Nationaal Lucht- en Ruimtevaartlaboratorium

National Aerospace Laboratory NLR

Executive summary

Integrated Airport Performance Analysis through the use of the OPAL Platform

Problem area
The increasing airport demand and its associated consequences, in conjunction with technical, physical, and political constraints in providing sufficient capacity, have stimulated vigorous policy discussions towards assessing and monitoring the airport performance with respect to various airport performance metrics such as capacity and delays, level of service, environmental impacts, safety and security, as well as commercial performance. At present, airport stakeholders lack modelling capabilities of the integrated set of airport processes, decisions, and their interdependencies in order to cope with the mismatch between demand and supply and effectively deal with the trade-offs between the various measures of airport effectiveness. Therefore, there is an urgent need for a decision support system that will allow decision makers and analysts to evaluate the efficiency of the entire airport complex simultaneously by considering trade-offs between measures of airport effectiveness.

Description of work
The project OPAL was in response to the aforementioned need. Within this project a facility has been developed that facilitates the integration of existing tools in order to model and to evaluate simultaneously airport airside and landside and their interactions in one application run. In addition, this facility provides the ability to integrate capacity and delay-oriented tools with others analysing environmental, safety, and cost-benefit impacts of airport operations.

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Results and conclusions

The objective of this paper is fourfold: to introduce the concept of total airport performance analysis, to describe the architecture of an integrated computational platform capable of addressing the requirements of total airport performance analysis, to present an overview of the platform capabilities, and to provide an operational proof-of-concept on the basis of two case studies for the platform demonstration in Amsterdam Airport Schiphol and Madrid-Barajas Airport.

Applicability

The OPAL facility can be efficiently used to model and support real-world airport planning problems and questions, and it produces results of reasonable accuracy that reflect reality and real-world conditions in the specific airport demonstration sites. On the other hand, it has been evident that there is ample opportunity for enhancements and further R&D efforts towards developing: a more harmonised computational and data exchange environment for all tool combinations including possibly new tools, a user-friendly computational environment that will not require training or prior familiarity of the user/decision maker with the selected tools or tool combinations, and a fully-automated computational environment for performing trade-off analyses and "what-if" airport studies by simultaneously integrating tools in a multi-tier, study or problem-oriented architecture that will interact with the user in the decision maker's (rather than tool expert's) language.

In response to this research challenge, a research initiative is currently in progress within the framework of the FP6 SPADE project (funded by EC DG-TREN) with the purpose of developing a seamless integration of tools capable of addressing a number of airport strategic planning decisions and their trade-offs through a pre-structured, pre-specified navigation (i.e., built-in use cases) [`http://spade.nlr.nl`].

NLR-TP-2007-039

Integrated Airport Performance Analysis through the use of the OPAL Platform

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Summary

The increasing airport demand and its associated consequences, in conjunction with technical, physical, and political constraints in providing sufficient capacity, have stimulated vigorous policy discussions towards assessing and monitoring the airport performance with respect to various measures of airport effectiveness. At present, airport stakeholders lack modelling capabilities of the integrated set of airport processes, decisions, and their interdependencies that are necessary to cope with the mismatch between demand and supply, and to effectively deal with the trade-offs between the various measures of airport effectiveness. Therefore, there is an urgent need for a decision support system that will allow decision makers and analysts to evaluate the efficiency of the entire airport complex simultaneously by considering trade-offs between measures of airport effectiveness. The objective of this paper is fourfold: i) to introduce the concept of total airport performance analysis, ii) to describe the architecture of an integrated computational platform capable of addressing the requirements of total airport performance analysis, iii) to present an overview of the platform capabilities, and iv) to provide an operational proof-of-concept on the basis of two case studies for the platform demonstration in Amsterdam Airport Schiphol and Madrid-Barajas Airport.

Contents

Abbreviations

AAS	Amsterdam Airport Schiphol
AENA	Aeropuertos Espanoles y Navegacion Aerea
A-SMGCS	Advanced Surface Movement Guidance and Control System
ATM	Air Traffic Management
BAX	Baggage
CBM	Cost Benefit Model
DG-TREN	Directorate General for Energy and Transport
EC	European Commission
ESUG	European SIMMOD User Group
FAA	Federal Aviation Administration
GUI	Graphical User Interface
HMI	Human Machine Interface
IATA	International Air Transport Association
IBDOM	Iberia domestic / national and Schengen flights
IBH	Iberia international flights
INM	Integrated Noise Modeller
LEONARDO	Leonardo Da Vinci Programme – Method for the Evaluation and Selection of Proposals
MACAD	MANTEA Airfield Capacity and Delays
MACS	Macro Cargo Simulation Tool
MANTEA	Management of Surface Traffic in European Airports
NAT	New Area Terminal (i.e., new terminal building and apron area for Madrid Airport)
NLR	National Aerospace Laboratory NLR
OPAL	Optimisation Platform for Airports including Landside
OPS	Operations
OPTAS	Optimization of Airport System
PAX	Passengers
PUENTE	Iberia Madrid-Barcelona shuttle flights
SARS	Severe Acute Respiratory Syndrome
SIMMOD	Airport and Airspace Delay Simulation Model
SLAM	Simple Landside Aggregate Model
TAAM	Total Airport and Airspace Modeller
TAPE	Total Airport Performance and Evaluation

THENA	Thematic Network on Airport Activities
TOPAZ-TAXIR	Traffic Organisation and Perturbation Analyser
TRANSLOG	TRANSportation Systems and LOGistics Laboratory
TRIPAC	Third Party Risk Analysis Package for Aircraft Accidents around Airports

1 Introduction

The increasing demand and its associated implications on airport operations, in conjunction with technical, physical, and political constraints in providing sufficient capacity, have stimulated vigorous policy discussions directed towards assessing and closely monitoring the airport performance. The airport decision making and implementation process necessitates the deployment of advanced capabilities in the form of analytical models and simulation tools (i.e., fast-time and/or real-time) capable of supporting airport planning decisions for a “total” airport (i.e., airport airside and terminal simultaneously) and the capture of the trade-off aspects between the various measures of airport effectiveness (e.g., capacity, delays, level of service, safety / security standards, environmental performance, noise, cost-effectiveness). The airport decision making process currently suffers from a large fragmentation between airside and terminal operations and the isolated manner in which the airport performance measures are assessed and handled.

The objective of this paper is fourfold: i) to introduce the concept of “total” airport (i.e., both airside and terminal) performance analysis, ii) to describe a system architecture and an operational concept proposed for the integration of analytical models and simulation tools in simultaneously analysing airside and terminal operations with respect to different performance measures, iii) to present an overview of the capabilities and functionalities of the herewith presented computational platform for total airport performance analysis, and iv) to provide an operational proof-of-concept on the basis of two case studies for the platform demonstration in Amsterdam Airport Schiphol and Madrid-Barajas Airport.

The remainder of this paper is structured into five main sections. Section 2 elaborates on the need for such a decision support tool for total airport performance analysis through the presentation of a brief literature review. Section 3 introduces the operational concept of an integrated platform for total airport performance analysis, presents its high-level architecture, as well as the basic capabilities and alternative scopes of platform use by the targeted user groups. Section 4 addresses the platform design and implementation. Section 5 presents the platform demonstration approach along with two relevant case studies for the platform demonstration in two airport sites: Amsterdam Airport Schiphol and Madrid-Barajas Airport. Finally, the paper is complemented by a concluding chapter and the lessons learnt from this experience, as well as some future research recommendations (Section 6).

2 Literature Review

The existing body of knowledge on airport modelling research allows capitalising on existing results as regards: i) well defined requirements and data for airport planning, design, and modelling [Horonjeff, 1969; Ashford, 1988; Federal Aviation Administration, 1988; Odoni and De Neufville, 1992; Tosic, 1992], ii) analytical models and simulation tools (e.g., detailed vs. aggregate, stochastic vs. deterministic, dynamic vs. static, macroscopic vs. microscopic) for the performance assessment and monitoring of airport operations with respect to capacity and delays, noise, conflict generation, detection and resolution models, human / automation models, as well as cost/benefit analysis [Odoni, 1991a; Odoni et al., 1997; Transportation Research Board, 2000; OPAL, 2003a], and iii) advanced methods and data for optimising the airport system and network [Odoni, 1991b; Andreatta et al., 1999; Zografos and Madas, 2004a].

Among the aforementioned research directions, substantial research efforts in the area of Air Traffic Management (ATM) have been recently placed and will undoubtedly intensify in coming years on the following: i) assessment of the performance of the various airport operations, ii) airport network modelling aiming to understand the way that local airport effects (e.g., delays) are passed on to the air, and iii) human performance modelling (i.e., human-in-the-loop, macroscopic / microscopic mathematical models) aiming to investigate the interaction between humans (e.g., pilot, controller) and automation (e.g., aircraft, air traffic control station, air traffic system) . This paper deals and will further elaborate below on the first category of ATM-related modelling research, those concerned with the performance assessment of airport operations at the local (i.e., not system-wide) level.

The state-of-the-art and state-of-practice review [Transportation Research Board, 2000; OPAL, 2003a; Zografos, 2003; THENA, 2003; Zografos and Madas, 2004b] clearly suggest that currently available analytical models and simulation tools provide decision support to all levels of decision making (i.e., strategic, tactical, operational) and for most types of airport management decisions (i.e., planning, design, operations) and types of problems / studies (i.e., capacity, delay, noise, security, etc.). A critical observation that can be drawn from the literature review is that, currently, there is a large fragmentation and sharp division between available airside and terminal models, as well as limited integration experience [Odoni et al., 1997] between models / tools able to provide capacity and delay estimates and models / tools able to provide environmental (e.g., noise), and safety / security assessment [OPAL, 2003a; Zografos and Madas, 2004b]. Existing models and tools capture only parts rather than the entire airport complex as a total entity and shed light into fragmented parts of the airport operations. This means that, currently, there is no academic reference or formal research paper documenting efforts towards the development of a “total” airport analysis system able to perform analysis of the entire airport complex including airport terminal and airside with the combined use of analytical models and simulation tools of different levels of decision making (i.e., strategic, tactical, operational) and levels of detail (i.e., macroscopic, mesoscopic, microscopic).

Recent and on-going European airport modelling research endeavours (e.g., TAPE, OPTAS, LEONARDO research projects funded by the European Commission) attempted the practical communication and interaction of pre-selected tool configurations in order to model and evaluate simultaneously airport airside and terminal and assess their interdependencies. In this direction, similar efforts have been documented in the literature [Zografos and Stamatopoulos, 1998; Zografos et al., 1998; Andreatta et al., 1999] that suggested and introduced an integrated use of airside and terminal models for airport strategic planning applications. Nevertheless, the common denominator and weakness of these efforts is reflected on the lack of a harmonised, integrated, and fully-automated computing environment needed to execute the various models and simultaneously report (with post-processing capabilities) their integrated results.

Relevant integrated airport modelling efforts have been quite recently brought into the forefront by Preston Aviation Solutions (i.e., Preston Airport Solutions Suite) and IATA in collaboration with LeTech Inc. (i.e., Total AirportSim) in the United States. The Preston Airport Solutions Suite basically combines TAAM with various simulation tools (e.g., PaxSim) and modules (e.g., Gate Module, Baggage Module, Check-in Module) offering an integrated, total airport solution. On the other hand, Total AirportSim is a commercial software simulating the total airport environment from the airspace to (and through) the passenger terminal covering a wide variety of airport elements (e.g., airspace, runway, apron, gate, passenger terminal) and flows involved (i.e., aircraft, passengers). Total AirportSim has been gradually developed over years starting from the Airspace/Runway Module in 1996 and thereafter integrating the Gate Module (2000) and the Terminal Passenger Flow Module (2001). In conclusion, Total AirportSim and the Preston Airport Solutions Suite basically represent the sole modelling efforts claiming some interaction modelling capabilities between airside and terminal (i.e., “total” airport). However, these are both “off-the-shelf” software products, these are almost purely simulation platforms, and both integrate a limited and pre-specified number of simulation tools at a detailed level.

Consequently, there is an urgent need for a decision support system that will: i) allow decision makers and analysts to evaluate the efficiency of the entire airport complex, ii) integrate various analytical models and simulation tools, and iii) provide both aggregate and detailed modelling capabilities. In response to the aforementioned need, an integrated computational platform was designed, developed, and validated within the framework of the “Optimisation Platform for Airports including Landside (OPAL)” research project funded by the European Commission (Directorate General Energy and Transport, 2000-2002).

Through its airport performance analysis and evaluation capabilities, the OPAL platform supports the decision making of airport authorities and operators, airlines, air traffic service providers, as well as policy making bodies (e.g., EUROCONTROL, European Commission, Civil Aviation Authorities) involved in airport operations and air transport. The platform supports the search for solutions, improvements, and “what-if” studies to frequently arising airport planning problems related to the impacts of new operational procedures (e.g., reduced separation minima, stricter security rules and procedures, collaborative decision making), investments in infrastructure expansion, advancement in technological procedures (e.g., adoption of A-SMGCS), changes in the traffic profile and volumes and, in general, the impact assessment of alternative scenarios on a broad spectrum of airport performance metrics (i.e., capacity and delays, level of service, safety, environment / noise, costs and benefits). A proof-of-concept of the OPAL platform has already been provided through the successful platform demonstration at six major European airports: Amsterdam Airport Schiphol, Athens, Frankfurt, Madrid-Barajas, Palma de Mallorca, and Toulouse-Blagnac [OPAL, 2003d]. Two case studies for Madrid-Barajas Airport and Amsterdam Airport Schiphol are further elaborated in Sections 5.2 and 5.3. Finally, relevant work demonstrating the use of the OPAL platform in Athens International Airport [Zografos & Madas, 2004b] is cited for further reading.

3 Integrated Computational Platform Concept and Approach

The major objective of the OPAL research project was to provide a generic concept for the development of an airport decision support system for: i) total, and ii) integrated (i.e., simultaneously addressing multiple trade-offs between measures of airport effectiveness) airport performance analysis [Van Eenige, 2002]. The OPAL system enables the combined and integrated use of selected (mostly available, but also a few newly developed) airport analysis tools (i.e., analytical, simulation). The currently selected tools have been integrated in a distributed computational environment consisting of (Figure 1): i) a Central Database that enables the use of common data elements and the communication between tools integrated into the OPAL platform based on an intermediate communication infrastructure, ii) an overall Human Machine Interface (HMI) that enables the access to and visualisation of the input requirements and output and results by navigating through the graphical user interfaces (GUI’s) of the individual tools, iii) a Model Base that consists of selected models / tools and model / tool configurations capable of performing trade-off analyses between various measures of airport effectiveness, iv) a Diagnostics Tool that enables the analysis of propagated impacts and interdependencies and identifies the overall bottlenecks in a total airport system, v) an Optimisation Tool that enables the user to optimise the airport configuration given a particular scenario, the models used and a specific optimisation criterion, vi) Data Converters that enable the integrated tools to read from and write to the central database of the platform, and vii) a Scenario Manager that executes, monitors, and controls the tools within the distributed platform, integrating them into a harmonised virtual working environment for the platform users.

Practically, the OPAL project introduced and implemented an operational concept for the integration of various models and tools for total airport performance analysis purposes [Van Eenige, 2002; OPAL, 2003b; Zografos & Madas, 2004b]. These tools were conceptually incorporated into the platform and designed to operate under the following conditions: i) interact and operate in a homogeneous computer environment on the grounds that the individual tools exhibited quite different hardware requirements and operating systems, ii) "communicate", interact, and share data on the basis of a global graphical user interface (GUI) operating above the individual (local) GUI's of the corresponding tools, iii) operate in a distributed European computer network through individual computers geographically located at different sites in order to accommodate the licensing and legal issues / problems associated with the use of proprietary software, and iv) support secured communications through the application of the appropriate communication protocols.

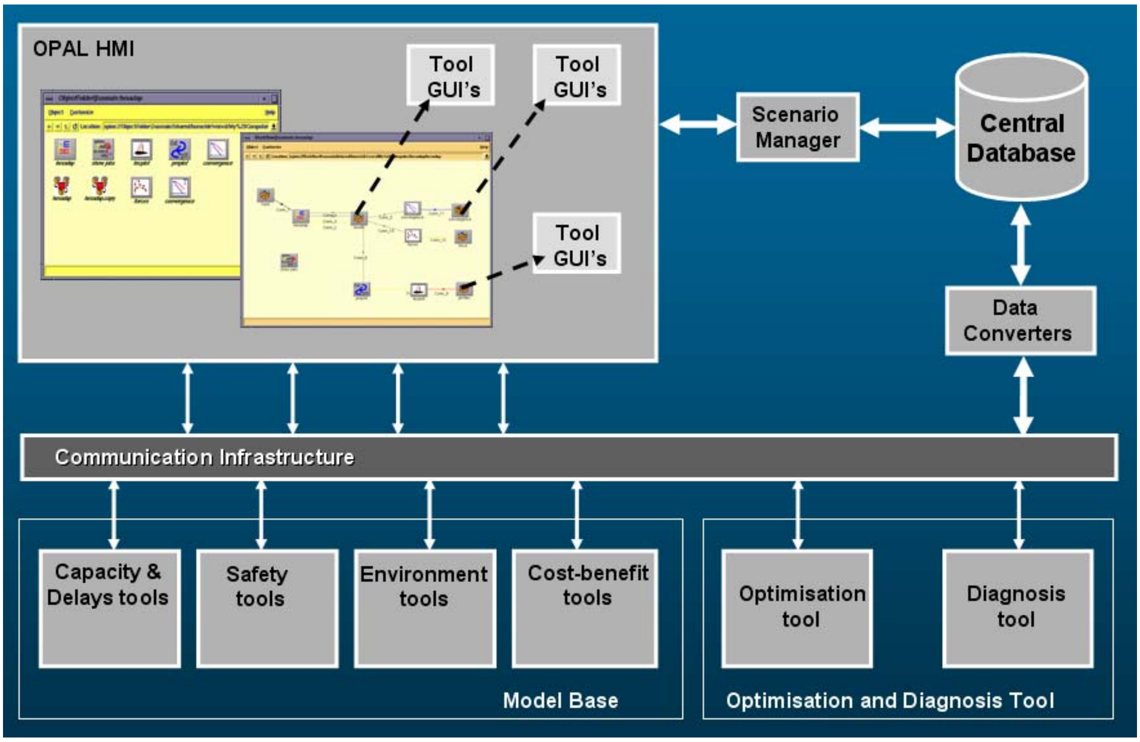

Figure 1: OPAL Platform Architecture [Van Eenige, 2002]

4 Platform Design and Implementation

The OPAL model base consists of four basic and interacting modules, each of them addressing different areas of study and capturing specific elements of the airport operations. These modules are summarised in the following: i) Capacity and Delays, ii) Environment, iii) Safety, and iv) Cost / Benefit. The Capacity and Delays module includes analytical and simulation models, addressing both airside and terminal elements of the airport, and provides estimates for the capacity and delays of a total airport. MACAD, SLAM, and MACS constitute the analytical part of the described module, while SIMMOD, TAAM, POWERSIM, WITNESS-MODA, and PAX / BAX represent the simulation part. As far as the analytical part is concerned, MACAD models the airside capacity and delays for aircraft, MACS deals with freight capacity, while SLAM models the terminal capacity, delays, and level of service provided to passengers. On the simulation part, SIMMOD and TAAM focus on the airside, while POWERSIM, WITNESS-MODA and PAX / BAX analyse the terminal elements of the airport. The Environment module incorporates an analytical model (INM) assessing the predicted noise exposure and levels around airports. The Safety module includes analytical and simulation models, addressing only airside elements of the airport, and provides safety assessment and estimates of the external risk due to aircraft accidents. TRIPAC represents the analytical part with TOPAZ constituting the simulation part. The Cost / Benefit module includes only analytical models addressing both airside and terminal elements and it is consisted by the newly developed CBM, which provides analysis and assessment of the operational costs and benefits for airports and airlines.

All these modules interact and communicate with each other. As it can be inferred from the graphical description of the architecture shown in Figure 2, each particular model / tool combination is implemented by means of local databases and data converters that communicate interchangeably the data / input requirements to each tool. Similarly, results and data pertaining to a particular tool combination are made available to other modules and tools through the central database, which represents the common reference and interaction mechanism between all modules and tool combinations. The Capacity and Delays module represents the core module in the model base architecture, which is further decomposed into Passenger and Freight sub-modules. Finally, all three Capacity and Delays, Safety, and Environmental analysis modules "feed" the Cost / Benefit module with input and data required in order to analyse and assess the net operational costs and benefits for airport and airlines.

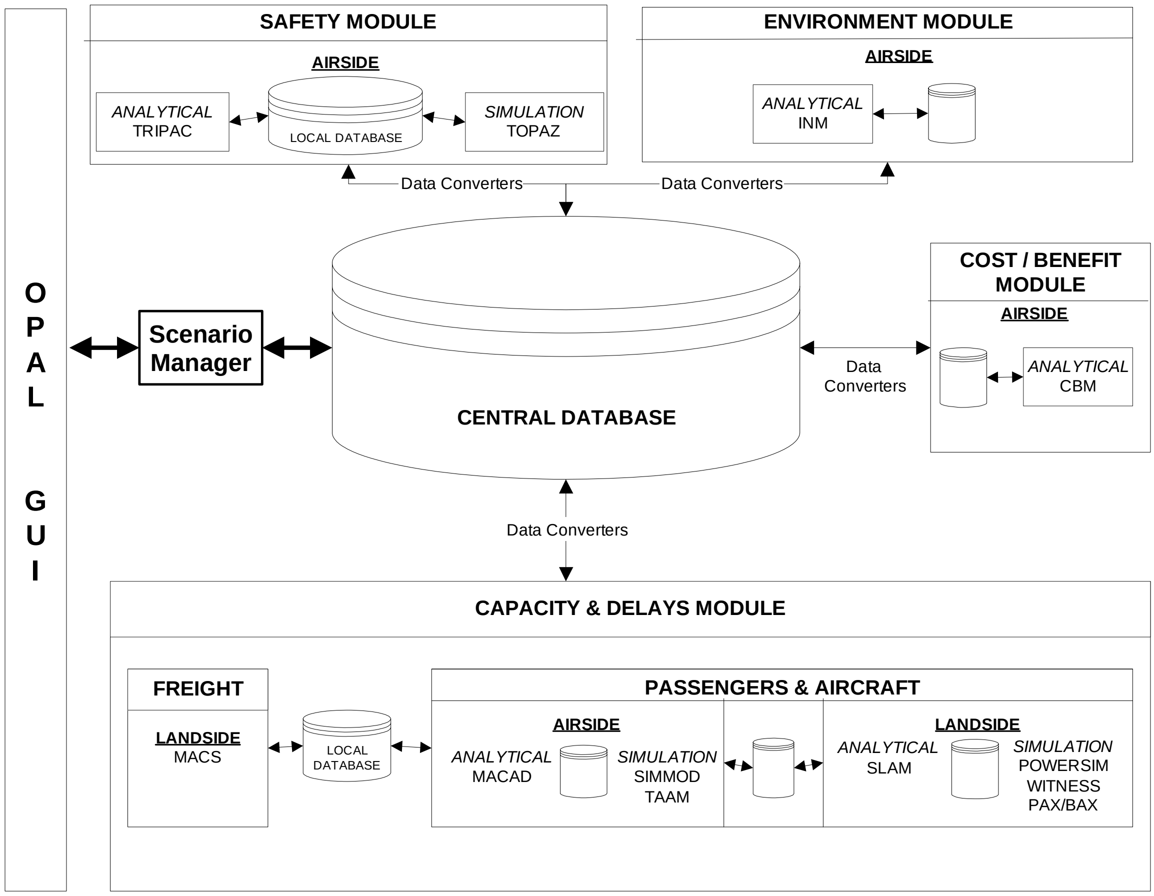

Figure 2: OPAL Model Base Architecture [OPAL, 2003b; OPAL, 2003c]

5 Platform Demonstration/Case Studies

5.1 Platform Demonstration Approach

The OPAL platform was demonstrated at six major European airports, namely Amsterdam Airport Schiphol, Athens Airport, Palma de Mallorca Airport, Madrid Barajas Airport, Frankfurt Airport, and Toulouse-Blagnac Airport. Table 1 summarises the types of airport studies that have been performed through the OPAL platform at each demonstration airport site [OPAL, 2003d; Zografos and Madas, 2004b].

For the purposes of this paper, two different case studies are further elaborated in the following sections. These case studies demonstrate the operational proof-of-concept of the OPAL platform by performing specific airport studies with the use of the platform in two airport sites: i) Amsterdam Airport Schiphol, and ii) Madrid-Barajas Airport.

Table 1: Overview of Airport Studies & Tool Combinations [OPAL, 2003d]

Airport Site	Types of Airport Studies	Tool Combination
Amsterdam	Integrated Capacity & Delay (including terminal), Noise, Safety, and Cost-Benefit study in view of the use of larger aircraft	TAAM, PAX/BAX, INM, TOPAZ, TRIPAC, CBM
	Capacity & Delay Study (including terminal)	MACAD, SLAM
Athens	Capacity & Delay Study (including terminal) in light of increased airport traffic (i.e., Olympic Games, establishment of hubbing operations) [Zografos and Madas, 2004b]	MACAD, SLAM
Palma de Mallorca	Implementation of interconnection mechanism between airside and terminal / Optimal Fleet Composition (i.e., Capacity & Delay Study)	SIMMOD, WITNESS
	Capacity & Delay Study (including terminal)	MACAD, SLAM
Frankfurt	Capacity & Delay Study examining the use of larger aircraft	TAAM, POWERSIM
	Capacity & Delay Study (including terminal)	MACAD, SLAM
Madrid	Capacity & Delay Study examining the optimisation of the taxiway use and the stand use / allocation (i.e., apron management)	TAAM, WITNESS
	Environmental – Operational Study	TAAM, INM
	Capacity & Delays (including terminal)	MACAD, SLAM
Toulouse	Capacity & Delay Study examining the organisation concept for airport spaces in freight areas	MACS, MACAD
	Capacity & Delay Study (including terminal)	MACAD, SLAM

5.2 Case Study 1: Platform Demonstration for Amsterdam Schiphol Airport

Amsterdam Airport Schiphol (AAS) is the main airport in the Netherlands and is located at about 15 kilometres to the south-west of the centre of Amsterdam. In 2003, the total number of air transport movements exceeded 408,000 corresponding to nearly 40 million passengers [Schiphol Group, 2004].

At the airside, AAS is one of Europe's most complex airports. It has five main runways (and a secondary runway for general aviation). Figure 3 illustrates the runway layout. The runway configuration enables AAS to cope with variations in wind direction without a significant impact on capacity. During outbound peaks, two main runways for departure and one main runway for arrival operations are normally used. During inbound peaks, two main runways for arrival and one main runway for departure operations are used.

At the landside, AAS has a single terminal building for passenger arrivals and departures of both domestic and international flights. This terminal building can be accessed by road (e.g., car, taxi, or bus) and by rail (through an underground railway station that is connected to the Dutch railway network).

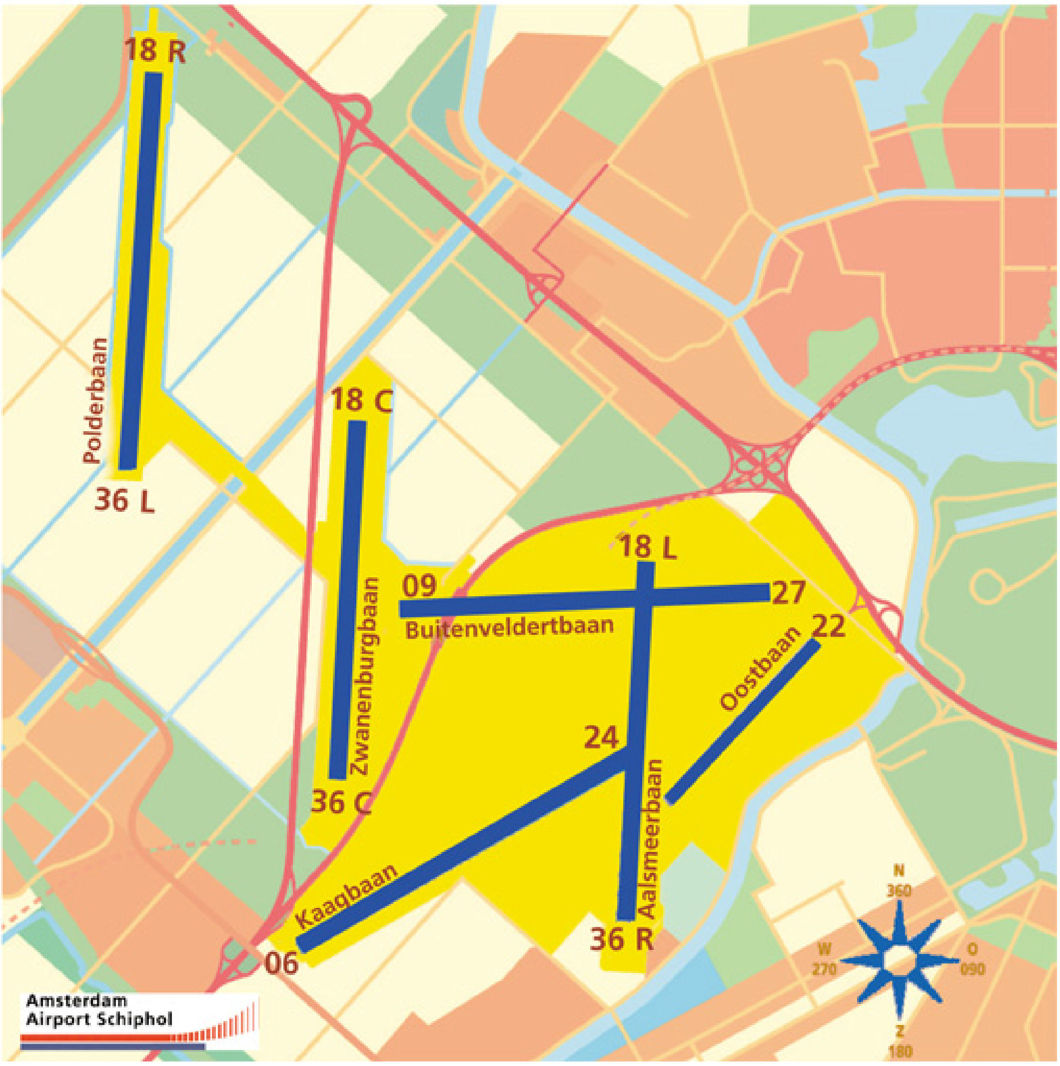

Figure 3: AAS runway layout - five main runways and one secondary runway (Oostbaan) [`www.schiphol.nl`]

5.2.1 Case Study

Within the frame of the OPAL project, a test study for AAS has been conducted to provide an example of the use of the OPAL platform, especially for performing trade-off analyses. This study concerned an assessment of larger aircraft, in particular of the A380.

To demonstrate the ability to perform total airport and trade-off analyses with the OPAL platform, different performance indicators were considered: capacity (both airside and terminal), safety (runway incursion and external safety), noise, and cost-benefit. The lack of detailed A380 performance data, however, prevented realistic (i.e., real-world) analyses, which was particularly the case for the assessment of noise and safety, but did not limit the demonstration of the platform's potential and added value.

For this test study, two scenarios were defined. The first (or baseline) scenario was based on an extrapolation of a calibrated 2001 scenario to 2003:

- 1,400 aircraft movements per day;
- Two arrival and two departure runways in use (independently).

The second (or alternative) scenario had the same characteristics as the first, except for a replacement of 50 % of Boeing 747 aircraft by A380 aircraft. For A380 aircraft, the wake-vortex separation criteria were (assumed to be) increased by 10 %.

5.2.2 Tools used

To assess the scenarios, the following existing tools (integrated into the OPAL platform) were used in combination:

- Capacity
  - Airside: Total Airport and Airspace Modeller (TAAM)
    TAAM is a fast-time simulator for the prediction of capacity and delay figures of flight operations. The Preston Group (as part of Boeing Company) maintains TAAM.
  - Terminal: Pax/Bax
    Pax is a simulation model for the evaluation of passenger handling facilities in the airport terminal. Bax is a simulation model for the evaluation of baggage flows through the baggage handling system. Incontrol Enterprise Dynamics maintains Pax and Bax.
- Noise
  - Integrated Noise Model (INM)
    INM is an analytical model for the determination of noise contours around airports, using a norm based on the European standardised 'Lden'-level (day-evening-night). FAA maintains INM.
- Safety
  - Runway incursion: Traffic Organisation and Perturbation Analyser-TAXIR (TOPAZ-TAXIR)
    TOPAZ-TAXIR is a tool that supports accident risk assessment for active runway crossings. NLR maintains TOPAZ-TAXIR.
  - External: Third Party Risk Analysis Package for Accidents Around Airports (TRIPAC)
    TRIPAC is an analytical model for third party risk analyses. TRIPAC is maintained by NLR.
- Cost-Benefit Model (CBM)
  - CBM is an analytical model for assessing cost and benefits of airport operations. ECORYS maintains CBM.

5.2.3 Tool integration

The tools mentioned in the previous section have been integrated into the OPAL platform and used in combination in order to assess the effect of larger aircraft at AAS for the airport airside and terminal, and with respect to a variety of performance indicators to enable trade-off analyses. The tool workflow starts with TAAM. TAAM does not require input from the other tools and its output is used as input to each of the other tools. Except for the cost-benefit tool, i.e., CBM, the other tools only need TAAM output and do not interact with each other. Consequently, these tools can run in parallel. CBM, on the other hand, does also need results from these latter tools. Therefore, it can only run after all the other tools have performed their calculations. The complete execution of the tool workflow (including data conversions and transfers) is controlled by the middleware SPINEware, without any (major) user interaction.

5.2.4 Scenario results

As mentioned in Section 5.2.1, the lack of detailed A380 aircraft performance data prevented a complete and realistic assessment of A380 aircraft at AAS. In particular, this limited the evaluations and trade-off analyses involving noise and safety. Therefore, the assessment focused on the use and capabilities of the OPAL platform, herewith clearly demonstrating its main purpose: the ability to perform total airport and trade-off analyses. Nevertheless, some indications concerning total airport (i.e., airport airside and terminal) delays could be made.

1. At the airside, the introduction of A380 aircraft has a direct impact on the maximum arrival and departure rates due to (the assumption of) increased wake vortex separation criteria. This results in sequencing delay for arrivals and line-up delay for departures. Moreover, it will result in stand-off delay, because fewer gates will be suitable. If increased wingspan is an issue regarding wingtip-clearances on the apron and in the manoeuvring area, more ground controller co-ordination activities might be required or the aircraft’s movement options (less available gates, longer taxi-routing) might be limited. In the simulations the introduction of A380 aircraft lead to an increase of the total cumulative delay by 2 % (see Figure 4).
2. For terminal processes, the scenarios provided general insight in the possible effects of the introduction of A380 aircraft, in spite of incomplete A380 performance data. For instance, passengers and baggage are expected to enter (and depart) in larger-sized batches, which results under present circumstances in congestion problems at, e.g., passport control and the baggage-handling system. These problems will then result in longer queues and waiting times for passengers and larger groups of bags waiting for transport on combis in the baggage handling system.
3. Due to an overall increase in delays (at both airside and terminal), the costs are slightly higher in the alternative scenario than in the baseline scenario.

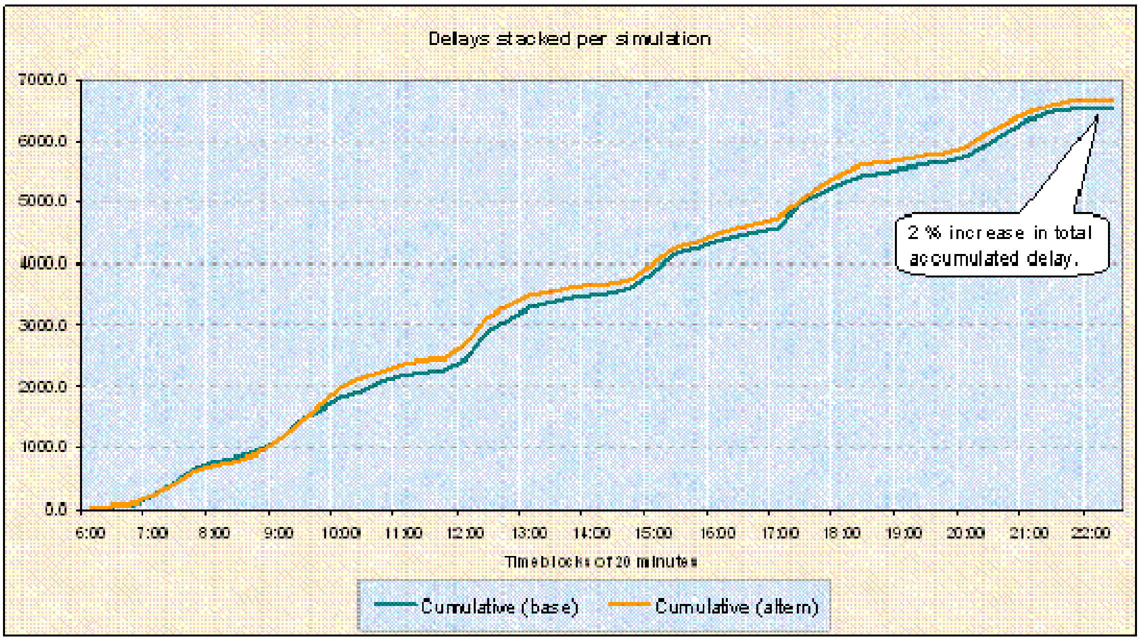

Figure 4: Delays stacked for baseline and alternative scenario

Although the possibilities for realistic total airport and trade-off analyses were limited for the small AAS test study, it clearly demonstrated the OPAL platform's capability in enabling such analyses. More specifically, the platform provided information on total airport operations for a variety of performance indicators (e.g., capacity, delay, noise, safety, and cost benefit) by executing the different tools (as listed in Section 5.2.1) in an integrated way. All this information would enable airport stakeholders to study trade-offs. For illustration purposes, Figures 5a and 5b display the noise contours provided by INM and the safety/external risk contours provided by TRIPAC, respectively, as presented through the OPAL platform.

Based on the results, the user can modify relevant airport parameters in his/her quest to find an optimum configuration of these parameters. In the present context, for instance, the user could seek for an optimum configuration by applying new methods for safely reducing wake-vortex separations, segregating (super-) heavy aircraft and other categories, dynamically using diverging departure routes, and applying departure and arrival management tools to minimise total required separation time (by order optimisation).

Furthermore, the OPAL platform automated the execution of the complete tool workflow (including data conversions and transfers), herewith avoiding actions that had otherwise to be performed manually. This automation obviously improves productivity and significantly reduces the risk of making errors.

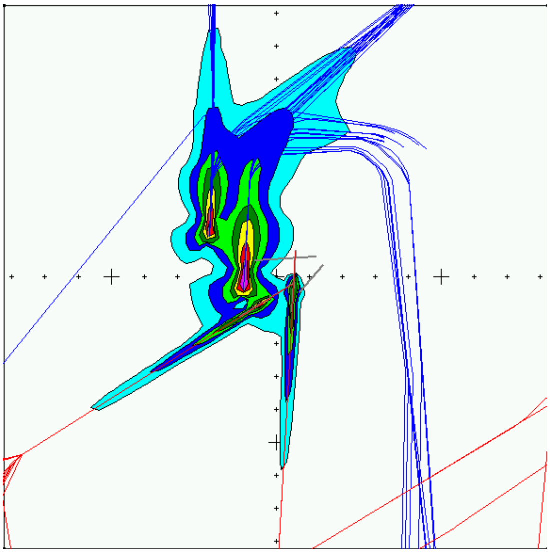

Figure 5a: Noise contours (from INM): noise exposure around AAS for a test scenario

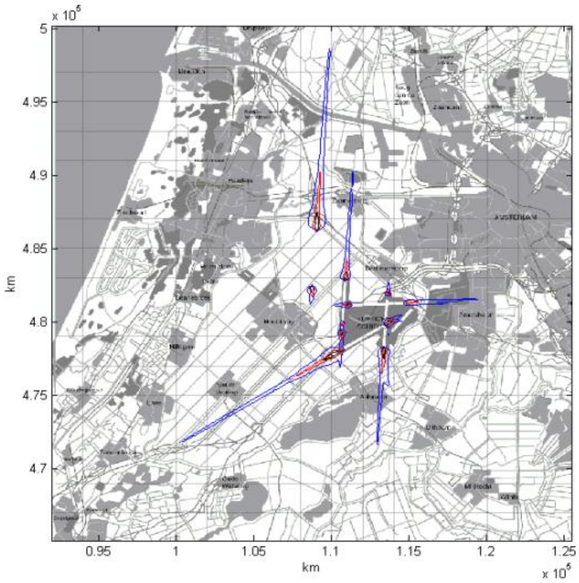

Figure 5b: Safety contours (from TRIPAC): Accident probabilities around AAS for a test scenario

5.2.5 Conclusion

It is apparent that the OPAL platform can support the integrated impact analysis by capturing trade-off's between various measures of airport effectiveness (i.e., capacity, safety, noise, costs and benefits). The herewith presented case study clearly demonstrated the ability to perform total airport performance and trade-off analyses through the OPAL platform, reducing the number of errors and improving productivity thanks to the automated, consistent, and standardised use of data and tools.

The quality of the results obtained through the OPAL platform depends first of all on the quality of the input data. Input data consist on the one hand of data collected off-line and on the other hand of data that are provided by another/preceding tool. In the former case, it is experienced that data collection is in general a difficult task. In the latter case, it is noted that when initiating a collaborative study with different issues such as safety, environment, cost impact and efficiency, excellent usable input data for one model might be unusable for another. For instance, minor displacements of route trajectories used for a capacity study will not significantly affect capacity/delay results, but it might seriously affect noise intensity or shapes of contours. Therefore, one must be aware of the model capabilities, limitations and constraints, and the context in which the model has to perform the study.

For the AAS case study, the quality of the results has been assessed with respect to:

- Total airport capacity and delays;

- Level-of-service of airport operations;
- True causes of total airport delays;
- Utilisation of airport infrastructure;
- Noise contours estimation;
- Safety assessment;
- Quantification of cost and benefits stemming from airport operations.

Five expert users of the tools used in the scenario (but who were not involved in the actual development of the OPAL platform), performed the assessment of the quality of the results obtained (herewith considering the lack of realistic A380 performance data) as well as the user friendliness of the computational platform. Their consolidated expert judgement was that the quality of the results was good (on average rated as 4 on a scale with the highest rating of 5) and that the platform significantly facilitates achieving study objectives and improving productivity. Hence, it can be concluded from the demonstration of the case study for AAS that the OPAL platform enables total airport performance and trade-off analyses with good quality of results.

5.3 Case Study 2: Platform Demonstration for Madrid-Barajas Airport

Madrid-Barajas is the biggest Spanish airport. The distance from the downtown to the existing terminal is around 15 km. The total surface of the airport was 1.925 hectares in 1997 and is expected to be 3.000 in 2010. The Madrid Barajas Airport is linked by road with Madrid’s main access and belt highways. Not any other European Capital City has an international airport so close to downtown (i.e., only 15 km.). On the other hand Madrid-Barajas is an airport submitted to a high pressure from the surrounding population, with big towns close to the airport, which impose operational restrictions on the airport.

The airport had two parallel runways in addition to a crossing one and three terminals, each of them designated to serve passengers in terms of their origin and destination flights. The declared capacity was 75 movements per hour with a maximum of 40 arrivals and 40 departures. During the implementation of the OPAL research project, the airport was considering its upgrade to provide four parallel runways, a new terminal area, and a number of technological systems that would make it the most modern airport in Europe. The future optimal management and operation of such a big infrastructure was a major concern during the project execution, in particular the allocation of terminal and stand positions to the various operating companies became a major issue. Additionally, the selection of the runway for taking-off or landing, and therefore, the noise impacts to the environment, would strongly depend on the assignment of the stand positions.

5.3.1 Case Study

Based on this challenge, a practical study was proposed to be run using the OPAL platform. The proposed analysis for Madrid-Barajas was the optimisation of the use of runways, taxiways, as well as the allocation policies and use of stands considering both terminal and airside operations. More specifically, the objective of the OPAL case study was to find the allocation and use of the runways, taxiways, and stands resulting to an optimum operation in terms of:

- the use (maximum throughput without generating delays) of the runways, runway exits, taxiways, and stands.
- the number of conflicts and interaction of the aircraft traffic.
- the minimum arrival and departure delays and minimum taxi time.

while, at the same time, the decision for the airside operations will not be detrimental to other aspects of the airport operation such as:

- Walking distance for passengers.
- Noise impact around the airport.
- The level of service offered by passenger processing facilities (e.g., customs, baggage handling system, security controls and checking points).

5.3.2 Tools used

This analysis involved the use of the OPAL platform (and its associated optimisation tool) to identify the optimum airport configuration, for a certain reference scenario (i.e., future traffic demand), and according to a cost function including several criteria with different weights. The airport configuration items selected for this case were: i) the use of taxiways, and ii) the distribution and use of stands. Furthermore, as noise impacts depend strongly on the assignment of the stand positions, a secondary objective of the study - once the optimum solutions for terminal and airside have been obtained from an operation point of view - was the evaluation for the resulting scenario with respect to the impact on environment.

To address the aforementioned types of analysis, two different tool combinations have been used as part of the OPAL demonstration for the future Madrid airport:

- TAAM + WITNESS + OPAL OPTIMISER
- TAAM + INM

TAAM was used to simulate the airside part of the Madrid-Barajas airport and WITNESS to simulate the terminal of the Madrid-Barajas airport. These tools constituted the core elements for the capacity and delays study. In order to model the complementary environmental aspects, the INM model was used. The OPAL optimization tool (i.e., OPAL Optimiser) is a component of the OPAL platform that has been used in order to enable the user to optimise the airport configuration given a scenario, the models used, and a certain optimisation criterion. It allows the user to investigate a set of possible alternative airport configurations and select the optimal one according to different criteria.

In the case of Madrid Barajas, a set of scenarios resulting from the combination of different airports taxiways and apron layouts were assessed. For each one of these scenarios, several runway and stand allocation policies were analysed. These combinations (airport layout as well as runway and stand allocation policies) had an impact on the performance of the landside elements of the airport (i.e., terminal) such as passenger walking distance, allocation of cheeking and control facilities, allocation of gates and lounges, etc..

The OPAL platform provided substantial decision support for the configuration and handling of the identified scenarios (through the OPAL Optimiser) allowing the user to define values for several parameters such as number of available desk counter, runway exits, police controls etc. The OPAL Optimiser automatically managed the input of these values.

5.3.3 Scenario description

A significant number of scenarios were evaluated in this case study corresponding to the future Madrid-Barajas airport with four parallel runways, which was expected to be operational by 2006. Figure 6 illustrates those areas of the airport layout that were subject to optimisation (achieving maximum throughput without generating delays and not being detrimental to the performance of the terminal elements of the airport.

The simulated scenarios constituted the combination of several alternatives related to:

- Physical design of the taxiway and apron layout (number and location of runway exits, taxi links and stands): In total 10 different layouts were considered (5 for north configuration and 5 for south configuration of the airport).
- Runway allocation depending upon the origin /destination of the traffic: at that moment there were four different strategies for traffic allocation to the parallel runway system depending on whether the origin or destination of the traffic was east/west or north /south.
- Stand allocation strategies: as it was not known in advance which will be the best allocation of companies between the various terminals, three mayor alternatives were considered corresponding to the allocation of the large alliances to the new terminal buildings (e.g., One World, Star Alliance).
- Taxiway routes: for some of the runways and stand allocation combinations several taxiway routes were possible. As it was not possible to anticipate their effect on ground congestion, all of them were evaluated.

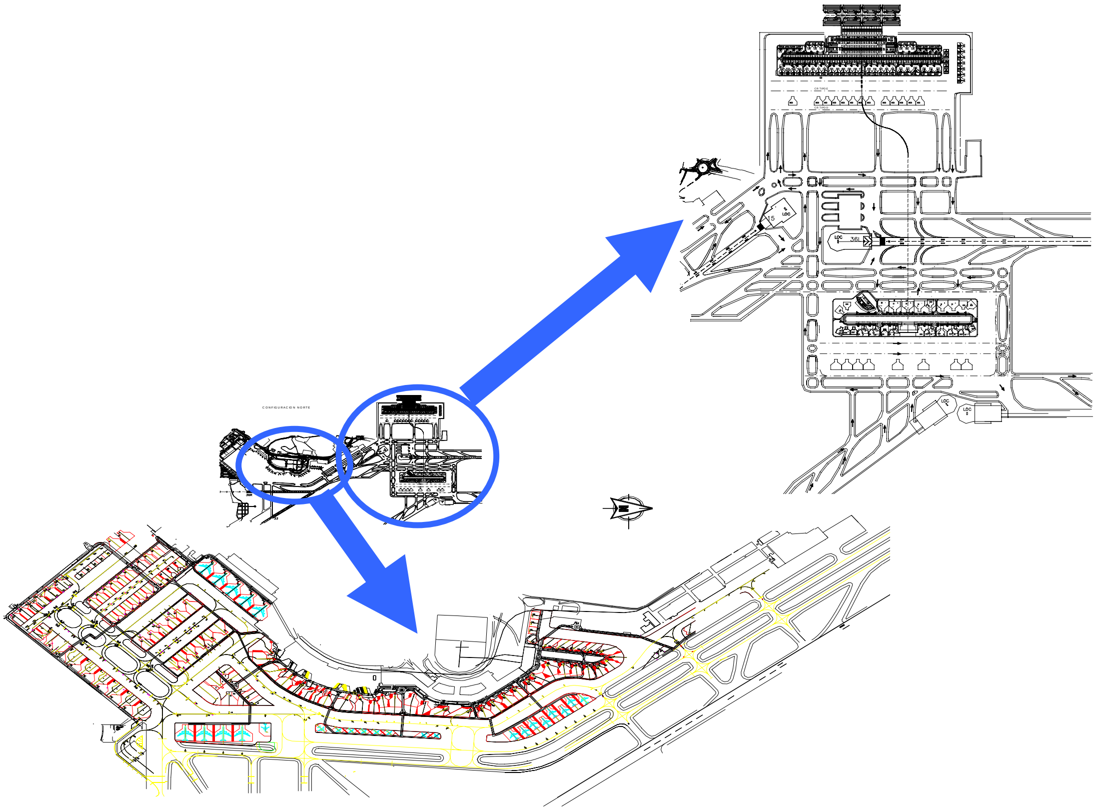

Figure 6: Schematic illustration of the Madrid Barajas airport layout subject to optimisation

- Terminal buildings design: the various stand allocation policies imposed modifications inside the terminal, mainly on the distribution of the passenger processing facilities as well as on passenger flows, whose effects were difficult to be estimated.
- Arrival and departure procedures: for the simulation of the future Madrid-Barajas airport with four runways, arrival and departure procedures have been designed in order to evaluate the noise impact on the surrounding population. Six cases were studied depending upon the configuration of the airport (North or South).

In total, resulting from the combination of the previous alternatives, more than 120 scenarios were considered. The input traffic sample corresponds to the 2010 time horizon with a total of 1.373 operations per day.

Additionally, for the airport capacity and delay study, Aena has used and implemented through the OPAL platform an internally standardised and extensively validated methodology that allows integrating in a single quality factor the combined effect of various parameters associated with the airport airside operations. This methodology was initially presented at the ESUG

(European Simmod User Group) 20th meeting (Turin, Italy). This basic methodology has been used to analyse two specific items: i) the optimisation of the airport layout, and ii) the use of the stands. All these parameters and the way they are combined using different weighting factors represent standard OPAL platform indicators.

As it can be observed in Figure 7, the method weights and sums up, in a single formula, indirect indicators covering airport efficiency on one side and human factors on the other. The selected indicators are the result of extensive sensitivity analysis developed to identify those indirect indicators that reflect the major impacts on the airport performance. These indicators are extensively used in airport simulation nowadays but in a fragmented way, while this method combines all of them to give a single value of the airport performance.

Three airport efficiency indicators are considered: delay of departing aircraft, taxiway times and delays of arriving aircraft. The influence of human factors is considered through only one indirect indicator, i.e., ground conflicts. As a matter of fact, one of the major factor influencing airport operations and performance is the complexity of the ground controllers' workload. Following interviews with ground controllers responsible for departure and ground movements of the airport, it was concluded that the most demanding and effort intensive operation event is the management the airport ground conflicts (including being aware of aircraft conflicts at crossing points, setting priorities, managing queues, giving authorizations, etc.). Taking this into account, the number and distribution of aircraft ground conflicts is considered as the major indicator of the airside operations' complexity (from controllers' viewpoint).

In the analysis, the complete taxiway layouts were modelled and baseline simulations were performed. From the baseline simulations, the occupancy of each airport element (e.g., taxiway, runway exit, stand, passenger processing facilities) has been calculated. These figures provide some first indications of under or over-utilisation. Thereafter, by means of the computational functionality provided by the OPAL optimiser, those elements were sequentially excluded from the assessment and the simulation runs were repeated (without this particular modification in the design) to check how much the airport performance has been degraded (or improved) as a consequence of the modification.

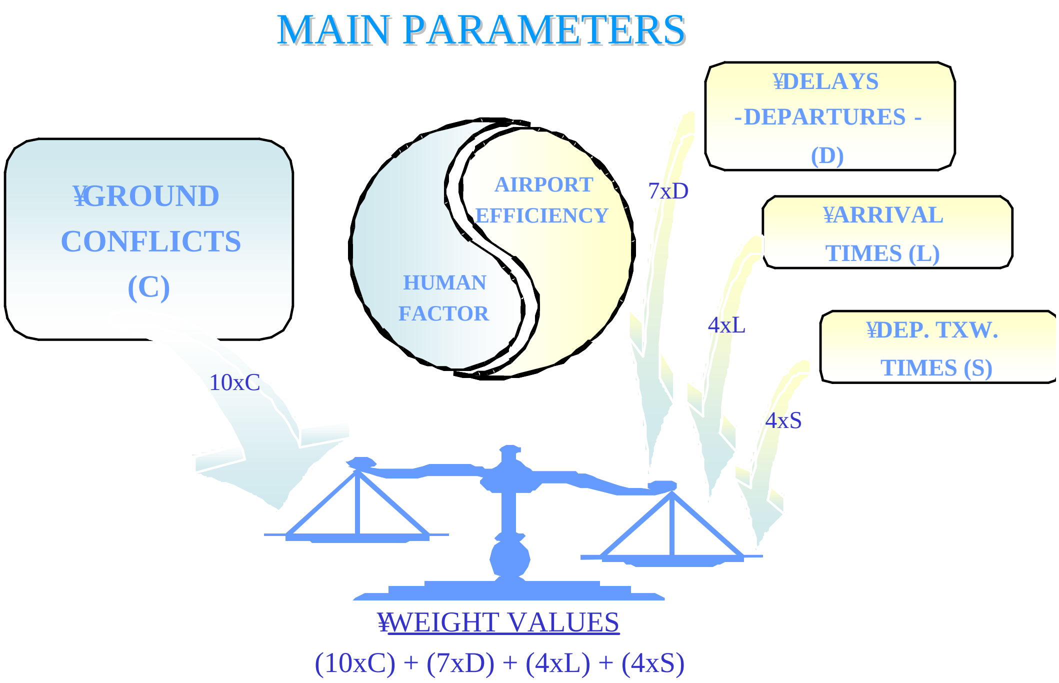

Figure 7: Standardised Madrid Airport study methodology

5.3.4 Scenario results

Some indicative results from the complete set of simulation runs are illustrated in this section. More than 120 scenarios were finally analysed to cope with the objectives of the following trade-off: to find the airport design and operation that provides maximum throughput on each of the layout elements without increasing delays, ground movement complexity and taxi time, while simultaneously not being detrimental to the level of service provided by the various passenger processing facilities or noise impacts around the airport. The final solution is a combination of a particular airport layout design, particular runway and stand allocation strategies, and a determined implementation of taxiway routes, terminal building design, as well as air space procedures.

- Physical design of the taxiway and apron layout. Figures 8 and 9 illustrates part of the layout optimisation exercise results, in particular the area close to the exit of runway 18R and 33L, respectively. These figures present on the left-hand side the original airport layout, and on the right-hand side, the optimised airport layout design resulted from the OPAL evaluation, for two of the most critical areas of the airport in terms of efficiency of the airport: the exit zone of runways 18R and 33R.

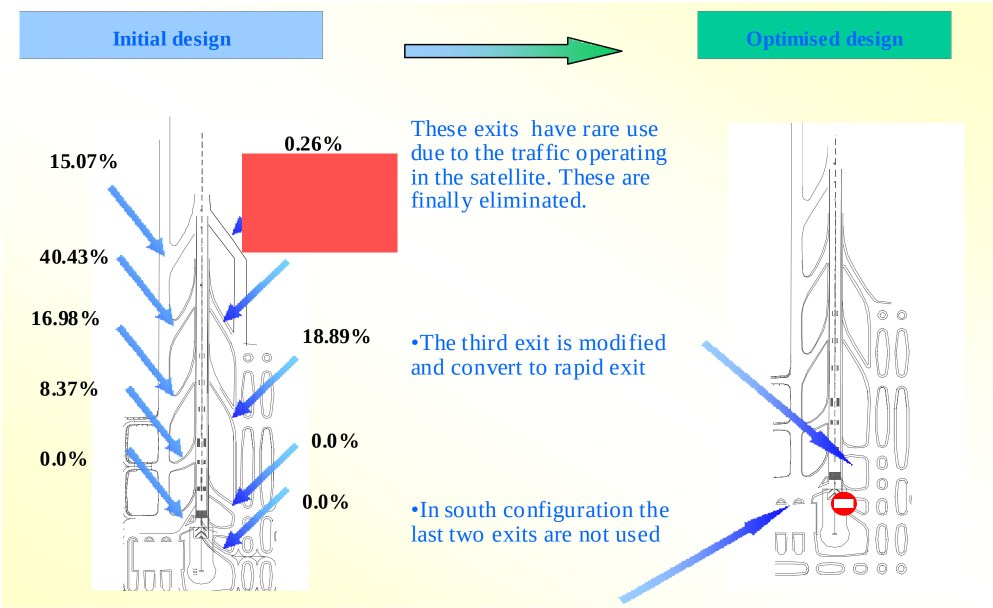

Figure 8: Runway 18R exits (Madrid Airport)

As it can be observed from Figure 8, the original airport design was quite inefficient as several exits from the runway 18R were never used. As a result, the final optimal layout did not include them. A similar situation can be also observed in Figure 9, which illustrates that a certain number of taxiways around runway 33L are not used, hence these are not part of the optimal layout design.

- Runway and stand allocation strategies: The results of the simulations have shown that both issues have to be considered simultaneously due to their strong interdependency.

The best option seems eventually to be a combination of the following runway and stand allocation policy. Inbound traffic will be allocated to runway left or right depending on whether it comes from east or west. This reduces significantly the arriving delays without increasing significantly the complexity on ground and taxi times. However, the optimal strategy for the departures seems to be the allocation of the runway according to the proximity of the terminal to the runway threshold instead of considering the flight destination. Being this the option that produces less conflict on ground, less delays and minimum taxi times for the flights can be achieved. Additionally, in combination with the following stand allocation policy, this option results to the optimum airport performance both in airside and terminal (especially for connecting flights).

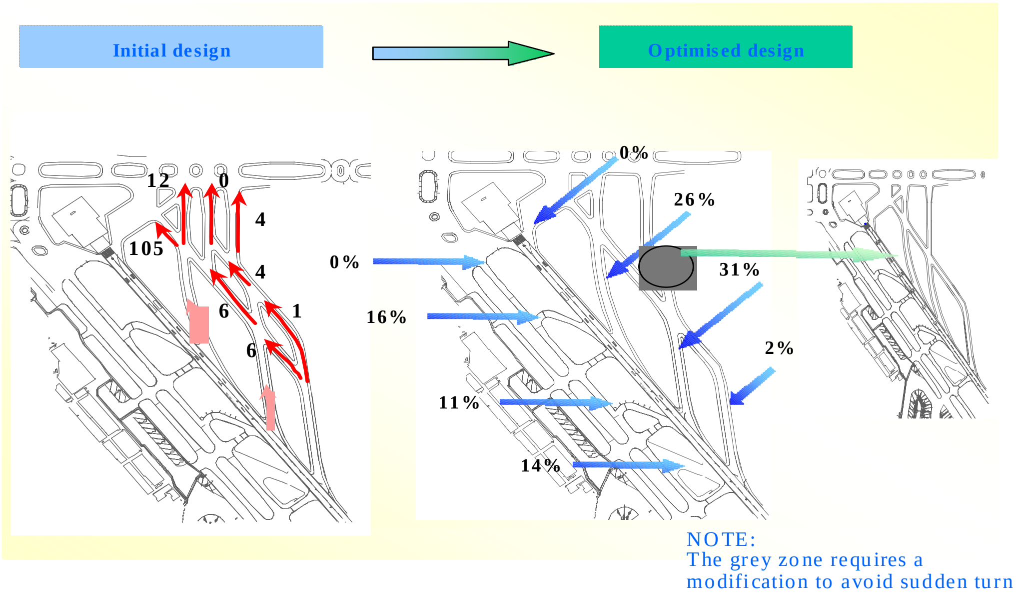

Figure 9: Runway 33L exits (Madrid Airport)

Figure 10 presents the stand usage of the alternative that finally brings a better equilibrium between airside and terminal operation. The main characteristics of this solution are:

- New terminals are dedicated mainly to One World group operation.
- All the Iberia international flights (i.e., IBH) are operated in the satellite between runways. This allows the concentration of terminal means for international flights such as passport controls and customs.
- Iberia Madrid-Barcelona Shuttle (i.e., PUENTE) passengers are given a very short and direct access.
- Current terminal use results to be:
  - T1: International flights, excluding Iberia
  - T2: Schengen flights
  - T3: National flights with national destinations
- Future terminal: A flexible use of the terminal 1 stands is implemented.
  - New terminal 1 (Satellite between runways): Iberia International (i.e., IBH), Schengen and national Iberia flights (i.e., IBDOM) using runway 33R and heavy aircraft of Iberia.
  - New terminal 2 (NAT): Iberia Madrid-Barcelona shuttle (i.e., PUENTE), national, regional and Schengen flights (i.e., IBDOM).

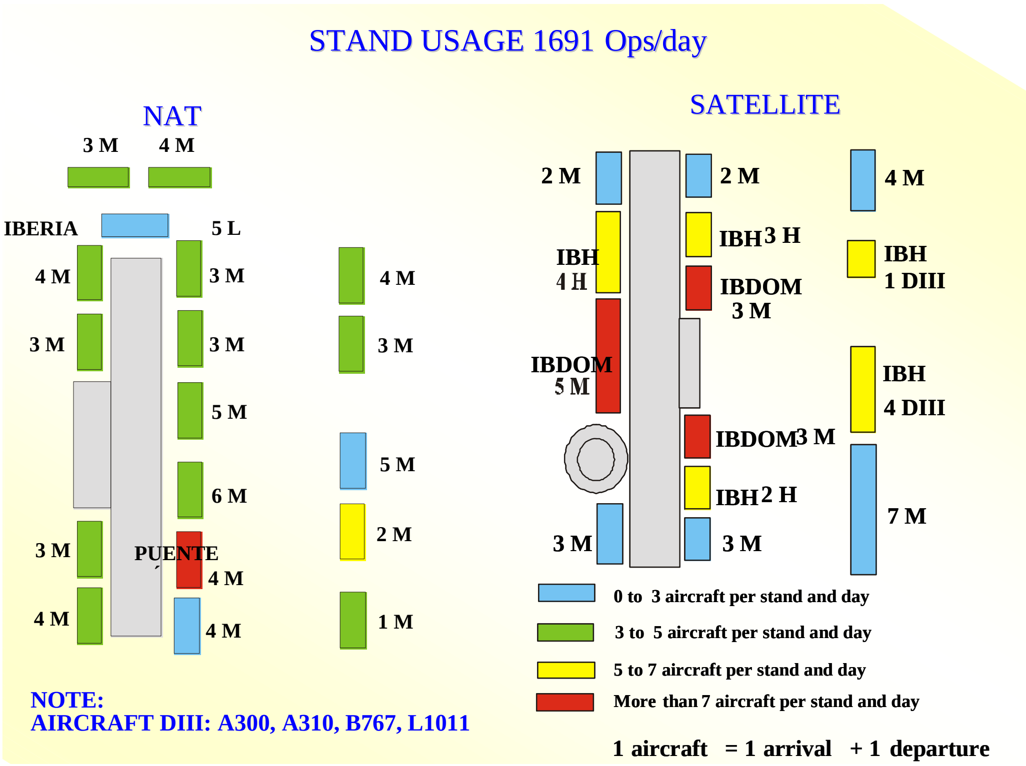

Figure 10: Stand occupation (Madrid Airport) Note: L, M, and H in the figure above stand for the different aircraft categories (i.e., light, medium, heavy)

This stand allocation policy means that approximately 30% of the Iberia flights use the stand positions of the satellite between runways and the remaining 70% is served by the New Area Terminal (i.e., NAT) terminal stands. Although Iberia international passengers are subject to longer walking distances from the checking counters as they are served through a people-mover train connecting the two terminals (i.e., NAT and the satellite between runways), the adverse effect is diminished.

As it can be observed in the figure above, the Madrid/Barcelona Shuttle positions (Puente Aéreo) are used intensively as their turnaround time is low. The usage of the NAT stands is medium, while the usage of the satellite is much more intensive. The heavy positions in the satellite are saturated with a medium usage value of 6 aircraft per day mainly due to the high turnaround time of this aircraft and the flexible use of these stand positions, which can serve heavy and medium aircraft. Although this seems to be the best option, the analysis concluded that, for the level of traffic considered, the facilities of the airport were saturated at some moments during the simulation, when there was not any stand position available for heavy aircraft in the satellite. Moreover, flexible stands were saturated with a medium usage of 9 operations per day and seemed insufficient to absorb all the national and Schengen flights served by runway 33R.

- Noise impacts. As far as the noise impacts are concerned, it was observed that the impact of the procedural changes, associated to the different runway traffic allocations patterns, was negligible in both North and South operation and capacity values.

The values of peak and total daily capacity remains constant for each case tested in South configuration, and no changes in peak times were observed. In the North configuration, the penalties can be assumed without major problems for the airport operation on the grounds that they only imply a loss of two operations in the peak hour and only a 10% of increase in the ground operation. The daily maximum operation values of saturation number of movement of the airport remain on 1.850 operations per day for the North configuration and 1.775 operations per day for the South configuration.

5.3.5 Conclusion

The case study clearly demonstrated the ability to perform total airport performance and trade-off analyses through the OPAL platform, reducing the number of errors and improving productivity thanks to the automated, consistent and standardised use of data and tools, and the facilities to manage great number of scenarios and rank of hypothesis. Besides the purely technical results from the Madrid Barajas scenario analysis, an overall impression has been assessed with respect to the OPAL platform usability and acceptance by the targeted users (airport operation and simulation experts). They unanimously agreed on the added value of the OPAL platform for supporting integrated impact analysis and capturing airport trade-off's by creating scenarios assuming various tool combinations and simulation runs. In other words, the OPAL platform has been considered quite efficient to develop a scenario in which various tools are interconnected and integrated with the aim to run various types of studies (e.g., capacity, noise, safety), while simultaneously being able to perform modifications (and estimate their impacts) to scenarios parameters ("what-if" studies) through the use of the OPAL Optimizer.

6 Overall Concluding Remarks and Lessons Learnt

This paper presented an integrated computational platform for total airport performance analysis that was developed and validated within the framework of the "Optimisation Platform for Airports including Landside (OPAL)" research project funded by the European Commission (DG TREN, 2000-2002). This platform has the form of a computational facility integrating various analytical and simulation airport performance models that allow the user to perform trade-off analyses to frequently arising airport planning problems. The presented decision support system has been successfully validated, demonstrated, and evaluated at six major European airports: Amsterdam-Schiphol, Athens, Frankfurt, Madrid-Barajas, Palma de Mallorca, and Toulouse-Blagnac.

The platform validation process was split into the following two major activities: i) the technical verification, and ii) the platform calibration. The aim of the technical verification was to ensure the technical stability, suitability, and proper functioning of the platform and its associated integrated components. The results of the platform verification clearly suggest that: i) the platform is properly and efficiently functioning with respect to the integrated tool combinations, and ii) the platform fulfils the elicited user requirements. Within the framework of the platform calibration activities, the platform has been tested against known, real-world airport data in order to develop confidence on the platform results and ensure that the integrated use of the specific tool combinations (within the OPAL platform) does not degrade the consistency and accuracy of the results of the individual tools per se (outside the OPAL platform). The results of the calibration process provide reasonable evidence that the integrated use of the tools within the platform does not degrade the use of the tools outside the platform context.

The platform validation has been followed by the evaluation process during which the platform has been demonstrated in real-world airport scenarios, and then evaluated by targeted airport users and experts with respect to user acceptance / friendliness criteria, the quality of results, the overall user experience from the interaction with the platform, as well as the potential socio-economic benefits and usefulness of platform in contemporary airport decision making problems. The results of the platform demonstration and evaluation activities clearly suggest that the OPAL platform: i) can be efficiently used to model and support real-world airport planning problems and questions, and ii) produces results of reasonable accuracy that reflect reality and real-world conditions in the specific airport demonstration sites. On the other hand, it has been evident that there is ample opportunity for enhancements and further R&D efforts towards developing: i) a more harmonised computational and data exchange environment for all tool combinations including possibly new tools, ii) a user-friendly computational environment that will not require training or prior familiarity of the user / decision maker with the selected tools or tool combinations, and iii) iii) a fully-automated computational environment for performing trade-off analyses and “what-if” airport studies by simultaneously integrating tools in a multi-tier, study or problem-oriented architecture that will interact with the user in the decision maker’s (rather than tool expert’s) language [OPAL, 2003a; Zografos and Madas, 2004b].

To bridge these gaps, a seamlessly integrated computing environment in the form of a tool-independent decision support system is required. This decision support system will be able to address a number of important airport planning and operations decisions in a user-friendly manner without requiring extensive training or prior familiarity of the user with the selected tools or tool combinations, and will report results on particular airport studies in a synthesised and integrated manner. In response to this research challenge, a research initiative is currently in progress within the framework of the FP6 SPADE project (funded by EC DG TREN) with the purpose of developing a seamless integration of tools capable of addressing a number of airport strategic planning decisions and their trade-offs through a pre-structured, pre-specified navigation (i.e., built-in use cases) [http://spade.nlr.nl]. The design of this enhanced, seamlessly integrated platform along with some early prototypes in the form of mock-up's are expected by the end of 2005 (end of Phase 1), while the full implementation of the platform is expected by late 2008 (end of Phase 2).

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