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OPTAS - FRAMEWORK 4 TASK 4.3.2/45

PART A

**OUTPUT DELIVERABLE TO WORK
PACKAGE 8 TO CONTRACT 2063**

FINAL REPORT

Version 1.1

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FINAL REPORT

Version 1.1

28 January 2000

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Executive Summary

This report constitutes the final deliverable report (deliverable D8) of the Optimisation of Airport Systems Part A (OPTAS A) project, a shared cost research study conducted by RED Scientific Ltd, Airsys ATM and Flughafen Frankfurt/Main AG (FAG) for the Directorate General for Transport (DG VII) of the European Commission (EC) as part of the 3rd call of the Framework 4 program.

The objectives of the project were:

- to use and evaluate a suite of airside and landside simulation tools to conduct a set of case studies to evaluate the potential capacity impacts of a range of initiatives likely to be introduced at European airports in the next 7 to 10 years. The case study scenarios were defined with reference to a baseline airport model which was developed using two airside simulation tools (Airport Machine and TAAM) and one landside simulation tool (Paxport). In the event, these case studies also allowed useful conclusions to be drawn about the applicability of the current generation of simulation tools to different future scenarios.*
- to evaluate the applicability of using the techniques of System Dynamics (SD) to develop a fast runtime, high level modelling tool (the SD Model) which integrates the airside and landside of an airport. This tool, while not yet market-ready, has been successfully proved as a concept and has been subjected to an extensive, although not exhaustive, set of validation tests. Furthermore, the development of the tool has provided valuable insights into the issues affecting airside/landside integration in general.*

The intermediate Work Packages which supported this work have also produced results which are of research interest in their own right. These include in particular:

- A survey of 9 major European airports, which has provided a large body of data relating to airside and landside operations at these airports.*
- A survey which produced a comparative evaluation of a range of airside and landside simulation and modelling tools, which was used to select the most appropriate tools to use within the project.*

OPTAS A has therefore produced a number of valuable research outputs, in addition to applying a novel technique to the development of an integrated modelling tool, within relatively tight budgetary constraints.

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DEFINITIONS AND INTERPRETATION

Unless the context otherwise requires, the following expressions shall have the following meanings:-

AMS	Amsterdam-Schiphol Airport
API	Application Programming Interface
ARTS	AiRport Terminal Simulation
AWOP	All Weather Operational Panel
BRU	Brussels Airport
A-SMGCS	Advanced Surface Movement Guidance and Control System
CDG	Paris-Charles de Gaulle Airport
DaFusA	Data Fusion for Airports
DCV	Destination-Coded Vehicle
DG VII	Directorate General VII Transport
DUS	Düsseldorf Airport
EC	European Commission
ECAC	European Civil Aviation Conference
FAG	Flughafen Frankfurt/Main AG
FRA	Frankfurt Airport
GUI	Graphical User Interface
HALS/DTOP	High Approach Landing System/Dual Threshold Operations
HBS	Hold Baggage Screening
ICAO	International Civil Aeronautical Organisation
LHR	London-Heathrow Airport
MAD	Madrid-Barajas Airport
MFC	Microsoft Foundation Classes
OPTAS A	Optimisation of Airport Systems, Part A
PMI	Palma de Mallorca Airport
PRM	Person with Reduced Mobility (in landside contexts) or Precision Runway Monitoring (in airside contexts)
RED	RED Scientific Ltd
RFID	Radio Frequency Identification
SLAM	Simple Land-side Aggregate Model
SD	System Dynamics
SIMMOD	the airport and airspace SIMulation MOdel
TAAM	Total Airport and Airspace Modeller
TAPE	Total Airport Performance Evaluation
VIE	Vienna Airport
WP	Work Package

Unless the context otherwise requires, words denoting the singular shall include the plural and vice versa, and words denoting any gender shall include all genders.

REFERENCES

- A. Project Plan. "Detailed Project Plan to Contract 2063", reference 0207-55.PLN Version 1.4
- B. Output to Work Package 2 "Survey of Airports, New Technologies and Traffic Management Procedures; Definition of Operational Scenarios" reference 0207-145.REP Version 1.2
- C. Output to Work Package 3 "Review Of Airport Simulation Software Tools And Integration Techniques", reference 0207-107.REP Version 2.1
- D. Output to Work Package 4 "Airport Simulation Functional Requirements Specification", reference 0207-113.REP Version 1.3
- E. Output to Work Package 5 "Implementation of Baseline Model", reference 0207a-219.REP Version 1.0
- F. Output to Work Package 6 "Report on Case Studies", reference 0207a-221.REP Version 1.0
- G. Output to Work Package 7 "Implementation of High Level System Dynamics Model", reference 0207a-229.REP Version 1.0
- H. R.G. Coyle, "System Dynamics Modelling: A Practical Approach", 1996, Chapman & Hall

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1. INTRODUCTION

1.1 Project Aims

1.1.1 This report constitutes the final deliverable report (deliverable D8) of the Optimisation of Airport Systems Part A (OPTAS A) project. OPTAS A is a shared cost research study conducted by RED Scientific Ltd, Airsys ATM and Flughafen Frankfurt/Main AG (FAG) for the Directorate General for Transport (DG VII) of the European Commission (EC) as part of the 3rd call of the Framework 4 program.

1.1.2 The objectives of the project were

- to use and evaluate a suite of airside and landside simulation tools to conduct a set of case studies to evaluate the potential capacity impacts of a range of initiatives likely to be introduced at European airports in the next 7 to 10 years,
- to evaluate the applicability of using the techniques of System Dynamics (SD) to develop a fast runtime, high level modelling tool (the SD Model) which integrates the airside and landside of an airport.

1.1.3 The intermediate WPs that supported this work have also produced results which are of research interest in their own right. These include in particular:

- A survey of 9 major European airports, which has provided a large body of data relating to airside and landside operations at these airports.
- A survey which produced a comparative evaluation of a range of airside and landside simulation and modelling tools, which was used to select the most appropriate tools to use within the project.

1.2 Project Consortium

1.2.1 The details of the Consortium partners are as follows:

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1.3 Project Structure

1.3.1 The work conducted during the project was divided into 8 Work Packages (WPs), as follows:

- **WP 1 Project Management:** led by RED.
- **WP 2 Survey of European Airports:** led by FAG. This survey was conducted in order to refine the objectives of and to provide data for the modelling exercises to be conducted in WPs 5, 6 and 7.
- **WP 3 Survey of Simulation Tools:** led by Airsys ATM. This resulted in the selection of the tools considered most suitable for the simulation exercises conducted in WPs 5 and 6 and for the modelling conducted in WP 7.
- **WP 4 Functional Specification:** led by RED. Used the results of WP 2 to define a set of requirements for the scope and content of the baseline airport model to be implemented in WP 5 and the case studies to be implemented in WP 6.
- **WP 5 Implementation of Baseline Model:** led by RED. Used the tools selected in WP 3 to implement a model of the airside and landside of an airport as specified in WP 4, which could be used as a baseline for the case study scenarios to be implemented in WP 6.
- **WP 6 Definition and Implementation of Case Studies:** led by RED.
- **WP 7 Development of SD Model:** led by RED.
- **WP 8 Production of this Final Report:** led by RED

1.3.2 The WPs are defined more fully in the Project Plan (reference A). The results of each of these WPs were fully documented in separate deliverable reports. Reference should be made to these reports for more details on the results of each of the WPs.

1.4 Document Structure

- 1.4.1 Section 2 briefly summarises the outputs of WPs 2 to 5.
- 1.4.2 Because WPs 6 and 7 produced the major study outputs, each of these WPs has a separate section devoted to it.
- 1.4.3 Section 0 provides a somewhat more in-depth summary of the results of each of the case studies conducted in WP 6. These are reported more fully in reference F.
- 1.4.4 Section 4 describes the SD Model developed in WP 7. This is described more fully in reference G.
- 1.4.5 Section 5 draws some conclusions from the results of the study as a whole.

2. SUMMARY RESULTS OF WORK PACKAGES 2-5

2.1 WP 2 Survey of Airports

2.1.1 The objective of WP 2, the results of which are fully reported in reference B, was to obtain data on current and future operations at major European airports in order to refine the objectives of, and to provide data for, the modelling exercises to be conducted in WPs 5, 6 and 7.

2.1.2 To achieve this aim, structured questionnaires were prepared and sent out to the following airports:

- Amsterdam-Schiphol (AMS)
- Brussels (BRU)
- Düsseldorf (DUS)
- Frankfurt (FRA)
- London-Heathrow (LHR)
- Madrid-Barajas (MAD)
- Palma de Mallorca (PMI)
- Paris-Charles de Gaulle (CDG)
- Vienna (VIE)

2.1.3 These airports were selected in order to represent a wide range of airport types with different topographical and operational characteristics. Where possible, the questionnaires were followed up with personal interviews with operations staff at the airports.

2.1.4 The questionnaire covered the following topics:

- Airside systems
- Passenger handling
- Persons with Reduced Mobility (PRMs)
- Passenger security and passport control
- Baggage handling (including Hold Baggage Screening (HBS))
- Cargo handling

- 2.1.5 All the airports surveyed reported capacity problems on the airside. This was particularly true of runway capacity, which at all the surveyed airports is failing to keep pace with increases in traffic demand.
- 2.1.6 The share of passengers using self-check-in machines is rising steadily and on some well-established business routes it already exceeds 50%. The importance of off-airport check-in at remote facilities such as railway stations is also beginning to grow as airports have begun to appreciate the opportunity this provides to expand check-in capacity without additional terminal space.
- 2.1.7 With regard to the handling of transfer passengers, new procedures are being developed in conjunction with the airlines for improving the minimum connecting times for transfer passengers, especially at hubs.
- 2.1.8 All airports stated that their facilities are suitable and sufficient for PRMs to follow the usual passenger flow. Future improvements are primarily aimed at check-in counter modifications for wheelchair users and passengers of small stature.
- 2.1.9 All of the airports use walk-through metal detectors for passenger security checks as this provides a higher throughput than using hand held detectors. Plans are also being put in place to increase the use of automation at border control.
- 2.1.10 There was wide variation in the levels of automation in baggage handling. Two airports still sort baggage manually, while others have been using DCV technology for some 20 years and are preparing for fully automated transfer baggage scanners and the introduction of RFID baggage tags. The issue currently causing most concern with regard to baggage is the forthcoming introduction of 100% HBS, which will require both improvements in throughput and reductions in false alarm rates.
- 2.1.11 Relatively little information was available on cargo handling. Responsibility for this is mainly taken by the airlines or by specialist handling companies.
- 2.1.12 The airports were also asked about their use of simulation tools. Although the benefits of computer based simulation are widely appreciated, there was wide variation in the extent to which it is applied. While some airports have in-house teams of simulation specialists who make an integral contribution to operations and planning, others rely on external consultants to carry out occasional simulation studies.
- 2.1.13 In conclusion, therefore, all of the airports surveyed are making substantial efforts to enhance their capacity but the focus of these efforts varies widely between airports, reflecting the particular operational, political and economic challenges which each airport faces. Certain common threads can nevertheless be discerned, in particular the urgent need to improve airside capacity and the need to address the issue of 100% HBS.

2.2 WP 3 Survey of Simulation Tools

- 2.2.1 The purpose of WP 3, the results of which are fully reported in reference C, was to conduct a review of currently available tools for airport simulation and Systems Dynamics (SD) modelling and, on the basis of this review, to select the tools most suitable for the purposes of the work to be undertaken in WPs 5, 6 and 7.
- 2.2.2 The review of airport simulation tools was conducted using a structured questionnaire, aimed at comparing the applicability of the available tools to modelling operations at major European airports. Questions were grouped into 2 separate categories - general (marketing and technical data), and specific (reporting and modelling facilities). An analysis of the completed questionnaires identified the most appropriate simulation tools from those examined, which were SIMMOD, TAAM, REDIM, Airport Machine and DaFusA for airside operations, and SLAM, ARTS and Paxport for the landside.
- 2.2.3 The study concluded that SIMMOD and TAAM appeared to be the most suitable air-side applications, as they provide an appropriate level of detail for simulating the approach, weather and air-side aspects. Of the remaining air-side tools, REDIM and DaFusA were discounted because they were too specialised (REDIM is dedicated to modelling runways and DaFusA to SMGCS and data fusion), and Airport Machine was discarded because although a good general tool it did not provide the same degree of detail as SIMMOD and TAAM. Subsequently, however, it became necessary to discard SIMMOD and replace it by Airport Machine. The reasons for this are fully set out in Annex A to reference E.
- 2.2.4 For landside operations, three simulation tools were assessed: Paxport, ARTS (AiRport Terminal Simulation) and SLAM. Of these, Paxport and SLAM offered similar facilities but Paxport included greater detail in the representation of the terminal and passenger flows and fuller reporting facilities.
- 2.2.5 In summary, the simulation tools selected for use in WPs 5 and 6 were SIMMOD, later replaced by Airport Machine, and TAAM for the airside and Paxport for the landside. The extent to which these tools were found to meet the needs of the project are discussed further below.
- 2.2.6 For the analysis of the commercially available SD tools, four software packages were considered - Cosmic, iThink, Powersim and Vensim®. Of these, Cosmic and iThink were discarded immediately as they were unable to meet the requirement to link with an externally Graphical User Interface (GUI). Powersim and Vensim® are similar in their capabilities but differ in a number of significant characteristics, such as run-time. A detailed analysis of these tools showed that, for the purposes of this project, Vensim® was the most suitable choice. In fact, subsequent experience in WP 7 showed that Vensim® includes certain extensions to the syntax of System Dynamics that were crucial to the successful development of the SD Model.

2.3 WP 4 Functional Specification

2.3.1 Under WP 4, the results of which are fully reported in reference D, the results of the survey conducted under WP 2 were taken as a starting point to define a set of requirements for the scope and content of the work to be conducted in WPs 5, 6 and 7.

2.3.2 WP 4 also investigated the feasibility of integrating the airside and landside simulations at the software level. It was concluded that this would not be feasible because of the following considerations:

- the tools selected in WP 3 are all commercial products provided by third parties and there would therefore be significant commercial obstacles to surmount if it were proposed adapt the tools themselves
- it was concluded that it would not be technically feasible, especially given the resources and timescales available to the project, to develop a front end application which would invoke the separate tools and transfer data between them.
- it was not possible, for reasons of commercial confidentiality, to make use of the results of an earlier DG VII funded research project, TAPE, which had sought to address the technical challenges of such an integration.

2.3.3 In summary, therefore, there are major technical obstacles which would need to be overcome in order to integrate the current generation of simulation tools (of which, from this point of view, those selected in WP 3 can be taken as reasonably representative).

2.3.4 These considerations made it necessary to modify the scope of the work to be conducted in WP 5. Rather than implement an integrated software application, it was instead decided to use the selected tools to implement in parallel three separate models of the same airport, two of the airside and one of the landside, which would then serve as a baseline for the case studies to be performed in WP 6. The rationale for and implications of this decision are discussed further in the next section.

2.3.5 WP 4 used the results of the survey in WP 2 to define minimum requirements for the scope and level of detail of this baseline model and to specify at a high level the scenarios for the case studies to be conducted in WP 6 (see Section 3 below). It also defined the relationship between these WPs and WP 7, the development of the SD Model. It thus can be said to have provided a bridge between the WPs 2 and 3 and the later WPs in which the major project deliverables were produced.

2.4 WP 5 Baseline Model

2.4.1 The purpose of WP 5, the results of which are fully reported in reference E, was to implement a model of the airside and landside of an airport which could be used as a baseline for the case study scenarios to be implemented in WP 6. This was successfully achieved, with two entirely separate airside implementations using two airside simulation tools, TAAM and Airport Machine, and an implementation of the landside model using Paxport.

2.4.2 The development of the baseline model was driven by the need to meet the following criteria:

- **genericity:** it must have features which are representative of major European airports in general
- **validity:** it must be based on real data

2.4.3 In order to seek to meet both of these requirements, it was decided to base the model on FRA, although with a number of simplifications. FRA was chosen because, as a member of the project Consortium, it was the airport for which the necessary airside and landside data was most easily obtainable. The simplifications were introduced in the light of the availability of data and in order to ensure genericity.

2.4.4 It will be seen, therefore, that it was not the objective of WP 5 to develop a complete and fully faithful model of FRA or any other airport. The purpose was rather to define a baseline against which the case studies in WP 6 could be defined and their results compared.

2.4.5 On the airside, the chief output used for assessing the results both of the baseline model and the case study scenarios was a response curve showing the number of minutes of total delay for a range of flight schedules with different numbers of movements. These schedules were all derived from a single 1286 movement schedule for a peak day at FRA in 1998.

2.4.6 One potential cause of discrepancies between the two simulation tools is the difference in the precise ways in which the total delay is defined and calculated. In the case of TAAM, it is the sum of the following quantities:

- **Gate delay:** total delay at gate, including delays due to in-trail separation, delayed pushback due to traffic in apron area, arrival sequencing and flow control at destination airport, gate delays caused by runway congestion, delays due to late arrival of next linked flight, etc.
- **Taxi delay:** the delay experienced by the aircraft because of taxiway and apron congestion. The taxiway delay time is calculated as follows:

taxi delay time = taxi time minus scheduled time (by TAAM simulation: no delays, unimpeded movement)

- **Runway delay:** includes delay due to speed control, airborne holding, trombone approaches for arrivals and line up queue for departures.

2.4.7 In Airport Machine, total delay is composed of the following quantities:

- **Arrival delay:** delays to arriving aircraft during the approach phase
- **Departure delay:** delays incurred by departing aircraft after taxi out
- **Taxi in delay:** delays to arriving aircraft whilst taxiing or on the apron
- **Taxi out delay:** delays to departing aircraft whilst taxiing or on the apron
- **Runway crossing delay:** delays caused by taxiing having to wait at runway intersections
- **Gate delay:** delays to departing aircraft waiting to push back from gate

2.4.8 The baseline delay curves generated by TAAM and Airport Machine are shown in Figure 2-1 below.

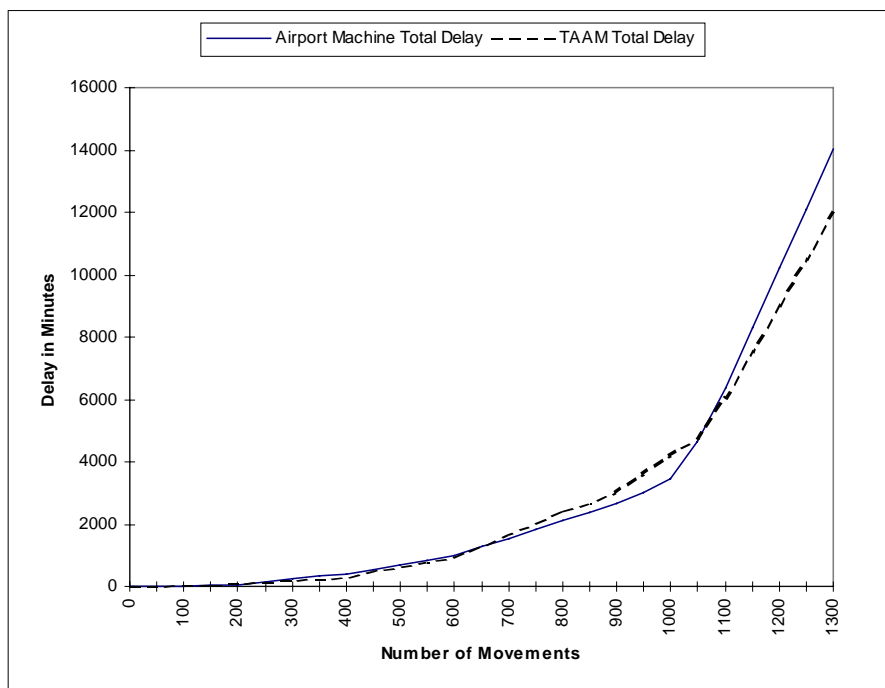


Figure 2-1 Total airside delay curves generated by TAAM and Airport Machine for the baseline model

2.4.9 One striking feature of these curves is the sharp steepening which occurs after approximately 1000 movements. This seems to indicate a saturation limit for the airside capacity of the baseline airport. In this connection, it should be borne in mind that the simplifications mentioned above mean in particular that the baseline model explicitly excludes the kind of sophisticated Air Traffic Management procedures in use at FRA and elsewhere, which are needed to handle high volumes of traffic.

2.4.10 The Paxport implementation of the landside was also based on FRA, using the same flight schedule, with a layout consisting of two terminals with five piers labelled A to E but also with a number of simplifications. The chief outputs were the **passenger delay** and the profiles and average values of the expected queuing times at the various process points (check-in, passport control, security check). The passenger delay for each aircraft is defined as follows:

Passenger delay = $\text{MAX}(0, T_a - T_b)$, where

T_a := the time that an aircraft has its full complement of passengers on board

T_b := the latest time that they would need to be on board for the aircraft to be able to push back on time (assuming that there are no other causes of delay)

2.4.11 Considerations of validity became an important issue during WP 5. The validity of the baseline model was affected by a number of related factors:

- **Availability of data.** Despite the assistance and co-operation of the authorities at FRA, it proved difficult, in a number of areas, to obtain data in the quantities and at the levels of detail which would ideally have been required. This was particularly the case for the landside model, for which it became necessary in some cases to make additional simplifications and even assumptions.
- **Cross-verification of the airside models.** It appears that the internal representations used by the two airside tools are radically different in a number of respects. This meant that the parameter sets used to define the same airside model in the two separate tools cannot be easily compared. Nor is it straightforward to make direct comparisons between the predicted delays as these are defined slightly differently by the two tools. This point is discussed in more detail in reference E.
- **Simplifications.** The simplifications introduced to ensure genericity meant that the predictions of the baseline model could not in general be directly compared with real data from FRA.

2.4.12 These findings highlight a general problem facing the development of airport modelling tools, namely the difficulty of obtaining suitable validation data sets.

2.4.13 An additional factor is **lack of stochastic variability**. The time and data constraints which have already been mentioned meant that all of the scenarios for both the baseline model and the case studies were ultimately based on a single traffic schedule, as mentioned in paragraph 2.4.5, whose topology was maintained whilst the actual number of aircraft movements was varied to produce the curves. Furthermore, only single, deterministic runs of these variants were made. Consequently, the results of simulation runs using the original schedule or the “reduced” schedules derived from it may be sensitively dependent on the precise traffic mix associated with that schedule.

2.4.14 This is well illustrated by the following two figures. Figure 2-2 shows the profiles of aircraft movements throughout the day for the original flight schedule and the “reduced” flight schedules derived from it. It will be seen that, while it was possible to retain the broad outline of the original profile, the correspondence is not perfect.

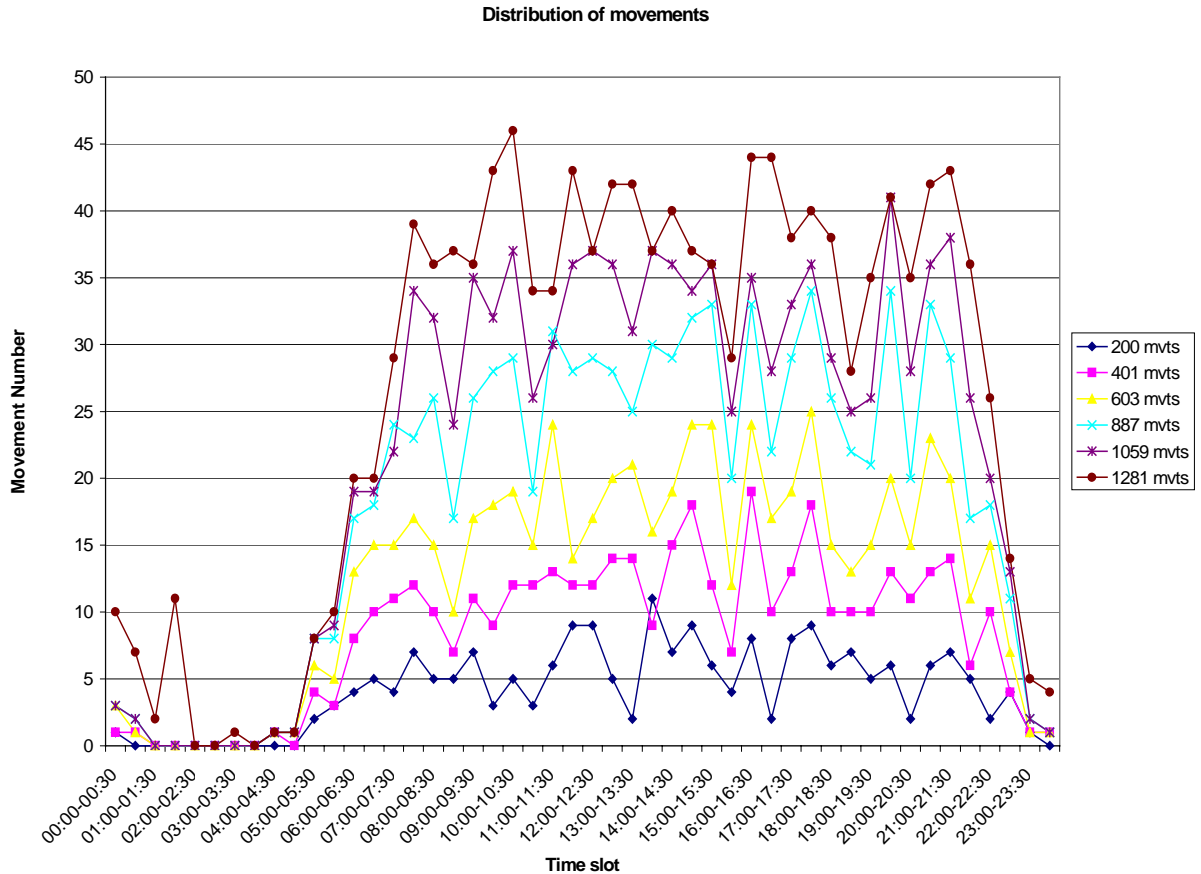


Figure 2-2 Profiles of aircraft movements over time

2.4.15 Figure 2-3 depicts the relative distributions of aircraft categories within each the schedules derived from the original schedule. Once again, there is a degree of non-uniformity in the curves which helps to explain the non-uniformities in some of the delay curves shown in WP 6, as many aircraft parameters depend on this classification, such as ground speed, approach speed, wake turbulence separations, etc.

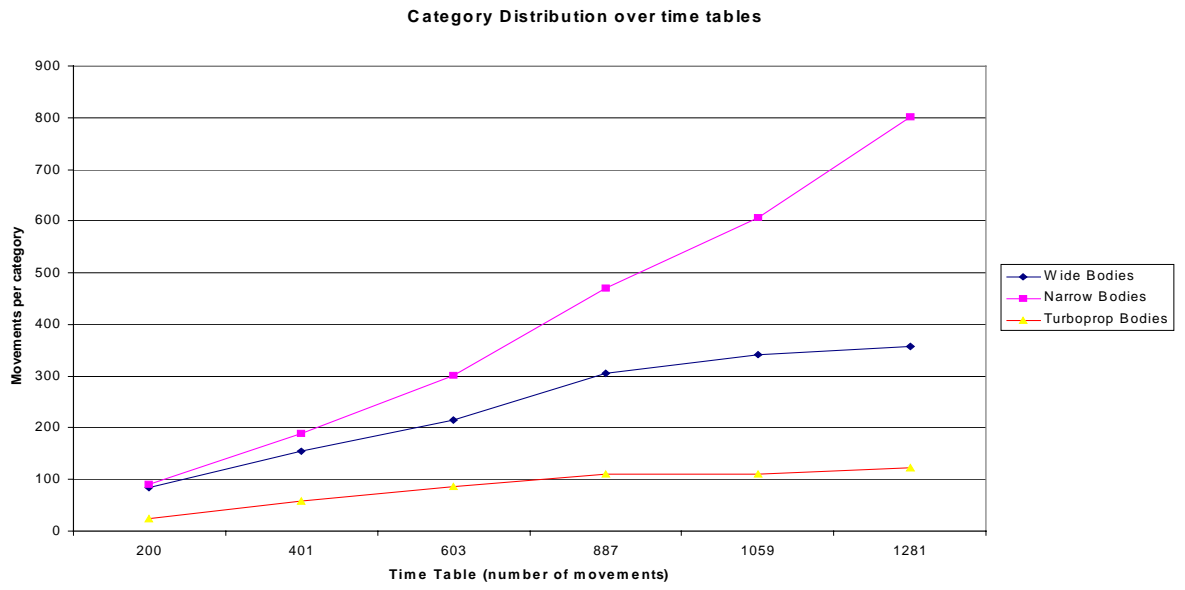


Figure 2-3 Relative distributions of aircraft categories for each flight schedule

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3. WP 6 CASE STUDIES

3.1 Introduction

- 3.1.1 WP 6 involved the detailed definition, implementation and analysis of the case study scenarios specified in WP 4. Each case study analysed the impact of applying a particular airside or landside initiative to the baseline model developed in WP 5. The case study definitions and their results are documented in full in reference F.
- 3.1.2 In addition to their intrinsic interest, the case studies also served to provide validation data for the SD Model developed in WP 7. In order to provide additional material for validation which was not directly related to the baseline model, an additional set of simple airport scenarios were also implemented and these are documented in an annex to reference F.
- 3.1.3 It is emphasised that caution must be exercised when considering quoted values for delay reductions resulting from the introduction of airside improvements. This is because, due to time constraints, these values were based on a single traffic schedule, as discussed in Section 2.4.11 above.

3.2 The performance of the Simulation Tools

- 3.2.1 The case studies also provided an opportunity to investigate in further detail the particular strengths and weaknesses of the three simulation tools. It became evident that, in certain respects, the requirements of the case studies exceeded the original design aims of the tools. The discussion below should not therefore be construed as a criticism of TAAM, Airport Machine or Paxport, but rather as an indication of the mismatches that exist between the capabilities offered by the current generation of tools and the modelling requirements exemplified by the case study scenarios.
- 3.2.2 **TAAM** was originally designed to support the analysis of enhanced airport layouts and the impacts of existing procedures. It proved to be well suited to the High Speed Exit and Precision Runway Monitoring case studies, the first of which was purely a layout update and the second of which was mainly a modification of approach separations.
- 3.2.3 By contrast, modelling HALS/DTOP requires changes both to the airport layout and separation standards as well as a fine-tuning of the approach sequence. Evidently, for this fine-tuning to be performed correctly would require an expert system to sequence heavy and medium aircraft on their optimum runway according to the types of the other aircraft in the sequence queue.

- 3.2.4 Unfortunately, this complexity is not handled by the current version of TAAM, version 2.9. It had been expected that version 3 would provide a fine tuning language that should have made it possible to create expert control algorithms, but it now appears that this version will not be released. A workaround would have consisted in building a specially re-ordered timetable, but this solution would have questionable validity.
- 3.2.5 It can thus be concluded that TAAM can be used most successfully if the following rules are adhered to.
- The outputs are correctly defined and extreme caution is exercised in drawing comparisons with the outputs of other tools where the definition of delays, workload, etc. is not the same.
 - Care should be taken in attempting to extrapolate the results for a given scenario to other airport layouts, timetables, or parameter sets, without performing new simulation runs.
 - The definitions of future scenarios should not be too far removed from current airport / airspace facilities, which can be directly validated.
- 3.2.6 **Airport Machine** was initially developed as a tool for stand and gate optimisation and taxipath routing analysis. It is also possible to model approach and departure procedures by defining suitable separation values, although the behaviour of aircraft in e.g. the approach phase is not modelled in as much detail as in TAAM. In practice, it proved possible to implement each of the scenarios in Airport Machine with certain qualifications which are discussed in the relevant sections below.
- 3.2.7 It seems to be generally the case that landside tools tend more frequently to be used by their originators to provide consultancy solutions, rather than being sold to end users as a self-contained product (although this also happens). **Paxport** fits fairly well into this pattern and is in consequence very much in a state of continuous evolution, more so than the two airside tools discussed above.
- 3.2.8 Much of the modelling capability provided by Paxport relates to issues surrounding crowd congestion in, e.g. service areas and retail areas. To be valid, such modelling requires a large amount of data at a low level of detail. Because of the unavailability of such data, and for other reasons which are discussed above, the emphasis in the baseline model and the case studies was placed on the responses in the performance of passenger process points to variations in demand and the potential impacts of these on delays.
- 3.2.9 As a consequence, it was found that for some of the case studies the facilities offered by Paxport did not fully match the requirements of the scenarios. In particular, the following points became evident.
- To model issues relating to PRMs in detail it would be necessary to specify numerous factors relating to the behaviour and handling of specific subsets of the passenger population. Although Paxport provides an

extensive facility for modelling different passenger types, this facility has not been specifically designed with PRMs in mind. This, combined with the relative lack of useable data, restricted the range of investigations that could be performed.

- As Paxport is primarily concerned with modelling passenger behaviour, it does not attempt to model the baggage handling system. For the HBS case study it was therefore necessary to implement a separate model, which accepts as inputs the predictions of passenger flows generated by Paxport. (Thanks are due to the Paxport Controlling Consortium for amending the Paxport source code to provide additional outputs so as to make this possible). For the effects of 100% HBS to be effectively modelled, dedicated tools would be required, which would have to be able to be configured to model the varied screening configurations discussed in reference B.
- For similar reasons, Paxport has not been designed to assess the impact of passenger congestion on aircraft departure delays. It proved to be fairly easy to provide a workaround solution to this problem by inferring passenger delays from the extensive output data produced by the tool. It is nevertheless indicative of the general point made above.

3.3 Airside Case Studies

3.3.1 High Speed Exits

3.3.1.1 High speed exits are a well-established means for reducing runway occupancy times. Nevertheless there is considered to be potential for further exploitation of this technology at some of the airports surveyed in WP2 and more generally within Europe. Another reason for including a high speed exits case study was that it would provide a relatively well understood scenario against which the SD Model could be validated in WP 7.

3.3.1.2 For the case study, 3 high speed exits were added to each of the three runways in the baseline model and suitable parameters defined to determine their use by different categories of aircraft. Airport Machine predicted delay reductions of approximately 10% for a range of flight schedules. These reductions were purely in runway departure delays.

3.3.1.3 TAAM, on the other hand, which models the approach phase in more detail, also predicted reductions in arrival delays, although the overall delay reduction was somewhat less than that predicted by Airport Machine.

3.3.2 Advance Surface Movement and Control System (A-SMGCS)

3.3.2.1 The introduction of A-SMGCS, as recommended by ICAO, is one of the major anticipated innovations in airport operations over the next 7-10 years. As a consequence it is currently a focus of major research efforts within the European Union.

3.3.2.2 The ICAO All Weather Operational Panel (AWOP) describes an A-SMGCS as “a modular system consisting of different functionalities to support the safe, orderly and expeditious movement of aircraft and vehicles on aerodromes under all circumstances with respect to traffic density, visibility conditions and complexity of the aerodrome layout”.

3.3.2.3 Current SMGCS procedures are based primarily on the “see and be seen” principle to maintain separations between aircraft and ground vehicles. To maintain safety levels in poor visibility, therefore, it is necessary to reduce ground speeds and introduce other specific rules which have the overall effect of reducing the capacity of the taxiway system.

3.3.2.4 The objective of A-SMGCS can therefore be said to be the implementation and integration of improved surveillance, monitoring, planning, guidance and control systems to ensure that controllers, pilots and drivers of ground vehicles all keep a safe level of situational awareness even in poor visibility.

3.3.2.5 While its significance necessitates its inclusion in the study, the actual capacity effects of a fully operational A-SMGCS system remain a matter for debate and conjecture. As it was not feasible to model the components of an A-SMGCS directly with either TAAM or Airport Machine, it was therefore necessary to make the following explicit **assumptions** about the effects of an A-SMGCS, and then to evaluate the capacity implications of these assumed effects.

1. An A-SMGS at the baseline airport would allow normal ground speeds to be maintained during poor visibility. Conditions in poor visibility without A-SMGCS were simulated in both TAAM and Airport Machine by reducing the input parameters which control aircraft taxi speeds.
2. An A-SMGCS at the baseline airport would remove the need for additional runway crossing rules at the baseline airport. It was also possible to simulate the effect of these rules in a similar fashion in both TAAM and Airport Machine.

3.3.2.6 Under these assumptions, the predicted effects on delays under poor visibility conditions were quite dramatic. TAAM predicted typical reductions in total delay over a range of flight schedules of approximately 2 minutes per flight and Airport Machine predicted slightly lower reductions.

3.3.3 High Approach Landing System/Dual Threshold Operation (HALS/DTOP) and Precision Runway Monitoring (PRM)

3.3.3.1 HALS/DTOP is a novel procedure currently under investigation at FRA, which promises to bring about significant improvements in the capacity of closely spaced parallel runways, which normally cannot be used for simultaneous independent approaches because of wake vortex considerations.

- 3.3.3.2 HALS/DTOP is based upon research findings which indicate that wake vortices do not rise more than 70 m above their original height during their lifetime. It therefore seeks to reduce the longitudinal, or in-trail, separation between succeeding aircraft by displacing their touchdown points. This is possible in the case of a heavy aircraft followed by a medium aircraft, since the medium aircraft requires a shorter landing distance. In this case the longitudinal, or in-trail, separation could be reduced from 5 to 2.5 NM.
- 3.3.3.3 This can be modelled in Airport Machine by reducing the relevant separations and suitably revising the runway allocations.
- 3.3.3.4 Separations in the model can be further reduced to account for the effect of combining HALS/DTOP with Precision Runway Monitoring (PRM).
- 3.3.3.5 PRM is based on the use of airport secondary surveillance radars with improved azimuth accuracy and a considerably higher update rate than the four- to five second update rate of present airport surveillance radars. This enables ATC controllers to monitor the progress of each aircraft in real time and with greater precision. This in turn can facilitate a safe reduction in radar separations to 1.5 NM.
- 3.3.3.6 Airport Machine predicted major reductions in total delays for HALS/DTOP both with and without PRM. Over the range of flight schedules, delay reductions were consistently greater than 10% for HALS/DTOP alone and consistently greater than 20% for HALS/DTOP with PRM. Perhaps more significantly, the sharp steepening of the baseline delay curve after 1000 movements was greatly reduced. Delays for the 1286 movement schedule were reduced by 49% for HALS/DTOP and by 59% for HALS/DTOP with PRM (see Figure 3-1 below).

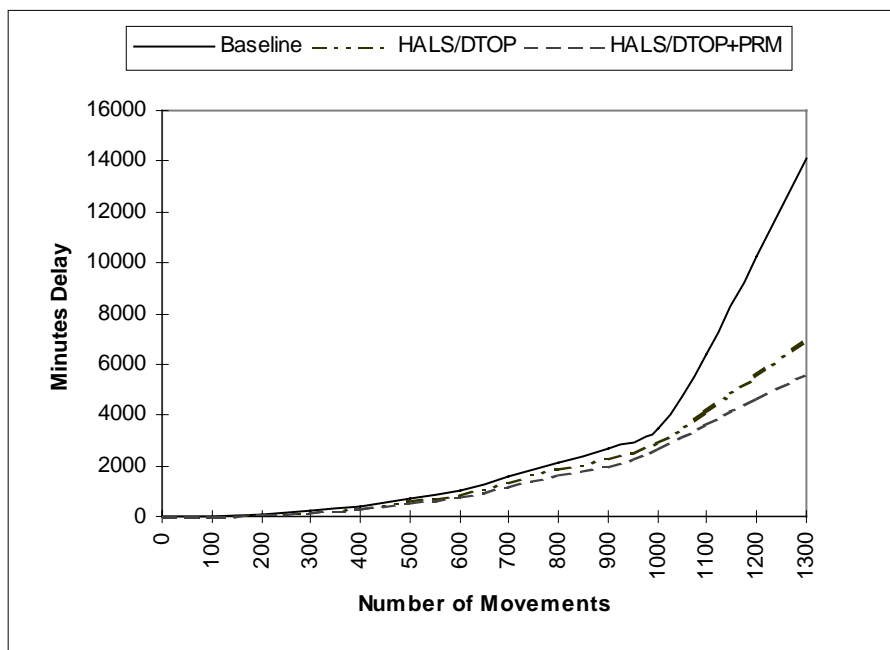


Figure 3-1 Comparison of the delay curves for the baseline model, HALS/DTOP and HALS/DTOP with PRM

3.3.3.7 Modelling HALS/DTOP with TAAM proved to be more problematic. TAAM does not seem to be able to optimise the sequencing of approaching aircraft to make full use of the reduced separations (in addition, the new separations were not always respected for reasons which remain unclear). Moreover, closing one runway for departures had the effect of increasing ground delays. In conclusion, therefore, it was not found to be possible to define a set of input parameters which would allow TAAM to model the effects of HALS/DTOP.

3.3.4 Standard Surface Movement Scheme

3.3.4.1 In the baseline model aircraft movements were based on the principle of shortest routes, in which the shortest available route is found for each individual movement. There was thus no attempt to perform a global optimisation of the traffic flow. This case study, which was only implemented with Airport Machine, applied a principle called "Standard Short Cuts" to all aircraft surface movements. The principle is based on dedicating specific runway exits and aircraft parking areas for inbound traffic. The details of its implementation are therefore highly specific to an individual airport layout but it illustrates an approach to reducing taxiway delays by introducing specific taxiing rules.

3.3.4.2 Airport Machine consistently predicted delay reductions in the region of 10% for flight schedules with numbers of movements up to 1063. The effect was, however, less marked after the critical point observed for the baseline model, with a reduction of only 2% for 1286 movements.

3.4 Landside Case Studies

3.4.1 Self Check-In

3.4.1.1 Self check-in kiosks are seen as a potentially very effective and economic means of improving capacity and service levels at check-in areas. The advantages they offer can be summarised as follows:

1. self check-in machines achieve on average a higher process rate than manual check-in desks. More specifically, users who are familiar with the system should be processed significantly more quickly. As the technology becomes more widespread and consequently familiar to a larger proportion of the passenger population, this effect is likely to become more marked.
2. self check-in machines occupy relatively little space and a larger number can therefore be placed in a given check-in area.
3. as they do not need to be manned by check-in staff, self service machines can remain open throughout the day and the total number of check-in points can be increased without a proportionate increase in staffing costs.

3.4.1.2 Points 2 and 3 above imply that it will be possible to replace a proportion of existing check-in desks with a larger number of self-service machines.

- 3.4.1.3 For the purposes of the case study, therefore, a future scenario was devised in which in which a subset comprising approximately 30% of all departure passengers use self check-in machines.
- 3.4.1.4 Ideally, it would have been desirable for the case study to be underpinned by real data on the processing times achieved by self check-in machines in the field. As this was not possible, an assumption was made that the process rate for these machines is on average twice that for manual check-in desks and space they occupy is half that for manual desks, with a consequent increase in overall check-in capacity.
- 3.4.1.5 The number of open self check-in machines remains constant during the day rather than being allocated dynamically as is the case for manual check-in. The scenario also assumes that all self check-in machines will be able to handle passengers with hold luggage. Some machines with this capability are already in service (for instance at FRA).
- 3.4.1.6 The scenario did not predict any significant impact on overall passenger delays, but it did predict a reduction in overall queuing times at both terminals of approximately 1 minute. Interestingly, there was also a smaller but still significant reduction in queuing times at manual check-in, namely 7% at terminal 1 and 24% at terminal 2. This was evidently a consequence of the overall improvement in check-in capacity mentioned above.

3.4.2 Smart Cards

- 3.4.2.1 Smart cards are machine-readable travel documents that have the potential to simplify and accelerate the handling of passengers at a range of different types of process points.
- 3.4.2.2 For the purposes of the case study attention was focused on the use of smart cards at check-in and passport control.
- 3.4.2.3 In each case, the scenario assumes that a passenger with a smart card will be processed on average twice as quickly as a passenger without a smart card but that the same processing channels are used for both types of passengers. Smart cards are carried by 57% of passengers on a defined subset of flights constituting 61% of all flights.
- 3.4.2.4 These figures imply that overall 33.40% of arrival passengers and 31.31% of departure passengers in the scenario are smart card users.
- 3.4.2.5 Once again there was no significant impact on passenger delays, but the effect on queuing times, both for passengers with and without smart cards, was significant. In particular, mean predicted queuing times at check-in were reduced by over 2 minutes (over 50%) at terminal 1 and by 22 seconds (17%) at terminal 2 (the difference between the terminal reflects the fact that, in the baseline model, terminal 2 already has spare check-in capacity). Similar, though less striking, reductions were predicted for passport control.

3.4.3 Combined Queuing for Check-In

3.4.3.1 In combined queuing a group of check in desks are assigned a single queue rather than each desk having its own queue. These combined queues usually consist of a roped-off area within the departure hall which forms a “snaking” queue.

3.4.3.2 A simple analysis suggests that a block of n check-in desks operating at capacity (i.e. handling a large number of passengers) will process passengers at the same overall rate regardless of whether combined queuing is operation or not. At times when a small number of passengers are being processed, however, combined queuing ensures that optimal use is made of the available desks, while under the standard arrangement small queues will tend to form at some desks while others remain under-used.

3.4.3.3 This was modelled by assuming that all the manual check-in desks are grouped into blocks of 5, each of which is treated by Paxport as a single desk with a process rate equal to 5 times the baseline process rate.

3.4.3.4 The predicted effect on queuing times was considerable, with mean queuing times being reduced by over 20%. This did not, however, feed through into a reduction in passenger delays.

3.4.4 Persons with Reduced Mobility (PRMs)

3.4.4.1 The term Person with Reduced Mobility (PRM) is applied to individuals who, for whatever reason, are not able to move as freely unaided through the terminal building as the general population. This point is discussed further in the report to WP 4 (reference D) but it suffices to say that PRMs represent a sizeable (25% of the overall passenger population according to EC data) and very diverse population with a wide range of specific needs and interests. In the baseline model this population was divided into three broad categories, based on the available data, and implemented as Paxport “passenger types”. These were:

1. A type which groups together individuals who suffer from some kind of physical impairment. This will include people who are wheelchair bound, blind or partially sighted and deaf or hard of hearing, amongst others. Clearly this covers a very broad range of individuals but aggregating them is necessitated by the available data. According to EC data, this group of passengers comprises 2.9% of the passenger population.
2. A type which groups together individuals whose mobility is impaired due to age (14.8% according to EC data) or pregnancy (0.2% according to EC data).
3. A type which covers adults with children and/or unaccompanied minors (7.1% according to EC data).

- 3.4.4.2 Given the considerations outlined above, it was decided to concentrate on investigating the effects on overall landside operations of reserving specific check-in desks and passport and security channels for the exclusive use of PRMs.
- 3.4.4.3 Three scenarios were investigated, one in which this facility was provided for PRMs belonging to group 1 above, one in which the same facility was extended to include group 2 as well and one in which it was extended to all three groups. Thus the scenarios involved providing the facility to 2.9%, 17.9% and 25% of the overall passenger population respectively.
- 3.4.4.4 Because passengers are effectively being routed through two separate sets of channels, the total number of channels required to maintain overall service levels and avoid additional delays may increase. The extent to which this happens will in fact depend on the profile of demand throughout the day, as well on the amount of spare capacity already in the system.
- 3.4.4.5 In each case, therefore, the investigation concentrated on finding the minimum additional allocation of desks/process channels which would be required to avoid significant increases in passenger delays and to maintain overall service levels in the baseline model.
- 3.4.4.6 For the first scenario, in which special channels were reserved for 2.9% of passengers, an increase of 2.6% was required in the number of passport channels for terminal 1 arrivals and an increase of 3.6% was required for terminal 1 security. No other increases were needed.
- 3.4.4.7 For the second scenario, in which channels were reserved for 17.9% of passengers, increases were again only required for terminal 1 arrival passport control (2.6% again) and terminal 1 security (14.3%).
- 3.4.4.8 For the third scenario, in which channels were reserved for 25% of passengers, no additional capacity was required for arrival passport control in terminal 1. This would appear to be due to an 'averaging' effect in which the proportion of passengers being specially routed is sufficiently large that the demand profile on the reserved channels approximates closely to the overall demand profile.
- 3.4.4.9 This effect was not observed for terminal 1 departures. Departure passport control required an additional 3.6% capacity and security required an additional 1.43%.
- 3.4.4.10 Reserving channels for 25% of passengers was also sufficient to have an effect on terminal 2. Here arrival passport control required an additional 38.3% of channels and security required an additional 10%.

3.4.5 Security at Departure Gates

3.4.5.1 Placing security checks at or close to the departure gates rather than at, say, the entrance to a pier has the advantage of removing a potential bottleneck by effectively distributing the screening of passengers over a wider range of locations. The trade-off is that, to handle a given volume of passengers, a greater overall level of screening capacity is required. If, however, it can be arranged that security channels can still be shared between neighbouring gates when necessary, then the total increase required in the number of screening channels may be relatively small.

3.4.5.2 The case study investigated the effects of introducing security at gate for pier A of the baseline model. In the baseline model pier A has 10 security channels and for the study attention was focused on determining how many additional channels would be required to maintain levels of service.

3.4.5.3 To this end three scenarios were implemented, in which the total number of screening channels for the pier as a whole were increased respectively to 11, 13 and 15 and suitably distributed around the pier.

3.4.5.4 In the 11 channel scenario, the number of channels was clearly insufficient, with large queues forming, which led to unacceptable levels of passenger delay. A further increase to 13 channels was, however, sufficient to remove this problem and reduce both queuing times and passenger delays to levels slightly below those for the baseline model. Pier A security had effectively ceased to be a bottleneck, so that a further increase to 15 channels, although it resulted in significantly reduced queuing times, did not lead to a further reduction in passenger delays.

3.4.6 Fast Track Passport Control

3.4.6.1 Fast track passport control, in which passengers from specified flights or belonging to a particular category are routed through special dedicated passport channels, offers some of the same potential benefits as security at gate. Because the channels are still co-located, however, the trade-off between improved passenger flow and the need for additional channels overall is less severe.

3.4.6.2 For the purposes of the case study, fast track channels were allocated to departure passengers on particular wide-body flights, roughly evenly spaced throughout the day. The additional channels were allocated between the piers on the basis of the proportional breakdown of passengers by pier.

3.4.6.3 The aim was once again to determine the minimum increase in the overall numbers of passport channels which would be required to avoid increases in passenger delays or mean queuing times. This was found to be 4 additional desks at each of terminals 1 and 2.

3.4.6.4 In percentage terms this represents an increase of 16% for terminal 1 and 57% for terminal 2. Queuing times for fast track passengers were significantly less than for the baseline model, but there were also improvements in mean queuing times for non fast track passengers.

3.4.7 Implementation of 100% Hold Baggage Screening (HBS)

3.4.7.1 A recent decision of the European Civil Aviation Conference (ECAC) requires that 100% of all hold baggage at European airports should be subjected to screening by 31st December 2002. For most European airports this represents a major change: although a small number of airports, notably London Heathrow, currently operate 100% HBS, the survey conducted in WP 2 (reference B) implies that the norm for major European airports is currently around 25%.

3.4.7.2 European airports are therefore having to consider a range of options to increase their HBS capacity to cope with the increased workload that a move to 100% screening will impose. Seeking to model any of these options would be a major challenge in itself, especially in the light of the available data. Moreover, Paxport does not explicitly simulate the handling, sorting and screening of hold baggage. For these reasons, it was decided, for the purposes of this case study, to implement a spreadsheet based model which uses Paxport data on passenger flows to model the movement of baggage through the handling and screening systems.

3.4.7.3 This model, which is more fully documented in the report to WP 6, is necessarily simplistic but can be used to provide estimates of the likely impacts on baggage delays of changes in the proportion of baggage which is screened. It assumes that the capacity of an HBS system is characterised by its maximum throughput in bags/hour. The survey conducted in WP 2 found that, for instance, the system at FRA has a maximum throughput of 2400 bags/hour for the airport as a whole.

3.4.7.4 The model was therefore run with different parameter values with the aim of addressing the following questions:

- For a given value of maximum throughput, what is the profile of baggage delays against for different proportions of HBS? Figure 3-2 shows such a response curve for a throughput of 2400 bags/hour.

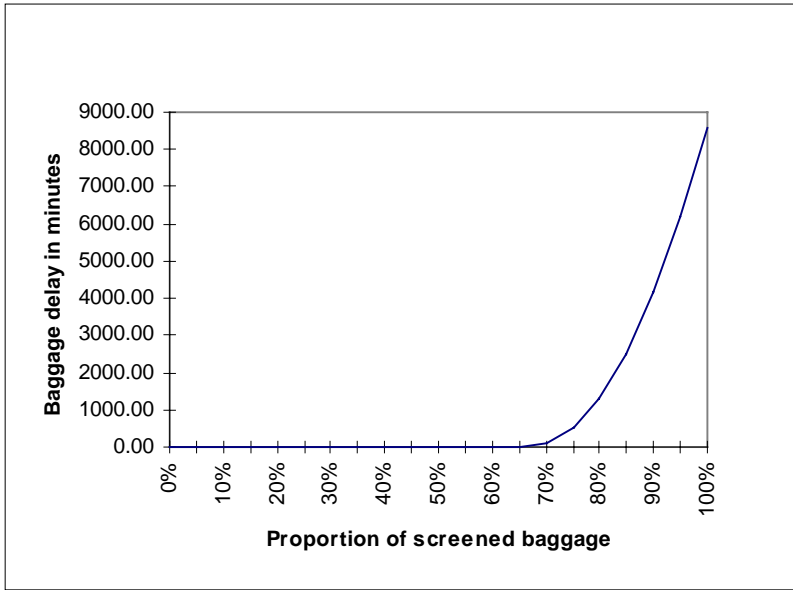


Figure 3-2 Baggage delays for HBS throughput of 2400 bags/hour

- For a given proportion of screened baggage (and especially for 100%) what is the minimum throughput value for which no baggage delays are incurred? This has been computed for proportions ranging from 0% to 100% and, as can be seen from Figure 3-3, varies almost exactly linearly.

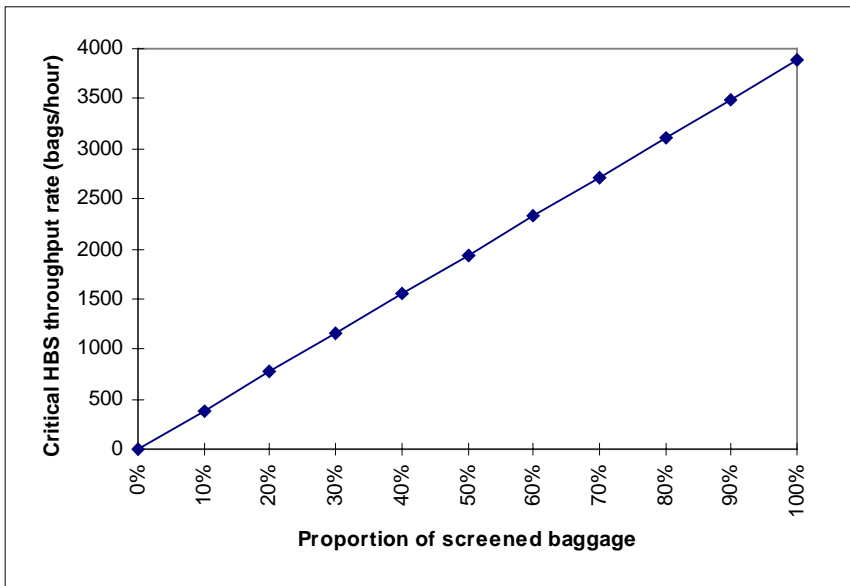


Figure 3-3 Critical HBS throughput rates for different screening proportions

3.4.7.5 Thus, on the basis of these results, the baseline airport would have to increase the capacity of its HBS systems fourfold in order to handle an increase in the proportion of HBS from 25% to 100% without incurring additional delays. This assumes that the screening takes place within the baggage handling system after bags have been checked in.

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4. WP 7 SD MODEL

4.1 Rationale

- 4.1.1 WP 7 involved applying a modelling technique known as System Dynamics (SD) to the development of a prototype integrated tool for modelling the airside and landside of an airport. This tool differs from established airside and landside simulation tools such as those used in WPs 5 and 6 in that it uses approximate mathematical formulae to compute aggregated or averaged values for the flows and levels of aircraft, passengers and baggage. It is designed to operate at a relatively coarse, or macroscopic, level of detail, with a much shorter run time and greater emphasis on ease of use.
- 4.1.2 It is envisaged that this tool, referred to in this report as the SD Model, could provide a useful adjunct to these more detailed simulation tools by allowing airport planners to conduct rapid preliminary investigations of scenarios before having to engage in costly and time consuming detailed simulation exercises.

4.2 Applying System Dynamics to Airport Modelling

- 4.2.1 SD is a technique for constructing a mathematical model of an evolving system. It provides a methodology for analysing a system in terms of a possibly large number of interrelated quantities of different types, which, put broadly, constitute the state and phase variables and control parameters of the system. The relationships between these variables are called influences and these can be represented graphically in an influence diagram. Everything on an influence diagram has a precise formal relationship with an element of the underlying model. The precise nature of the relationships between variables is expressed as a set of equations each of which expresses the value of a variable at each time step in terms of the values of those variables which influence it.
- 4.2.2 A fuller exposition of SD is given in reference H.
- 4.2.3 A model developed using SD will therefore consist of a system of coupled equations governing the evolution of a set of state variables in discrete time steps. Any SD Model of an airport will therefore differ fundamentally from a simulation tool in that it will not maintain an internal representation of individual passengers or vehicles. Instead, it will operate in terms of quantities which are attributes of the system as a whole. SD therefore lends itself best to developing models which operate at a sufficiently high level of detail to allow the relationships between aggregated quantities, such as the numbers of passengers at specified process points, to be dealt with in a consistent way.

- 4.2.4 This necessarily implies that the SD Model will produce results with a lower degree of accuracy than can potentially be obtained with more detailed tools such as TAAM and Airport Machine on the airside and Paxport on the landside. On the other hand, to realise the potential degree of accuracy offered by these tools requires a major and sustained effort of calibration and testing and, as we have seen, can be confounded by the unavailability of suitably detailed data sets. Because it operates to a greater degree of approximation *by design*, implementing a model using the SD tool should require correspondingly less effort.
- 4.2.5 To illustrate the consequences of this approach, we can take as an example the total runway delay, one of the output variables, which gives the sum total, in minutes, of the differences between the actual and scheduled take off times of all aircraft in the simulation. This value can be compared directly with the corresponding values generated by TAAM and Airport Machine for the purposes of validation. It would not be meaningful, however, to attempt to make the same comparison between delays for individual aircraft. To take another example, this time on the landside, while in Paxport, the tool used for the landside modelling in WPs 5 and 6, it is possible - at least in theory - to monitor the length of an individual queue at an individual passport control channel, the SD Model only gives the total number of passengers currently going through passport control for each pier.
- 4.2.6 It will be seen, therefore, that the SD Model exploits a trade off between the potential accuracy which can be achieved by a tool and the effort required to capture and enter data inputs.
- 4.2.7 The extent to which this approach can be successfully applied to modelling an airport depends on the feasibility of abstracting the behaviour of the system to a level which can be expressed in terms of averaged or aggregated quantities. This in turn seems to vary for different sub-systems of an airport. On the landside, it can be achieved by focusing attention on the allocation and performance of process points such as check-in, passport control etc. On the airside, the approach lends itself well to the modelling of runway capacity but is less well suited to the taxiway system.

4.3 Graphical User Interface (GUI)

- 4.3.1 The SD Model has been developed using a Windows based proprietary toolkit called Vensim® (see reference C). Models developed with Vensim® can be run either within the Vensim® application or from another application via an Application Programming Interface (API). The latter option has made possible the development of a Graphical User Interface (GUI) for the SD Model which greatly simplifies the processes of data entry and analysis.
- 4.3.2 The GUI has been written in C++ using the Microsoft Foundation Classes (MFC) application framework, and utilises the Document/View architecture which MFC supports. This makes it possible to store all the parameter settings for a given scenario in a single binary file.

4.3.3 By means of the Vensim® API, the GUI also enables the user to exploit the graphing and data analysis facilities provided by Vensim® for analysing model outputs. It also allows the user to export data to a spreadsheet application such as Excel for further analysis.

4.4 Validation

4.4.1 Validation tests of the SD Model have been performed by replicating the implementation of the WP 5 baseline model and the WP 6 case studies and comparing the results obtained. Additional validation tests were also conducted on a set of simplified scenarios which were also implemented in WP 6. Clearly the concerns over validation which came to light in WP 5 also impacted on this WP. Nevertheless, the validation tests described here made it possible to verify that the SD Model was able to produce similar results to the other tools when supplied with corresponding sets of input data.

4.4.2 For comparisons with the airside runs, the SD Model generated corresponding curves of total airside delay against number of movements. For the comparisons with Paxport profiles were generated of expected queuing times at the relevant process points and these were then compared using a statistical test, backed up by a qualitative analysis.

4.4.3 In both of the above cases, the coupling between the airside and the landside was temporarily removed for the purposes of the comparison and then re-introduced so that its effect could be identified.

4.4.4 The validation results are not reported here for reasons of space but they are documented in full in the WP 7 report (reference G).

4.4.5 In summary, the validation tests showed a generally good level of agreement, although this was not invariably so. Where discrepancies did arise, it was generally possible to identify their causes. On the landside in particular, these were related to two factors: the flow profiles of passengers entering the terminal building and the rules that determine the opening of check-in desks and process channels in response to variations in demand.

4.5 Resourcing Requirements - Data Capture

4.5.1 The SD Model requires 77 input parameters. A complete list of these is appended at Annex A to reference G. It is not possible to give a precise estimate of the effort which would be required to capture the data for these parameters, not least because airports vary widely in this respect. It is, however, possible to gain a general picture of the level of effort which would be required by grouping the input parameters into the following broad categories:

4.5.2 Airside:

- flight schedule with aircraft types, runway usage and stand allocation (to be precise, allocation to a pier)

- number of runways and how used
- rules for aircraft separations including runway interdependencies
- usage of runway exits and associated runway occupancy times
- mean times to taxi in and out for each runway

4.5.3 **Landside:**

- mean distances between process points
- numbers of process points
- mean process times at process points
- passenger type information e.g. walk speeds, number of bags per person
- mean passenger loads, including proportions of transfer passengers
- sequencing and location of process points for different classes of passengers/flights (e.g. Schengen/non-Schengen)

4.5.4 A number of these categories are covered by the responses to the Survey of Airports reported in reference B, implying that they can be relatively easily obtained by airport operations staff. In cases where a reliable value for a given parameter cannot be readily obtained, the ease of use and fast runtime of the SD Model should allow users to have recourse to parametric variation to gain an understanding of how the behaviour of the model varies for a range of values of that parameter. This will then enable them to proceed with taking into account the uncertainty in the relevant parameter value.

4.6 **Resourcing Requirements - Data Entry**

4.6.1 All of the inputs for the SD Model can be entered through the GUI and the largest and most complex of these, the flight schedule, can also be imported from a text file. Data entry is therefore a relatively straightforward process. The GUI includes help files which provide definitions and supporting documentation for each of the input parameters.

4.6.2 It is, of course, usual to have to go through several iterations of fine-tuning a model before one is fully satisfied with the results. This process is greatly facilitated by the fast run-time of the SD Model (about 25 minutes on a Pentium P-200 with 64 Mb of RAM), combined with the ease of data entry and of analysing the output parameters. Consequently, it is estimated that setting up a scenario with the SD Model once the necessary data has been captured should not take more than 1 day.

4.7 Conclusion

- 4.7.1 The validation tests, together with the analytical work underpinning its development, clearly indicate that, while the tool is not yet market ready, the concept underlying it is valid for most airport subsystems. In particular, the modelling of the runway system has been shown to be satisfactory. On the landside, the modelling of passenger flows through process points such as check-in, security and passport control has also proved successful, although subtleties remain in the algorithms which allocate open channels/desks, which might benefit from further investigation.
- 4.7.2 There are areas where the approach underpinning the SD Model is less applicable. This is particularly true of the taxiway system but it also applies to modelling the effects of the details of the terminal layout on the flow of passengers through the system. Future work on the SD Model is therefore expected to focus on refining the scope of the tool to concentrate on modelling those subsystems for which it is most applicable (which may, for instance, include the airside/landside interface).
- 4.7.3 In addition, the work has produced valuable research findings into the factors affecting the integration of airside and landside models in general.

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5. CONCLUSIONS AND RECOMMENDATIONS

5.1 Overview

5.1.1 OPTAS A has been a wide-ranging study which, within relatively tight budgetary constraints, has produced a number of successful results.

- **WP 2** has provided a large body of data relating to airside and landside operations at major European airports.
- **WP 3** has produced a comparative evaluation of a range of airside and landside simulation and modelling tools.
- The work conducted in **WPs 4, 5 and 6** has resulted in the implementation of a set of airside and landside scenarios, which have been used both to evaluate the potential capacity impacts of a range of initiatives likely to be introduced at European airports in the short to medium term, and to assess the performance and capabilities of the suite of airside and landside simulation tools used in their development.
- **WP 7** has produced a prototype modelling tool which has illustrated the feasibility of applying the techniques of System Dynamics (SD) to the integrated modelling of the airside and the landside at a high level of detail.

5.1.2 From the results of these activities and the technical challenges which they presented, a number of conclusions can be drawn, which are summarised below.

5.2 Airports Survey

5.2.1 A principal finding of WP 2 is that capacity problems, particularly on the airside, are widely recognised as presenting a serious and pressing challenge to European airports. Although there is considerable diversity both in the priorities being accorded to different aspects of the problem and in the technical solutions being considered, certain common themes can be clearly identified, in particular the urgent need to improve airside capacity and the need to address the issue of 100% HBS.

5.3 Definition and Validation of Simulation Scenarios

5.3.1 Some of the technical issues encountered in **WPs 3, 4, 5 and 6** indicate a degree of mismatch between the aims of the case studies (which were defined so as to be representative of the needs of the airport community, as ascertained in WP 2) and the capabilities of the available simulation tools. This mismatch arises, in particular, with respect to the levels of detail to which scenarios can be defined within the tools and the precise definition and interpretation of the output metrics which they generate.

- 5.3.2 This implies a need for a commonly agreed definition of the simulation requirements of the airport community both in terms of scope and level of detail. This could then be used to help scope future developments or enhancements of simulation toolsets.
- 5.3.3 A closely related issue is the need for suitably large and detailed datasets to be available for implementing and validating scenarios both on the airside and the landside. The content of these datasets would need to correspond in their scope and level of detail to the simulation requirements discussed above. They should also be large enough to ensure that the results of any simulation exercise can be shown to be statistically valid.
- 5.3.4 A good example which illustrates the interrelationship between these two points is the treatment of PRMs. For a simulation exercise to be able to contribute towards forming policy in this area, it would be necessary to determine which particular features of the terminal infrastructure (which may vary according to the particular initiative being evaluated) and which aspects of the behaviour and handling of PRMs themselves would need to be captured by the simulation tool. Once this set of requirements has been defined, it would effectively determine the scope of the data collection exercise needed to populate the datasets for initialising and validating the simulation. (It should be stressed that the case of PRMs has been used here for the purposes of illustration, but the point being made is a general one).

5.4 SD Model

- 5.4.1 The prototype modelling tool developed in WP 7 has made it possible to evaluate the feasibility of using System Dynamics to implement rapid-time, macroscopic models which integrate the airside and land side. It was found that the potential advantages offered by this approach include:
- ease of use,
 - fast run-time,
 - access to a wide range of output data, thereby providing many options for analysing the results of simulations,
 - a viable way forward for modelling the airside/landside interface.
- 5.4.2 The applicability of the modelling approach was found to vary considerably between different airport subsystems, and this necessarily affects the range and scope of scenarios for which tool would be most suitable. For those subsystems for which the approach is suitable, however, the model performed well. The SD Model therefore, while not yet market-ready, shows promise for future, carefully scoped, exploitation.

- 5.4.3 Such exploitation will have to be preceded, however, a lengthy period of evaluation and assessment to determine the most appropriate market for those aspects of the tool which perform most successfully. This in turn will enable the scope of future development to be more sharply focused towards producing a marketable product.