once the aircraft passed the runway threshold, another search algorithm was activated to find intruding aircraft on the runway. This algorithm did not search for targets along the whole runway, but for targets within a circle (radius as user parameter). The circle had intentionally been kept small to prevent interference with other runways. Once the circle was made larger, the discontinuity problem was fixed, but solving this problem introduced another problem, e.g. aircraft landing on runway 27 created RIAs with aircraft departing from runway 24 as illustrated in Figure 14. The search algorithm looked for targets on a runway, within the circle and not for targets on the *same* runway as the landing aircraft was approaching. Due to the layout of Schiphol, this kind of implementation of a Runway Incursion Alert tool was not operationally acceptable to the Schiphol ATCOs.

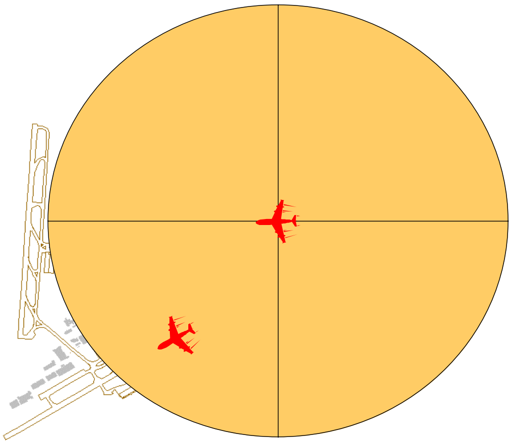

Figure 14 Runway Incursion Alert detection

Arriving aircraft had a very high speed on final approach (160 kts) due to an error in the Tower Simulator software that could not be corrected at the time. The high approach speed was not representative of the real world situation. In the simulations it considerably increased the number of critical and warning alerts due to both an increase in aircraft runway occupancy time due to the higher landing speed and a decrease of the time needed to travel the distance from outer marker to the runway threshold. Even with increased spacing in the low visibility exercises 60% of arrivals were given a go-around. Due to this fact, the outcome of the RIA simulations is not comparable to an actual operational environment.

On some occasions a critical alert was missed by an ATCO due to the fact that multiple line-ups were causing a lot of warning RIAs. The critical alert information was lost amongst the other non-critical alerts. A RIA with various stages of alert to prioritise the alerts that are presented to the controller needs to be provided.

Distractions were caused to ATCOs by the RIAs generated for a runway *not* under their responsibility of a specific ATCO. Alerts should only be presented to ATCOs who are actually responsible for the targets in conflict.

The core procedure with respect to how to cope with a Runway Incursion Alert tool has never been tested.. During the preliminary stages of the trial the controllers were of the opinion that the drafted procedures did not represent a useable procedure. It did not give them guidance on how to respond in certain situations when a RIA is generated. Consequently the controllers put their operational experience to use, coping with the simulated RIAs as best as they could. However, it is relevant to note that since no actual incident or accidents occurred, other than those that were intentional by either Pseudo-pilot or ATCO, it is probable that the use of the A-SMGCS incursion function did not have to effect the safety of operations of airports in a negative way.

5.2.3. Tactical Ground Movement Control Instructions

During all visibility conditions (good, medium and low) the ATCOs applied tactical ground movement instructions as if they were working in good visibility conditions. The Labelled SMR helped to provide them with a clear understanding of the actual traffic situation on the airport. Basically the ATCOs applied their operational experience and day to day (good visibility) practices independent of the simulated visibility conditions.

According to the ATCOs, the procedure with respect to tactical ground movement instructions was not really a procedure, but more a general description of their usual way of operating. Instead of visual references (looking outside) they were now supposed to use the information as presented to them on the labelled SMR display, which they successfully did. It should be noted that there is a likelihood that in real operational low visibility situations, where there are real traffic and passengers the controllers may be a little more reluctant to use the HMI as freely as was done in ATOPS.

5.2.4. Conditional Clearances

The ATCOs during all visibility conditions (good, medium and low) applied clearances as if they were working in good visibility conditions. The Labelled SMR helped to provide them with a clear understanding of the actual traffic situation on the airport. Basically the ATCOs applied their operational experience and day to day (good visibility) practices independent of the simulated visibility conditions.

According to the ATCOs, the procedure with respect to clearances was a general description of their usual way of operating. Instead of visual references (looking outside) they were now supposed to use the information as presented to them on the labelled SMR display, which they successfully did.

5.3. A-SMGCS PERFORMANCE PARAMETERS

5.3.1. Surveillance Performance

5.3.1.1. Positional Accuracy

Unfortunately there was not much to analyse with respect to the needed positional accuracy when using an A-SMGCS. Attempts were made at running exercises with a reduced set of sensors (only SMR and no multi-lateration or DGPS) with an error model applied to it. It was immediately apparent that the user parameter (positional accuracy) did not relate to the observed magnitude of the positional error on the labelled SMR display. Furthermore, the error modelling itself was unrealistic. The error in x-and y-direction were the same, resulting in track-jitter along the line y=x instead of within a circle with a radius equal to the user parameter.

Since the relation between the user parameter and the actual error observed was not obvious, it was impossible to perform any tests to find out what kind of positional accuracy would be acceptable to ATCOs in combination with a labelled SMR and RIA functionalities.

5.3.1.2. Detection Probability

Due to the instability and the lack of a sufficient level of realism supplied by the simulation platform for this kind of test, it was decided not to investigate requirements for the probability of target detection with respect to the surveillance function. Neither qualitative nor quantitative results were obtained with respect to surveillance subsystem performance so there was nothing to analyse.

5.3.1.3. Wrong Initialisation of Label

Due to the instability and the lack of a sufficient level of realism supplied by the simulation platform for this kind of test, it was decided not to investigate requirements for wrong label initialisation with respect to the surveillance function. Neither qualitative nor quantitative results have been obtained with respect to surveillance subsystem performance so there was nothing to analyse.

5.3.2. Control Performance

5.3.2.1. Parameters for Triggering Runway Conflicts

The team was not able to investigate what the optimal parameters would be for triggering runway incursion alerts for two main reasons:

- The simulation of the airport operations was not realistic enough due to the unrealistically high approach speed of aircraft (160 kts or more). This was an error in the Tower Simulator software that unfortunately could not be fixed. The high approach speed was not comparable to the real-world situation and therefore any parameter which would be right for the simulation, would not be valid for the real airport and therefore of no value.

- The test of runway incursion alerts could only be carried out for a single operational runway. Due to the way the incursions were detected. The search algorithm looked for other targets within a circle (with a user definable radius), penetrating a runway zone. In order to include aircraft anywhere along the runway, the circle had to have a radius with at least the same length as the runway itself (approximately 3500 m). However, since the algorithm did not check whether a detected target was penetrating a zone of the runway the aircraft was on, it also alerted for aircraft on other runways.

6. CONCLUSIONS AND RECOMMENDATIONS FOR FURTHER WORK

A Report was prepared to discuss the lessons learnt, conclusions and recommendations of the ATOPS project [16]. Highlights from this report are included in the sections below.

6.1. CONCLUSIONS

6.1.1. *Achieved Objectives*

The ATOPS project was successful in achieving the following objectives:

- Identifying the need for specific operational procedures using A-SMGCS that can be expected to enhance the efficiency and capacity of airport ground movements;
- Collating these candidate procedures together with comments of end-users and facility providers and then select procedures for testing that could provide significant operational benefits;
- Conducting simulation tests using the SAMS platform to enable pilots and controllers to evaluate procedures;
- Providing initial evidence for business cases for implementing A-SMGCS;
- Analysing the data, developing conclusions and recommendations for future work.
- Successful dialogue between ‘end-users’, technology providers and researchers that is necessary if a practicable A-SMGCS is to be achieved.

6.1.2. *Partially Achieved Objectives*

The ATOPS project was partially successful in achieving the following objectives:

- Preparing appropriate Advanced A-SMGCS procedures for all functions (Surveillance, Control, Routeing/ Planning and Guidance).
- Identifying significant areas for detailed technology improvements (e.g., RIA algorithms)
- Assessment of the validity of the A-SMGCS architecture inherent in the ICAO Manual for A-SMGCS
- Disseminating progress and results of project to a wide audience.

6.1.3. *Objectives Not Met*

The ATOPS project had limited success in achieving the following objectives:

- Recording performance data

6.1.4. *General*

- The ATOPS project was very reliant on the SAMS project. The delayed progress in development of the SAMS platform had a big impact on the ATOPS project both in terms of knowing what it was capable of (knowledge needed for writing procedures) and having all the functions and sub-systems working as desired (disruption and diminished success of simulation). In future it would be better to plan and manage dependent projects such as SAMS and ATOPS with less overlap and therefore with more certainty about what the first project is going to deliver.

- It is of paramount importance to projects such as this to involve ‘end-users’ from the start since they will be the ones using the resulting tools.
- ‘End-users’ must be involved in the drafting of new operational procedures for A-SMGCS because they are already familiar, through regular use, with current operational procedures; they may have experience of suggesting changes to current operational procedures; they may have experience of the process of drafting new procedures and they can relate suggested ‘new operational’ procedures to their current tasks and assess their viability for future use.

6.1.5. Technical Conclusions

A key conclusion that can be made from the ATOPS project is that the implementation of a labelled A-SMGCS display in a control tower will be beneficial in terms of providing the ATCOs with a better understanding of the traffic situation on the airport surface. This would apply particularly in medium and low visibility conditions. If the labelled A-SMGCS display will improve the Controllers’ situational awareness (as the ATOPS simulations indicate), it is likely to increase the efficiency and number of movements handled on the airport surface in medium and low visibility conditions. Another potential benefit of the labelled A-SMGCS display is that it can provide the ATCOs with a clear ‘picture’ of the cul-de-sacs, apron areas or blind spots on the airport.

6.2. RECOMMENDATIONS FOR FURTHER WORK

6.2.1. General

- ‘End-users’ should be involved in the design of A-SMGCS sub-systems and operational procedures from an early stage.

6.2.2. Identification and Identification Verification

For these tasks and the related interactions with the system, specific ergonomic investigations are needed for future systems. Examples for such subjects of investigations are:

- In which format shall the identification states be presented to the controller (colour, label, electronic flight strip etc.), which identification states are of relevance for the controller
- How can the recording of the identification verification process be simplified by the system (clicking on a field in the label or in the electronic flight progress record etc.)
- What kind of system integrity and accuracy is minimally required for the ATCO to be able to use an A-SMGCS for identification and identification verification purposes (positional accuracy, label swap, label drop, etc.)
- Further work is required on simulation of multi-sensors. In particular the ability to introduce realistic delays for various sensor performances should be addressed. Eventually the reliability of sensors should also be simulated to present realistic situations to the users of the simulator.

6.2.3. Conflict Detection And Alert

The airports consulted and the Controllers involved in the simulations were convinced that Conflict Detection/ Alert systems were required. Areas that need to be addressed for such systems include:

- Designing alert systems for particular areas of airports (e.g. so the ATCO would only see alerts relevant to the area under his/her control)

- Presentation of alerts on displays and associated warnings (including which displays and format)

- Procedures for alerting controllers irrespective of whether they are working head up or head down.

6.2.4. *Conditional Movement Plans and Conditional Clearances*

Possible items for future investigations with respect to the use of conditional movement plans and conditional clearances identified during the ATOPS project are:

- How to provide the controller with system generated movement plans to support him/her in the movement and route planning activity (e.g. questions of optimal mnemonic presentation of plans etc.)

- How to give the controller the opportunity to modify and accept plans in order to select the optimal plan.

- How to present conditional movement plans and conditional instructions in most concise form to the controller (e.g. 'cross after ...', 'give way to ...')

- How to present issued clearances and instructions (including conditional ones) for the moving mobiles (label information, presentation of electronic flight and movement progress records etc.) in a way that the controller can easily memorise the issued clearance

- How to ease the recording of the controller decisions and the issued clearances by the system (clicking on way-points and selecting time slots on the movement screen or in the electronic flight progress record etc.)

6.2.5. *Advanced A-SMGCS Procedures*

The ‘advanced’ procedures still require a lot of investigation in the near future:

- A number of advanced procedures were listed that could have been simulated in ATOPS but were not because of the lack of particularly capability of the SAMS platform. These procedures can be further developed in future work.

- The interaction of the ATCO with these advanced A-SMGCS tools is an area that requires research. Tools such as automatic routeing and planning have an important impact on the way the ATCOs perform their task.

- Another area of research would be the involvement of other users besides the ATCOs. Pilots for instance will also have to be involved if one starts to develop automatic routeing tools.

- Ways of presenting information related to automatic routeing to pilots need to be investigated further.

- If on-board tools are going to be used, one will need to keep in mind that most likely not all aircraft will be equipped with this kind of instrumentation. How will an A-SMGCS cope with a mix of equipped and non-equipped aircraft?

6.2.6. *A-SMGCS Sub-System Performance*

The performance of A-SMGCS sub-systems is something that needs to be investigated. Once it is known what acceptable performance figures for A-SMGCS sub-systems are, A-SMGCS manuals can be completed with performance requirements of which many are still unknown. A simulation platform would be ideal for this kind of investigation.

6.2.7. *Simulation Platform*

- For any further testing of new procedures for A-SMGCS, the simulation platform should be well understood in terms of its capabilities and the ‘end-users’ and authors of procedures should be well familiarised with it.

- Further testing of A-SMGCS and associated new procedures are carried out in simulation as it allows new concepts to be well tested under all conditions before expensive airport installations.

- Future A-SMGCS platform development, whether based on SAMS or otherwise, should take account of the technical and management findings.

7. LIST OF PUBLICATIONS, CONFERENCES, PRESENTATIONS FROM THE PROJECT

There were no publications or conferences that resulted from the ATOPS Project.

NLR produced a short video highlighting the SAMS and ATOPS Projects which was presented to the EC.

The opportunities taken to present the ATOPS Project (progress or results) were as follows:

- OPTAS-B Thematic Network meeting, Rome, January 1999.
- ICAO AOPG PT/2 Meeting, Barcelona, September 2000.
- Eurocontrol AOT/6 Meeting, Brussels, December 2000. (Planned at time of issuing this report).