A proposal for improvement of mid-term capacity planning for gates and remote stand at Amsterdam Airport Schiphol (AAS)



Stefanie de Man Master Thesis Systems Engineering, Policy and Management November 2011

MASTER THESIS PROJECT

'A PROPOSAL FOR IMPROVEMENT OF MIDTERM CAPACITY PLANNING FOR GATES AND REMOTE STANDS AT AMSTERDAM AIRPORT SCHIPHOL'

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Preface

This research was executed as internship within Schiphol Group and as final assignment for the Master of Science program Systems Engineering, Policy and Management (SEPAM) at the Faculty of Technology, Policy and Management of Delft University of Technology. It was a challenging task within the dynamic aviation environment. With pleasure I joined the working environment and the learning experience.

During the last months I have been challenged in the professional and personal field. I would like to thank several people who have supported me during this time. First, I would like to thank Lotte Harbers and Maraat de Bruijn from the Schiphol Group for their supervising tasks. And Joyce Groot from the Schiphol Group and Marlies Wouters from Incontrol Simulation Software for helping me with the simulation activities. And Ronald Grosmann from National Aerospace Laboratory (NLR). Of course, I would like to thank my SIM roommates for our discussions about the projects, what to do after graduation and fun talk.

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Finally I would like to thank Paul Sonneveld and my parents Ton and Doreen de Man for their unlimited support.

I can describe the current balance between capacity and demand on aircraft stand area as critical and the operational ad hoc solutions are not sufficient for this critical balance. So, the planning activities and responses to potential imbalances should shift in time towards mid-term planning analysis. I hope the exploration and suggestions for improvements of the mid-term planning activities for the aircraft stand area described in this thesis are a step in the right direction to notify and manage imbalances between demand and capacity of gates and remote stands.

Rotterdam, November 2011

Stefanie de Man

Summary

Air transport plays a significant role in peoples life's all around the world, for business and leisure. Within Europe the number of commercial flights is up to 25 million in 2050 compared to 9.4 million in 2011 (European Commission Aviation Research, 2011). Amsterdam Airport Schiphol (AAS) is one of Europe's five major intercontinental airports. For the midterm traffic forecast the air traffic demand in terms of passengers at AAS is expected to grow to 56,300,000 passengers (pax) in 2016 for the medium scenario.

Problem exploration: Aircraft stand capacity planning at AAS

The objective of Schiphol Group – the exploiter of AAS – is to offer sufficient infrastructure for handling aircrafts, passengers and baggage for current and future demand. Airports are challenged to accommodate growth in the airport industry. To offer sufficient capacity for this growth, efficiency can be improved and/or airports can expand. AAS needs to manage the capacity in such a way that the capacity imbalances are notified in the earliest stage possible. This project will focus on the capacity of the aircraft connected stands and remote stands. At this moment imbalances are detected at aircraft stand area. Currently operation airside management is solving those imbalances ad hoc in daily operation. However, the 'sense of urgency' for notifying at an early stage and managing the imbalances grows due to the higher occupation rate of the stands. Currently demand is growing and the number of stands doesn't/cannot grow in order to accommodate this demand.

This research is focused on midterm basis and there are several important moments in time when the initiator of this project (department Airside Operations (AO)) wants to perform planning activities in order to analyze the demand and supply balance. First, every year Schiphol Group is developing the integrated development plan for the coming 5 years. For this plan AO needs to deliver output of demand-supply analyses on a 5-yearly level. Furthermore, department AO is responsible for performing analyses on the demand-supply balance of aircraft stands for various questions from different organizational levels and departments.

Currently, for the analyses of the demand-capacity balance a static analysis in an Excel spreadsheet is done by calculating the maximum number of stands needed from a forecasted flight schedule and this is compared to the available gates and remote stands. However, capacity is not only determined by the number of stands available but other aspects are of influence on capacity as well and should be taken into account when analyzing the balance between supply and demand. The planning activities (tool, organizational procedures and cooperation between internal stakeholders) on midterm level of the gates and remote stands should be improved in order to notify imbalances in the earliest stage possible.

Initial project assignment and research objective

The opinion of AAS is that the current method of capacity planning can be improved. Therefore, the department Airside Operations (AO) initiated this project with the following project assignment: there is a need for impact analysis on gate and remote stand capacity considering several changes, such as fleet changes in the flight schedule. In the project assignment the proposal was made to develop a tool in which parameters - which determine the gate and remote stand capacity - can change and in which supply and demand characteristics can be changed in order to run scenarios. In

the assignment it is also described that the impact analyses will be used for investment decisions and therefore a visualization of the planning is wanted.

The main research objective and sub objectives are defined as follows:

Main research objective: "Analyze aircraft stand capacity planning on midterm level at Amsterdam Airport Schiphol in order to suggest improvements for better performing capacity planning and supporting decision making on aircraft stand area."

Sub-design objective (1): "Re-design computational tools in such a way that the tool is a support for decision making on aircraft stand area."

Sub-design objective (2): "Propose a decision support environment and embed this in the current organizational working processes at Amsterdam Airport Schiphol."

Research Approach

Planning of resources has several aspects and therefore the analyses of current aircraft stand capacity planning at AAS is explored by assessing several aspects. First the dynamics of the flight-togate assignment system is outlined by describing the variables which determine the overall capacity, this is done by interviews, desk research and field trips. Furthermore the methods, heuristics and algorithms for the flight-to-gate assignment problem described in literature are outlined and those methods are compared to commercial tools available. The current situation of the decision making cycle from forecasted flight schedule towards investment decisions is analyzed, hereby the organizational procedures, tools and position and cooperation of/between internal stakeholders are taken into account. For those three elements (suggestions for) improvements are made in order to perform capacity planning activities with a valid and more realistic view on the aircraft stand area system. Currently AAS is using an Excel spreadsheet in order to calculate the maximum demand according to a flight schedule after which this number is compared to the available gates and remote stands. In this research an already existing Enterprise Dynamics planning tool is reintroduced to replace this Excel spreadsheet, furthermore improvements are made on this planning tool and suggestions are done to further improve the planning tool. Those improvements and suggestions for improvements are derived from user requirement sessions, expert sessions and information from literature review and the analysis phase. The second and third elements which are analyzed are the organizational procedures of the planning activities and cooperation between internal stakeholders. Those procedures and cooperation are described after several interviews and discussions with AAS employees and suggestions for improvements are made in order to incorporate the tool and avoid current occurring problems and miscommunication. The research is divided in three phases; the analysis phase, design phase and the implementation phase. The thesis ends with conclusions and recommendations.

Analysis Phase

In the analysis phase the context of the problem and situation is explored.

Aircraft stand supply versus air traffic demand (im)balance

The aim of capacity management is to reach a balance between the amount and size of aircraft stands (supply) and current and future air traffic demand. This balance must be reached without overruns in costs and/or neglected service levels to the customer. There are serious consequences of

getting the balance between demand and capacity wrong. If an operation has too much capacity the costs are spread over few customers, however if an operation has too little capacity its costs will be low but service to customers will be of lower quality, operation needs to turn down customers or they have to wait.

Physical infrastructure of and demand for gates and remote stands

According to (Janic, 2000) the capacity of any airport component – and thus also for gates and remote stands – can be expressed by four different measures that represent capacity attributes: the physical infrastructure, fluctuations of demand over time, profiles of user entities, and the quality of service provision. The **physical infrastructure** is the supply of aircraft stands at AAS. Total dynamic capacity of stands at AAS is determined by:

- the number of stands;
- the type of aircraft each stand can accept;
- mix of aircraft types that uses the airport;
- minimum handling time;
- governmental rules;
- preferences of airlines.

The **demand** for aircraft stands is determined by the number of flights – number of flights is determined by the air traffic demand – and fleet characteristics, the peak patterns and runway capacity.

Preference of airlines: quality of service

The assignment of an aircraft to an aircraft stand is done based on the directive Regulation Aircraft Stand Allocation Schiphol (RASAS), preferences of airlines and other parties and according to the knowledge and experience of the operational gate planner. In RASAS the **quality of service provisions** (preferences to be taken into account of airlines for the assignment of their aircrafts) are described. At AAS there is no specific norm about the service level for assigning an aircraft to a gate.

Planning horizon versus detail of information

Department Aviation, Statistics and Forecast (ASF) generates every year a forecasted flight schedule for in 5 years for a high, medium and low scenario. Almost every midterm or strategic decision taken stems ultimately from a forecast. At the same time, forecasting is the area in which inaccuracies are most frequently made and the one about which is least certainty. Yet forecasts have to be made since so many decisions flow from them (Doganis, 2010). For longer planning horizons it is harder to gather specific details on demand and flight characteristics. Airlines do design their flight schedules based on demand factors such as oil prices, technological development, economy, etcetera. Subsequently airlines need to request for landing or take off slots for AAS. The final detailed flight schedules (with allocated slots) are available on April for next Winter season and on September for next Summer season¹. A strong relation exists between the midterm and operational planning. But during the day of operation the level of detail of information is far larger than during midterm planning. Fluctuations of demand due to forecast inaccuracy or due to the dynamics of arrival and departure times should be taken into account when planning on the longer horizon. The detail of information versus the planning horizon is visualized in figure Summary-I. For capacity planning it will be of relevance to perform sensitivity and what-if analyses to get insight in the system interdependencies.

¹ Winter season starts at the end of October until mid April, Summer season is from mid April till end of October.



Figure Summary-I: The longer the planning horizon the less detailed and certain information

Current use of tools for planning activities on midterm level

In figure Summary-I the tools for planning activities currently available at AAS are described. Currently AAS is analyzing the balance between supply and demand for aircraft stands by using an Excel spreadsheet as described in the first sections of this summary. For performing analyses on the demand-supply balance of aircraft stands in 2006 an allocation tool is developed in Enterprise Dynamics in cooperation with the company Incontrol – the Gate Capacity Manager (GCM). This GCM tool allocates a flight schedule rule-based. The tool uses *if...then* rules in order to determine the most wanted stand for a particular flight. The GCM tool is currently not in use by department AO.

Stakeholders involved in planning the assignment of aircrafts to stands

In the assignment of aircraft to gates three most important groups can be indicated as stakeholder; AAS, Airlines and Handling Agents. Important conclusions drawn from the stakeholder analysis:

- AAS wants to accommodate growth now and in the future to enhance the competitive position as Europe's preferred airport.
- The airport is responsible for the planning of aircraft stands, assigning an aircraft to an aircraft stand. This task has to be done within several constraints such as border status, security rules and physical limitations.
- AAS wants to deliver a high service level to its customers the airlines.
- Airlines want a punctual service, convenience for their passengers and lower and competitive visit costs. In relation to the planning of aircraft stands airlines would like to see that their preferences are taken into account when planning.

Stakeholder engagement

For the success of the implementation of improvements for mid-term capacity planning (tool and organizational issues) internal stakeholder engagement is necessary. For this purpose the power and interests for the project of different departments within Schiphol Group are analyzed by using the power versus interest grid as shown in figure summary-II. It can be concluded that engagement of the following groups is needed:

- the management team Aviation (MT-A);
- department Capacity Management (CAP);
- management of department Airside Operations Process Management Airside (AO-PMA);
- and Aviation, Statistics and Forecast (ASF) department.

Several engagement tactics are known and described in the right diagram in figure summary-II. Department AO – PMA is responsible for providing reliable analyses on the demand and supply balance at the midterm planning horizon (1-5 yr). CAP needs to provide timely sufficient, reliable and sustainable capacity for AAS its airlines and passengers (5-10 yr). MT-A is responsible for taking decisions on infrastructural or procedural changes on aircraft stand area.



Figure Summary-II: The power versus interest grid and the tactics for engagement of stakeholders

The decision making cycle for the development plan period

Department AO needs a tool in order to perform demand-supply balance analyses on the aircraft stand area. The tool can be used for performing analyses for the development period, however it must be flexible in such a way that the tool is also useful for various other questions concerning the aircraft stand area. Because those various questions come from different organizational levels and departments it is hard to analyze the activities from original question to final decision making. However, the decision making cycle for the development plan can be analyzed more accurately due to the more structured procedures and yearly return of the integrated plan. Therefore, the activities towards final decision making are analyzed for this yearly development plan. For gate and remote stand decision making it starts with the forecasted flight schedule from ASF, subsequent AO-PMA performs the capacity analysis of gates and remote stands in the Excel spreadsheet, CAP integrates all processes in the yearly development and investment plan and finally MT-A decides on investment decisions. The shortcomings in this cycle are:

- decisions are based on assumptions made to develop the flight schedule and those assumptions are not taken into account in the output of the analyses;
- the dynamics of the flight-to-gate assignment system is not taken into account;
- there is a lack of standardized measures of performance indicators;
- and there is no optimal cooperation between the departments.

KPI's aircraft stand area

To assess the performance of the aircraft stand area measurable variables are needed. To measure capacity shortage the total number of aircraft for which no connected stand is available at the scheduled in-block time (SIBT) should be evaluated during the stand allocation process in planning phase. The following aircraft stand KPIs were defined:

- the total number of aircraft for which no connected stand is available at the (SIBT) -MINIMIZE
- the total number of towing movements MINIMIZE
- the total number and characteristics of stands needed to be built in order to offer service level X MINIMIZE INFRASTRUCTURAL COSTS, MAXIMIZE SERVICE LEVEL
- the stand occupation in % per category per 5 minutes MAXIMIZE
- assigned flight-gate preferences in % taken into account during planning

Service level and capacity level are in contradiction with each other because preferences of stakeholders often decrease capacity. Furthermore key areas are costs and benefits, delays and robustness. Delays have a major impact on the utilization rate of the gates and remote stands. Airport planning department would like to see robustness in gate planning in order to limit the amount of gate changes during the day of operation. By implementing a buffer time it is tried to increase the robustness of the planning.

Characteristics of the flight-to-gate assignment problem

Analytical models are capable of doing macroscopic aggregated analyses to support decision making at strategic level and simulation models are able to support decision making at tactical/midterm level with more detailed and microscopic description of the process. The tool needed for planning activities on midterm level for the aircraft stand area at AAS needs a microscopic character due to the scenarios which are wanted to run with the tool and the indicators.

The characteristics of the flight-to-gate assignment problem can be described as multiple criteria, multiple constraints, multiple objectives and conflicting objectives. In fact, the multiple criteria and multiple constraints nature of the problem make it very unlikely that an optimal solution can be found and verified. As the gate assignment is a type of job-shop scheduling problem, its complexity increases exponentially if constraint size such as number of flights, available gates, aircrafts, flight block time etcetera changes which is a very realistic assumption in airport operation. The NP-hard characteristic of the problem implies that there is no known algorithm for finding the optimal solution within a polynomial-bounded amount of time. In literature the gate assignment problem is solved using several methods to develop a solution algorithm, e.g. branch and bound techniques, column generation algorithm, meta-heuristics like Pareto Simulated Annealing and Genetic Local Search. While traditional operations research techniques have difficulty with uncertain information and multiple performance criteria and do not adapt well to the needs of operation support, many researchers focus on the design of the so-called rule-based expert systems (Dorndorf, Drexl, Nikulin, & Pesch, 2007). The rule based technique uses a set of rules and the production rule (IF <condition> THEN <conclusion>) to produce assignments of flights to gates/buffers. To find a near-optimal solution heuristics scheduling methods can be chosen to satisfy constraints.

The airports researched in the benchmark and the described software tools use the rule-based technique with heuristics scheduling methods to satisfy constraints. AAS is also focusing on the rule-based approach on operational level, the new purchased software tool (Inform Groundstar) for their operational planning (which also embeds a strategic planning module) uses the rule-based approach as well. For this project no argumentation can be found to use the solution methods researched in literature because it is not proved that those solution methods can tackle the dynamics and the nature of the problem in the real-life situation at AAS and commercial tools do not incorporate the latest developments in algorithms and solution methods. Therefore the rule based technique and a heuristic for finding the best stand is chosen to tackle the problem.

Design Phase

In the design phase the user requirements and design criteria for the decision support tool are described. Furthermore the functionalities, process of requirement and drawbacks of the original GCM tool version 1.0 (developed in 2006) are described. Implemented improvements during this project from version 1.0 towards GCM version 1.1 are described and suggested improvements towards GCM version 2.0 are outlined.

User requirements and design criteria for the decision support tool

The user requirements are categorized in categories: usage of the tool, functionality and performance and output. The decision support tool needs certain functionalities to perform elaborated analysis and to fit in the problem environment. A flight schedule is the demand input for the model. The supply component of the model must be formed by databases with stand characteristics and policy rules. It is recommended to implement in the sourcing module of the tool an option for a level of uncertainty on the input data to run scenarios. The initial values do have an expected variance and when this variance can be quantified this must be incorporated in the simulation. Furthermore it is recommended to have a cost and benefit module in the tool which evaluates the total costs for implementing a particular service level.

The Gate Capacity Manager (GCM) tool

The GCM tool version 1.0 is developed in 2006 in Enterprise Dynamics (ED) (currently not in use by AAS employees) and exists of a priority heuristic, parameters, databases as input and assigns flights to gates based on required, preference and avoidance rules. For this research the code and heuristics of the already existing *GCM tool first version* and the steps that need to be taken to perform a planning are analyzed.

- The preference and avoidance rules have a score, with those scores the end score of a stand is calculated and thereby the allocation of a flight to a stand is determined.
- The Enterprise Dynamic module (GCM tool) embodies the heuristic and parameters, however the databases are imported from Microsoft Access databases and the visits² are generated in Microsoft Excel.
- The Input_Rules database is an important database, with the data stored in this database the user decides on which requirements and preferences or avoidances will be taken into account for the planning.
- In the heuristic of the ED GCM tool the aircrafts in the largest category are planned first.

² For the planning of gates and remote stands it is needed to know the visits, so the coupled arrival and departure flights on one aircraft.

- 1. The planning starts with the midterm forecasted flight schedule forecast in Excel.
- 2. With the help of macros in Excel visits are generated with the flight schedule as input data.
- 3. This generated visit and flight lists must be pasted in the Access databases. For running a simulation in the GCM tool more databases are required. Other databases in Microsoft Access are required to 'feed' the data needed to run a simulation and are called feeding databases.
- 4. The databases from Access can be imported in the ED GCM tool.
- 5. The model must be built and parameters must be chosen for several constants in ED GCM tool.
- 6. The output can be exported to Excel or shown in a Gantt chart.

The program of requirement of 2006 – for the development of GCM 1.0 – are similar to the requirements described by the problem owner of this project. A drawback of the design and validation process in 2006 is that only one person at AAS participated in the design and validation of the tool.

Implemented improvements on the original GCM tool version 1.0: towards GCM version 1.1

During this research updates and improvements are made to the Excel visitgenerator, Access databases and output evaluation, this has lead to GCM version 1.1. The original Excel spreadsheet from 2006 is improved in such a way that it is more user-friendly and faster to generate visits. The databases in Access are updated according to the current status of the infrastructure and updates are done on the 'feeding-databases', such as new airline codes and aircraft types. Furthermore the visualization in ED improved. The ED code is not changed. Furthermore a user manual is written for GCM version 1.1. The improvements made during this research – from version 1.0 towards version 1.1 – solved some problems, however generating a planning with the GCM 1.1 tool is still complex. Therefore suggestions are made to improve the version 1.1.

Suggested improvements on the GCM version 1.1: towards GCM version 2.0

The suggestions for improvements for GCM version 2.0 are categorized according to category +++, ++, +. Improvements categorized in category +++ are most needed in order to maximize the acceptance of the new users at AO. Category ++ are improvements that will add functionalities to the current tool. And category + improvements are 'nice to have' improvements. Category +++: Planning a scenario in GCM 1.1 is complex and time consuming, therefore the suggestion to create userfriendly GUIs in the form of a wizard is done. A wizard will guide the user from input data towards output analyses. The user does not have to open three different programs (Excel, Access, ED), but will open one program and will be guided by the user-friendly wizard. An integrated solution whereby input databases, modeling and output evaluation is integrated in one wizard. The wizard will also include a feedback mechanism which will directly generate feedback when the input is not according to specified requirements and a performance evaluation screen. Category ++ suggestions contains the following suggestions: functionality of the tool should be expanded with the dynamic aspect of variability in arrival and departure times. Enterprise Dynamics is a platform which is meant as simulation platform which can work with stochastic values like variability in arrival and departure times.

Implementation phase: organizational procedures and internal stakeholders

The demand for gate and remote stands depends on a number of factors with complex interdependencies and human interaction. To improve the current situation a proposal is made to re-

implement the ED GCM tool. However, as indicated in the analysis phase not only the lack of a tool which fits the system complexity was missing but also the organizational framework in which the tool must perform. The well known decision making process steps³ are not followed.

Suggested improvements on the decision making cycle To improve the decision making cycle it is recommended to:

- intensify the cooperation between department ASF and department AO-PMA. ASF creates
 the forecasted flight schedules with assumptions and AO-PMA draws conclusions on capacity
 (im)balances. AO-PMA and ASF must discuss the variance of the input and assumptions
 made. In such a way conclusions based on input data with high assumptions are avoided.
- Evaluating different alternatives is suggested: create scenarios for input parameters such as airside lay-out, rule setting (service level), governmental regulations, towing procedures, fleet characteristics, peak pattern and arrival and departure variances. Run a baseline scenario and the generated scenarios in the GCM V1.1 or after improvements are implemented the V2.0. Monitor and analyse the output on the defined with all internal and external stakeholders indicators and review the output on costs and benefits.
- It is suggested to organize expert sessions with experts from different organisational levels to discuss the different alternatives and let soft and hard information come together.

How to engage the internal stakeholders?

It is important to engage all important identified internal stakeholders to the project of improving the midterm capacity planning. Identified stakeholders of relevance are AO-PMA (problem owner and management), MT-A, CAP and ASF. The key to generate interest for this project is clarity about what the project is designed to achieve and the advantages of the project in relation to current capacity analysis. The aim of the implementation project is defined during this research, this definition can be used to engage stakeholders.

The project needs budget for improvements for the support tool, support for organizational changes in the decision making cycle and support for changing the current capacity planning. For those needs engagement is needed and suggestions are done to engage the stakeholders. Proposed engagement tactics are engage AO-PMA manager 1:1, engage CAP and MT-A in a group session and start cooperating and creating a plan with ASF on an informal basis.

A demo of the GCM tool V1.1 – as currently available – is given to Joyce Groot (employee of CAP-ADI) and Jan van Rooijen (AO-PMA employee). During this demo experiments were shown and an experiment is simulated by using the user manual written for the GCM V1.1. Both parties were enthusiastic and noticed the added value compared to the current analysis in the Excel spreadsheet. Concerning the improvements for the cooperation and decision making, management of OPS is responsible for taking initiative in this matter. Currently the expectations for cooperation in terms of discussing the forecasted flight schedule as input and starting point for the decision making cycle seems to be different from each other. ASF does expect that AO-PMA will intensify the cooperation after capacity analyses with the flight schedule on the aircraft stand area are done. To align the

³ (1) recognizing a decision situation, (2) identifying appropriate alternatives, (3) choosing and justifying the best alternatives according to indicators and (4) implement the chosen alternative.

expectations it is suggested to organize a brainstorm session with several employees from OPS and from ASF.

Conclusions & Recommendations

The current situation and (suggested) improvements can be visualized and described according to figure summary-III. At the left box the current situation is visualized according to the decision making cycle, the red circles are the problem areas which are described in the text box below. In the right box the (suggested) improvements are indicated at the cycle, the orange circles are suggested improvements and the green circles are improvements implemented during this research.

The problems at the current situation are:

(1) the dynamics of the flight-to-gate assignment system are not taken into account when notifying imbalances on aircraft stand area;

(2) imbalances are notified merely based on expert judgement of the AO-PMA employee.

With a forecasted flight schedule as input (based on a 5 minutes schedule) an Excel spreadsheet is created and at the day of analysis on the morning peak the number of demand for gates per category is calculated. Subsequently this amount of gates per category is compared to the supply of gates per category. With common sense and expert judgment of the capacity planner the demand and supply balance is analyzed concerning the loose of capacity due to allocation rules and the winning capacity due to planned upgrades of infrastructure. The complex allocation rules and need for flexibility in order to run scenarios need to be incorporated in a rule based support tool.

(3) decision making process steps are not followed when looking for alternatives to solve imbalances; The decision making process consists of the following steps:

- recognizing a decision situation,
- followed by identifying appropriate alternatives,
- choosing and justifying the best alternatives according to indicators and
- implement the chosen alternative.

Currently the steps are not followed when making decisions on infrastructural or procedural changes on the aircraft stand area.

(4) there is a lack of standardized measures of performance indicators;

(5) forecast uncertainties and forecast failures are not taken into account elaborated when planning on the midterm level;

(6) and there is no optimal cooperation between the departments.

As a result investment decisions for procedural and infrastracture changes are made based on weak analyses on the imbalances of the aircraft stand area and potential solutions. To generate insight into the system and its interdependencies and to support decision makers it is recommended to integrate a support tool in the midterm planning horizon. There are improvements made to the already existing support tool GCM 1.0 which created GCM 1.1. Currently the GCM tool version 1.1 is able to

perform 'what-if' analyses, however the tool need further updates and improvements. It is suggested to improve the GCM V1.1 into V2.0 by incorporating (in a user-friendly wizard GUI):

- a module for capacity input: in this module the user can change the physical lay-out of airside, characteristics of gates, production rule set;
- a module for demand input: in this module the user can change the initial forecasted flight schedule. Changing the fleet characteristics, adding distribution on arrival and departure times and changing the peak structure;
- a module for evaluation output on performance criteria.

Next to recommendations for the support tool it is necessary to change the decision making procedure. Those suggestions are described in the text box below the right cycle.



Figure Summary-III: Current and improved situation notifying and managing imbalances aircraft stand area

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1. Introduction

Air transport is one of the most dynamic industries in the world. The air transport industry must continue to modernize its infrastructure to avoid capacity constraints, improve airspace efficiency and minimise costs in order to meet airline requirements for safety, efficiency and functionality (www1). Air transport plays a significant role in peoples life's all around the world, for business and leisure. External factors do influence the performance of the industry, the industry must perform agile to constant shocks like volcanoes and earthquakes, terrorism, pandemics, price of oil, institutional development, environmental regulations, etcetera. Furthermore, as (Wijnen, Walker, & Kwakkel, 2008) describe the industry is also stimulated by internal forces such as new alliances between airlines, low cost carriers and aviation technology. Those rapid changes and uncertainties create a challenge for airports to make investment decisions that will shape the future of the airport for many years to come.

Europe's airports, representing over 400 airports in 46 European countries, welcoming nearly 1.5 billion passengers and over 17 million tons of freight each year (www2). Within Europe the number of commercial flights is up to 25 million in 2050 compared to 9.4 million in 2011 (European Commission Aviation Research, 2011).

Airport Council Internationals 2010 full-year passenger and cargo figures shows the following ranking for European airports (ACI - World Airport Ranking 2010, March 2011):

Rank	Airport	Total Passengers
1	London Heathrow Airport	65,884,143
2	Paris Charles de Gaulle Airport	58,167,062
3	Frankfurt Airport	53,009,221
4	Madrid-Barajas Airport	49,786,202
5	Amsterdam Airport Schiphol	45,211,749

Rank	Airport	Tons of freight
1	Paris Charles de Gaulle Airport	2,399,067
2	Frankfurt Airport	2,275,106
3	London Heathrow Airport	1,551,405
4	Amsterdam Airport Schiphol	1,538,135

Table 1 Top 5 European Airports 2010 – Passenger Volume and Top 4 European Airport 2010 – Freight Volume

The mainport – major intercontinental airport – position of Amsterdam Airport Schiphol (AAS) is competed by other airports and it cannot be taken for granted that AAS will keep the top 5 position. AAS aim is to position the airport as Europe's Preferred Airport (Schiphol Development Plan 2012-2016, April 2011). For the medium-term traffic forecast the air traffic demand in terms of passengers at AAS is expected to be over 56 million passengers (pax) in 2016 for the medium scenario. The expected demand is outlined in figure 1. The scenarios are based on the following key drivers: economic development, emission trading scheme, oil price developments, market share of AAS in catchment area and market share in the transfer market (Schiphol Development Plan 2012-2016, April 2011). Due to the increase in expected passenger demand the number of aircraft movements is also increasing to a total of more than 480.000 expected aircraft movements in 2016, see figure 2.

One of the factors which determine the position of AAS is the possibility to grow. Airports are challenged to accommodate growth in the airport industry. To offer sufficient capacity for this growth, efficiency can be improved and/or airports can expand. Nevertheless to meet the needs of growing demand, capacity is needed on environment level (social, climate) and in terms of physical capacity. Europe is a region which faces considerable constraints on airport expansion, and thus the issues of allocation of scarce capacity are particularly relevant (Forsyth, 2007).



Figure 1 Market Development Pax 2010-2016 (Schiphol Development Plan 2012-2016, April 2011)





As said it is needed to offer sufficient capacity for the expected growth, in terms of increasing the efficiency and/or expanding the airport. Airport decision makers are frequently facing complex decision-making problems related to airport planning, design and operations. The airport decision-making process is further perplexed by the large number of stakeholders having different, and sometimes conflicting, objectives regarding the assessment of airport performance (Zografos & Madas, 2006). The objective of Schiphol Group – the exploiter of AAS – is to offer infrastructure for handling aircrafts, passengers and baggage. Having more demand than possible at the current

infrastructure could jeopardize the objective of Schiphol Group. Difficulty with airport infrastructure is that the infrastructure is not being able to react agile on increases or decreases in demand and due to the number of external forces and the unpredictable nature of the aviation industry it is very hard to forecast demand in detail. To assist in this decision making process computational tools can help in analyzing the impact of a particular demand or changes in supply characteristics on capacity.

Before clarifying the problem situation particular terms must be explained. The area where aircrafts park to (un)load passengers, baggage and execute several technical activities is defined as an aircraft stand. An aircraft stand can be connected to the terminal by bridges – from now on a gate – or an aircraft can be handled not connected to the terminal – from now on remote stand – the latter needs other resources such as a bus to transport passengers from the remote stand to the terminal.

At this moment imbalances between supply of and demand for gates/remote stands are detected at aircraft stand area. A mismatch between the supply – stands – and demand – flights – whereby the demand is larger than the supply can be defined as bottleneck or imbalance. Currently operation airside management is solving those bottlenecks ad hoc in daily operation. However, the 'sense of urgency' for notifying and managing the imbalances grows due to the higher occupation rate of the stands. Currently demand is growing and the number of stands doesn't/cannot grow in order to accommodate this demand.

In airport operations there are usually two interdependent stages in the gate assignment process: the planning and the real-time stages. This project will focus on the planning stage. At AAS planning is done on daily operation, one-day-ahead, seasonal and midterm basis. This project is focused on midterm basis and there are several important moments in time when the initiator of this project (department Airside Operations (AO)) wants to perform planning activities in order to analyze the demand-supply balance. First, every year Schiphol Group is developing the integrated development plan for the coming 5 years for AAS. For this plan AO needs to deliver output of demand-supply analyses on a 5-yearly level. Furthermore, department AO is responsible for performing analyses on the demand-supply balance of aircraft stands for various questions from different organizational levels and departments. An example is the question if the upgrade of several stands in terms of category⁴ will be a solution for accommodating the demand of next year.

For the development plan period of 5 years executed by Schiphol Group for AAS (midterm planning, tactical planning) a static analysis is done by calculating the maximum number of gates needed for a busy week in the Summer of the forecasted flight schedule. The calculation is done for the different categories of gates. Those amounts are compared to the supply of different categories gates at that time of analysis and when the demand will exceed the supply of that category gate it is said to be a bottleneck. The opinion of AAS is that current method of capacity planning can be improved. Capacity is not only determined by the number of stands available but other aspects are of influence on capacity. There is a need from the department 'Airside Operations' to have a tool in which the flight-to-gate planning is done to answer capacity cases, to perform 'what-if' studies and support decisions for tactical airport planning. The tool will not be a day-to-day gate planning tool, but is used for analysis of current and future gate capacity.

 $^{^{4}}$ The wingspan of aircrafts are categorized in categories (CAT 1 – 9). The biggest categories are the so called widebody (WIBO) aircrafts (>CAT 5), the smaller ones are the narrowbody (NABO) aircrafts (CAT 1-4). The aircraft stands at airside are also categorized according to the wingspan of the aircrafts, NABO has a maximum wingspan of 36 meters and WIBO from 37-65 meters (A380 – CAT 9 –wingspan 80m).

The desired tool must be a tool that can be used to support decision making and can analyze the capacity and demand relation, though the tool also needs to be flexible in such a way that changing the parameters which determine the capacity of the supply and demand figures is possible. The current infrastructure is in a certain way capable to deal with larger aircrafts and larger passenger numbers, however the question is if this handling is sufficient enough in terms of passenger perception and quality level. So, in addition decisions should be made about which service quality is acceptable.

1.1 SESAR and CDM projects

The threat exists that an airport will act as a bottleneck for the aviation system because an airport cannot accommodate the growing demand of the aviation sector. Therefore, the European Community took action in order to improve efficiency and safeguard fluidity and safety and started the SESAR (Single European Sky ATM Research) Joint Undertaking in February 2007. The mission of the SESAR JU is to develop a modernized air traffic management system for Europe. This system will ensure the safety and fluidity of air transport over the next thirty years, will make flying more environmental friendly and reduce costs of air traffic management (www4).

Efficient use of the European airspace needs to be a common goal and EUROCONTROL (the European organization for air traffic) introduced under the SESAR program the Collaborative Decision Making (CDM) way of working. EUROCONTROL has the opinion that airspace can only be efficiently prevailed with integral efficiency on the ground (Schiphol Development Plan 2012-2016, April 2011). The idea behind CDM is to make all actors to share their information about the flights and other airport activities with each other. If this is done, it will enable better planning which in turn, can make the utilization of the resources more effective. After the 1st of January 2012 AAS would like to see that information of arriving flights is coupled with information of departing flights. The predictability of the following handling processes of arrival flights will increase when sharing operational information, with this more accurate information resources and infrastructure can be more efficiently used (Schiphol Development Plan 2012-2016, April 2011).

CDM will finally deliver more accurate information in daily operations. However this more accurate information has also influences on the tactical planning horizon. It is possible that in the tactical planning – with the forecasted flight schedule – a flight cannot be assigned to a gate based on the scheduled time but in daily operation with the accurate real-time CDM-information the gate and remote stand resources can be used more effectively and the flight can be assigned to a gate. This relation between operational planning and tactical planning should be taken into account when making decisions on the output of the tactical planning.

1.2 Company Profile

Schiphol Group is the initiator of this project. AAS is the largest airport in the Netherlands, serving as an international hub and as the home base for Air France-KLM. AAS is exploited by Schiphol Group. The operations of AAS involve three linked business areas: Aviation, Consumers and Real-Estate. This project will be done at the business area Aviation. Aviation provides services and facilities to airlines, passengers and handling agents (www3). In Appendix I part of the organizational diagram of the area Aviation is shown. The highlighted yellow part is the unit, division and department who initiated the project.

The mission of AAS is to connect the Netherlands with the rest of the world and their vision on the future is to position AAS as Europe's Preferred Airport. The strategy is based on the interaction between the social function of AAS and the entrepreneurial conduct of business. The business strategy to realize the mission and vision is based on creating Airport Cities (Schiphol Development Plan 2012-2016, April 2011). An Airport City is a dynamic hub integrating people and business, logistics and shops, information and entertainment.

The project is organized from the innovative mainport alliance 'Samenwerking Innovatiemainport' (SIM). SIM is an alliance between aviation related parties, including Schiphol Group, Koninklijke Luchtvaart Maatschappij (KLM), National Aerospace Laboratory (NLR), Delft University of Technology and a Dutch



knowledge institute for applied research (TNO). SIM has as main purpose to position AAS as innovative European airport. NLR will contribute to this project in an advisory role. The division 'Air Traffic' has a department 'Air Traffic Control & Airport (ATAP)' which focuses on modeling airport operations.

1.3 Research objective, scope and questions

In this section the research objective, scope and questions are outlined. These questions were the guidance through this research and will be answered at the end of this thesis.

As described in the introduction the 'sense of urgency' for notifying and managing the imbalances on the aircraft stand area grows due to the higher occupation rate of the stands. Currently demand is growing and the number of stands doesn't/cannot grow in order to accommodate this demand. To analyze the interdependencies in the system of assigning aircrafts to gates and to test various solution alternatives there is a need for a tool to perform 'what-if' studies and support investment decisions. The problem is that AAS has difficulty with notifying the imbalances on the aircraft stand area.

1.3.1 Research Objective

The research objective can be formulated as follows:

Research objective:

Analyze aircraft stand capacity planning on midterm level at Amsterdam Airport Schiphol in order to suggest improvements for better performing capacity planning and supporting decision making on aircraft stand area.

Sub-design objectives:

- *Re-design computational tools in such a way that the tool is a support for decision making on aircraft stand area.*
- Propose a decision support environment and embed this in the current organizational working processes at Amsterdam Airport Schiphol.

Users of the tool will be the employees of Schiphol Group who are responsible for facilitating sufficient capacity of aircraft stands in the coming 5 years. Therefore, the tool should satisfy the requirements of problem owner and users.

The main objective of the tool is to get an overview of capacity: Is the current aircraft stand infrastructure able to accommodate the future growth? And the service level of this accommodation is of importance, can all flights be assigned to connected gates or is handling at remote stands needed?

1.3.2 Scope

Air transportation can generally be divided into three different parts: airlines operations, air traffic management (ATM) and airport operations. Each part has different activities, responsibilities and decisions to make. Airlines operations need to plan their resources such as crew and aircrafts and have to decide about marketing elements such as which destination to fly to. ATM is responsible for activities in the air and at runways, e.g. the space between two aircrafts or which runway can be used on a particular day. AAS as an airport operator needs to make decisions about the planning of their resources such as which gate a certain flight will be allocated. The latter is the area in which this project can be categorized.

The airport can be divided into the landside and the airside. The terminal is on the landside. Runway system, taxiway system and aircraft stand area is on the airside. This project will focus from the perspective of the airport operator on the aircraft stand area. The tool will only plan the aircraft stand area. However, the passenger flows from a certain scenario planning exert an influences on the other resources of the airport such as the terminal.

The matching of aircrafts from the flight schedule to an aircraft stand is done according to a rulebased tool at operational level – operational as in seasonal, one-day ahead and daily planning. The focus of this project is on the midterm planning (tactical planning, 5 year ahead). From now on the term midterm planning will be used. So, the tool has no operational planning purposes. Therefore an exact planning for daily operation of flights-to-gates is not needed.

The aim of this project is to evaluate what is required for the aircraft stand capacity planning and which tools are already available and which improvements are needed to match the requirements with existing tools.

Finding solutions for the bottleneck(s) is not within the scope of this project. Developing a new tool is not within the scope of this project.

1.3.3 Questions

Analysis Phase

Problem identification

- **1.** What is the situation of the current procedure for midterm planning (decision making) of aircraft stand capacity?
- 2. Which actors are involved in this procedure and how do they interact?
- 3. Which tools are currently used for capacity cases on aircraft stand area?

- 4. Which variables determine the supply and demand for gates and remote stands?
- 5. How do other airport perform analyses on imbalances on aircraft stand area?
- 6. Which tools are available within AAS to perform capacity planning of aircraft stand area?

Capacity management:

- 7. How are the operational and midterm planning (planning horizon) related to each other?
- **8.** Which indicators are needed to support decision making for investment decisions on aircraft stand area for midterm planning?

Method availability

- 9. Which method/tool is used for the operational flight-to-gate assignment?
- 10. What does literature say about flight-to-gate assignment?
- **11.** Which methods are available from literature and most appropriate to model the aircraft stand allocation in a dynamic and flexible way for the use by AAS?

Design Phase

- **12.** What are the user requirements for the tool?
- **13.** What are the design criteria for the tool to perform valid capacity planning for aircraft stand area for midterm planning?
- 14. Which data are input for the tool and is data availability a problem in this case?
- **15.** Which improvements/adjustments must be made to the tool in order to perform aircraft stand 'what-if' analyses?

Implementation Phase

- **16.** Which improvements must be made to the current working processes between departments in order to incorporate the dynamics of the aircraft stand area?
- **17.** How can those improvements be embedded in the current working environment?
- **18.** Which aspects should be taken into account when implementing the tool, such that it will receive support of the stakeholders involved in the decision making procedure?

1.3.4 Question framework

To structure the research, having all the questions answered at the end of the research and to show the linkages between the questions and different phases the following question framework is developed. The research is clearly divided into two important elements, that are the support tool element and the organizational element.



Figure 3 Question framework

1.4 Approach and methodologies

The project is divided into three phases, namely the analysis phase, design phase and the implementation phase.

1.4.1 Analysis Phase

Planning thus distributing airport capacity is a complex process due to the dynamics of the aviation industry and the influence of different stakeholders such as airlines. The problem is explored and given context by analyzing different subjects. The context of the dynamics of the industry and the stakeholder incentives of planning (operational and tactical) flight-to-gate assignments will be outlined in the analysis phase. Furthermore theory of capacity management will be outlined and an analysis is made of the aircraft stand capacity to gain insight in the capacity at AAS. An analysis is made of the current decision making process on aircraft stand area, hereby the procedures, tools and stakeholders are taken into account. Output key performance indicators of aircraft stand area must be known. What is needed for support to decision makers on midterm planning of aircraft stand area is described. In the second part of the analysis phase modeling methods are analyzed in the context of the proposed tool and flight-to-gate assignment methods will be discussed from literature.

Furthermore the uncertain elements in the planning procedure are highlighted and discussed and the added value of adding stochastic variables in modeling capacity is outlined. The methodologies used are outlined in table 2.

(A) Analysis Phase		
Торіс	Method(s)	
- Dynamics of aviation industry	 Interviews with employees Aviation, Statistics and Forecast department Interviews with employees KLM capacity planning Literature study 	
- Capacity management	Literature study	
 Aircraft stand capacity 	Data analysis	
 Current procedure analysis Current used Models/Tools (internal Schiphol Group) Stakeholder incentives in capacity planning aircraft stand area 	 Interviews with employees Capacity Management and Airside Operations Desk Research at Schiphol Group to explore existing models 	
- Benchmark other airports	Interviews	
 Stakeholder incentives planning flight- to-gate (operational&tactical) 	 Interviews with employees Aviation, Statistics and Forecast department Interviews with employees KLM capacity planning 	
- Output Key Performance Indicators	 Strategic objectives of AAS Service level to customer (airlines) description 	
 Modelling methods Flight-to-gate assignment methods Stochastic elements in planning capacity (uncertain elements in procedure) 	 Literature study Expert sessions Schiphol Group and NLR 	

Table 2 Steps and methods used in Analysis phase

1.4.2 Design phase I & II

In this phase it is of importance to firstly analyze the input criteria and user requirements for the tool. This is done by user requirement sessions with the problem owner (employee division Airside Operations) and a feasibility study with experts on those requirements. The input criteria and the data availability are analyzed by field studies when users are planning and interviews with planners. Subsequently the design criteria and constraints are defined.

Then with the knowledge of the analysis phase, literature, brainstorm sessions and existing tools the choice is made to analyze and suggest improvements for the Gate Capacity Manager (GCM) Enterprise Dynamics tool. In 2006 this allocation model is developed in Enterprise Dynamics in cooperation with the company INCONTROL, this model can allocate a flight schedule rule-based. Currently the GCM version 1.0 is not in use. During this research several improvements are implemented and GCM version 1.1 is the new version. For this version user manuals are written. However, not all requirements are implemented and therefore suggestions for improvements are described for GCM version 2.0. The last part is the validation and verification part. The methodologies used are outlined in table 3.

(B) Design Phase I		
Торіс	Method(s)	
 Input criteria Data availability and interdependencies 	 Currently used data for modelling capacity (field study while employees – operational and tactical – are planning) Interviews employees Airside Operations and Aviation Statistics and Forecast 	
 User Requirements Importance of rules in flight-to-gate planning Design criteria and constraints 	 Interviews and Brainstorm session with (potential) users Literature; comparable models; experts 	
	(C) Design Phase II	
Торіс	Method(s)	
Choice to be made: Current tool(s) versus new tool: heuristics, user-friendliness	 Interviews with designers previous tool(s) Information from analysis phase Field study 	
 Describing functionality and heuristics GCM 1.0 Improvement towards GCM 1.1 Suggestions for further improvements for GCM 2.0 	 Field study Experiments Interviews with designers GCM Input: analysis phase / requirements 	
- Validation and verification of the tool	 Running the model: experiments Interviews with the users Validating with experts 	

Table 3 Steps and methods used in Design Phase I & II

1.4.3 Implementation Phase

The most important aspects in the implementation phase is the organizational embeddeness of the tool. The usability of the tool will be discussed and evaluated and, hereby the acceptance can be measured. A user manual for GCM 1.1 is written and a demo will be given to the user for a correct sequence of this project and handing over the project. Next to that further developments for total capacity planning will be discussed.

(D) Implementation Phase	
Торіс	Method(s)
 Organizational Embeddeness Decision making under uncertainty 	 Literature: Process management and Decision Making Processes under uncertainty
- Stakeholder engagement	 Literature Demo and feedback moments on engagement plan with employees
 Usability of the tool Next problem owner 	• Giving a demo of GCM 1.1 to user (current responsible person for mid-term capacity planning of gates)

Table 4 Steps and methods used in Implementation Phase

1.4.4 Research methodologies

In order to conduct the research the approach of this research is a multi-method approach, thus more than two research methods are used to gather information and data and thus to ensure the validity of the research. In this project different research methods are applied as introduced in the tables in the previous section. This section will explain those methods in further detail.

Desk Research

The most important characteristic of desk research is that the material used has been produced by others (Verschuren & Doorewaard, 2010). According to (Verschuren & Doorewaard, 2010) there are three categories of existing material that can be used for carrying out desk research, namely: literature, secondary data and official statistical material. The authors continue to explain the difference between the categories of material as follows: "Literature is understood to mean books, articles, conference proceedings and such works that contain the knowledge products of social scientists". By secondary data they mean "empirical data compiled by other researchers" and finally, official statistical data is "understood to mean data gathered periodically or continuously for a broader public". During this research project, literature and secondary sources are used. Literature is used to define the elements of capacity management, to explore the flight-to-gate assignment problem, to analyze previous work on models for capacity planning of the aircraft stand area, decision making under uncertainty and stakeholder engagement theories.

Expert Sessions and Interviews

Due to the fact that the material derived from the desk research is not specially researched for this project data and information must be derived from other sources. The information of expert sessions has closed this gap. In this research experts were interviewed, especially in the field of simulation and modeling methods in order to answer the question *"Which methods are available from literature and most appropriate to model the aircraft stand allocation in a dynamic and flexible way for the use by AAS?".* The experts are from AAS, from NLR, KLM and Delft University of Technology.

In order to explore and define the current situation several interviews were planned with AAS employees. Those interviews were semi-structured, which means that several topics were known beforehand and several key questions were structured according to the researchers preferred sequence. The key questions are open questions and during the interview the researchers asks more questions based on the answers of the person that is being interviewed (Baarda, De Goede, & Teunissen, 2005).

Field study

Field study is the collection of raw data in natural setting. To get an idea on planning flights to gates several times the operational planning procedure is analyzed during the day of operation. Despite the fact that this research is not focused on the operational planning procedure the planning activities are of great importance and influence on the midterm planning activities (e.g. a part of the allocation rules). Therefore those activities were investigated by observing the operational gate planners during their daily activities. Also the use of the GCM tool was investigated by watching and observing several persons using the planning tool.

Experiments and Demos

To assess the value of the current available GCM tool several experiments with different input were done. Those experiments were evaluated with experts in the field of the aircraft stand area. Furthermore a demo is given of the final GCM version to several AAS employees. Demoing will contribute to the willingness of finally using the tool and gives the researcher the ability to observe reactions and ask for (potential) users' opinion.

1.5 **Research framework**

To structure the project and to show which part is discussed in which chapter a research framework / thesis outline has been developed, shown in figure 4.



Research framework

Figure 4 Research Framework

1.6 Thesis outline

This report is divided into 4 parts, design phase I & II (B, C) is combined in one phase. The first three parts A-D correspond to the three phases explained in the previous section. The analysis phase involves a description of the static & dynamic capacity definitions, capacity management in relation to planning horizon, current planning tools and decision making process, benchmark of airports abroad, stakeholder analysis, indicators needed for decision making and a review of modeling techniques for flight-to-gate planning from literature. This can be found in chapters 2 till 5. Chapters

6 and 7 will describe in general the user requirements for the support tool and the design criteria. This leads to a conceptual model of the support tool. The functionalities and heuristic of the GCM version 1.0 tool are described in chapter 8, followed by the evaluation of the implementation process in 2006 and improvements for the 1.1 version in Chapter 9. In chapter 10 an experiment with GCM version 1.1 is conducted, this experiment is a run of the forecasted flight schedule of 2016. Suggestions for improvements of 1.1 towards GCM version 2.0 is described in chapter 11. More process related issues for the re-implementation of the GCM tool are discussed in chapters 12 and 13. The last phase consists of the conclusions and recommendations and provides a reflection on the research. The lay-out of the content and chapter numbers are illustrated in figure 4.

Analysis Phase

This phase will give context to the problem by analyzing different subjects: aircraft stand capacity at AAS, capacity management, current procedures for decision making on aircraft stand bottlenecks, complexes in different planning horizons, a stakeholder analysis, benchmark of airports abroad, indicators needed for decision making and from literature flight-to-gate assignment developments and incorporating stochastic elements in planning aircraft stand capacity.

2. Capacity at an airport: aircraft stand area

In this chapter the analysis of the aircraft stand capacity is described. First the dynamic capacity definition, capacity management and capacity and peak relation is outlined. The next section provides an analysis of the demand and supply of aircraft stands. In the third section the current occurring bottlenecks and solutions for those bottlenecks from development plan 2012-2016 will be described. Subsequently the benchmark of airports abroad is described. In the last sections the current tools and procedures for decision making on aircraft stand bottlenecks are described.

According to (Janic, 2000) the capacity of any airport component – and thus also for gates and remote stands – can be expressed by four different measures that represent capacity attributes: the physical infrastructure, fluctuations of demand over time, profiles of user entities, and the quality of service provision. All elements will be introduced in this phase.

2.1 Capacity: dynamics, management and peak relation

In airport operations capacity is an important aspect because when traffic demand exceeds the operational capacity the aim of the airport is at risk. Gates and remote stands can be considered as resources of the airport and a particular capacity is available. In case of traffic demand exceeding the supply of gates the aircraft needs to be handled at a remote stand which decreases the service level to the customers – the airline and airlines' customer the passenger.

2.1.1 Static and dynamic capacity

Capacity can be viewed two-sided, namely static and dynamic capacity. Static capacity is the number of gates and remote stands available and dynamic capacity which means the number of aircraft per hour that can be accommodated at a gate or remote stand. The number of aircraft per hour at a gate or remote stand is determined by the time an aircraft is scheduled to spend at a gate/remote stand – Scheduled Occupancy Time (SOT), the time to position aircraft into and out of a gate/remote stand – Positioning Time (PT) and the buffer time. The buffer time in the gate planning at AAS is set to standard 20 minutes for all flights⁵. This buffer time is to ensure that there is sufficient time between scheduled departure time of the first aircraft and the scheduled arrival time of the second aircraft to absorb stochastic flight delays. By implementing a buffer time it is tried to increase the robustness of the planning. A robust planning is not sensitive to disruptions, every deviation will decrease the

⁵ Except for the aircrafts handled at the H-pier with a maximum turnaround time of 30 minutes, buffer time is set on 10 minutes for those flights.

robustness⁶. However, buffer times do decrease the capacity. The planning of a gate is visualized in figure 5.



Figure 5 Planning of gate X: SIBT, SOBT, SOT and buffer time

The capacity of the total of stands (gates and remote stands) depends on the number of stands, the types of aircraft each stand can accept, the mix of aircraft types that use the airport, the minimum handling time and the actual turnaround times dictated by the airline schedules (Andreatta, Brunetta, Odoni, Righi, Stamatopoulus, & Zorgrafos, 1998). The assignment of flight-to-gates is restricted due to governmental rules such as security rules and border status rules (Schengen, Non-Schengen) and therefore capacity is enforced fragmented and is less useful. Furthermore, preferences of airlines and other stakeholders – if taken into account when planning the flight-to-gate – are also of influence on aircraft stand capacity.

2.1.2 Capacity management: planning aircraft stand area

Primary goal of capacity management is to ensure that capacity of a certain resource – in case of this project the gates and remote stands – meets current and future traffic demand. There are two components of capacity management: capacity planning and capacity control. Capacity planning and control is an issue which every operation is faced with. Furthermore it is an activity which can profoundly affect the efficiency and effectiveness of the operation. Capacity planning and control is concerned with making sure there is some kind of balance between the demand placed on an operation and its ability to satisfy that demand (Slack, Chambers, & Johnston, 2006). There are serious consequences of getting the balance between demand and capacity wrong. If an operation has too much capacity the costs are spread over few customers, however if an operation has too little capacity its costs will be low but service to customers will be of lower quality because operation needs to turn down customers or they have to wait.

In airport operations there are usually two interdependent stages in the stand assignment process: the planning and the real-time stages. This project will focus on the planning stage. At AAS planning is done on daily operation, one-day-ahead, seasonal and midterm basis. This project is focused on midterm basis and there are several important moments in time when the initiator of this project (department AO) wants to perform planning activities in order to analyze the demand-supply balance. Assessing if air traffic demand can be accommodated by AAS and the impact of changes in infrastructure, operational procedures or traffic volume is the objective of midterm capacity management.

⁶Interview Alexander Verbreack, 27th of June'11 , Professor Faculty Technology, Policy and Management TU Delft
First, every year Schiphol Group is developing the integrated development plan for the coming 5 years. For this plan AO needs to deliver output of demand-supply analyses on a 5-yearly level. Furthermore, department AO is responsible for performing analyses on the demand-supply balance of aircraft stands for various questions from different organizational levels and departments. An example is the question if the upgrade of several stands in terms of category⁷ will be a solution for accommodating the demand of next year.

2.1.3 Capacity and Peak Moments

Capacity planning and peak developments are closely linked. Peak can occur on a daily basis and on a seasonal basis. During holidays the demand is higher for air traffic due to leisure activities. For planning activities on a midterm (5 years) AAS has chosen to plan their processes on a busy week in the Summer usually in July or August. Normally the most busiest moment at AAS are in May during the mid-term break, however AAS has chosen not to use that moment to avoid building infrastructure on peaks. The question is if infrastructural capacity such as gates need to be built according to the nearest busiest moments at AAS. Overcapacity will lead to a loss of money. When capacity is not used investments cannot be returned because visit costs⁸ payback the investment costs for infrastructural changes. However, AAS wants to deliver high quality of service to its customers and would like to see all flights handled connected. Therefore it is needed to have a norm about which (service) level is accepted when peaks and gate capacity are confronted. In the standards document – which is a supplement of the Schiphol Development Plan – it is stated that for the total of aircraft stand capacity for every aircraft between arrival and departure an aircraft stand should be available (Schiphol Standards Document 2011-2015, 2010). This is still a broad norm because aircraft stand can be a gate which is connected to the terminal or a remote stand which is not connected to the terminal.

During the day peak hours are caused by different factors such as slot capacity, peak patterns and fleet developments (Schiphol Development Plan 2012-2016, April 2011). To realize a large set of connections a high concentration of arrival and departure flights will be the consequence and will lead to high peak development. Currently under normal weather conditions the hour capacity of AAS when using 2+1 runways is 106 aircraft movements in arrival peak (68 arrival and 38 departure and 110 aircraft movements in departure peak (74 departure and 36 arrival) (ATC the Netherlands and Schiphol Group, Strategic Environmental Report, 2008). The 2+1 runway systems means that AAS is using 2 inbound runways and 1 outbound runway in the inbound peak and 2 outbound runways and 1 inbound runway in the outbound peak. Until 2015 slot capacity is not expected to increase and not all slots are used in operation, therefore slot capacity does not need to be increased (Schiphol Development Plan 2012-2016, April 2011). KLM introduced the 7-wave system again in 2011 after changing this system into a 6-wave system in 2009. This can lead to less crowded peaks, however due to the expected growth in air traffic demand the peaks will be on a high level again (Schiphol Development Plan 2012-2016, April 2011). This peak pattern influences the demand for stands during the day. In figure 6 the wave system is set out in a graphic drawing.

⁷ The wingspan of aircrafts are categorized in categories (CAT 1 - 9). The biggest categories are the so called widebody (WIBO) aircrafts (>CAT 5), the smaller ones are the narrowbody (NABO) aircrafts (CAT 1-4). The aircraft stands at airside are also categorized according to the wingspan of the aircrafts, NABO has a maximum wingspan of 36 meters and WIBO from 37-65 meters (A380 – CAT 9 – wingspan 80m).

⁸ Visit costs are the total costs an airline has to pay when visiting an airport. Visit costs are composed of: airport charges, handling charges, government charges and other costs like rentals etcetera.



Figure 6 The 7-wave system introduced again in 2011 (Schiphol Development Plan 2012-2016, April 2011)

Developments in fleet composition – replacement of smaller aircrafts by larger ones – are of importance because this will ask for more and larger aircrafts stands. It is expected that the number of WIBO will increase with approximately 15% during the peak and a replacement of CAT 3 aircrafts by CAT 4 aircrafts in the NABO sector (Schiphol Development Plan 2012-2016, April 2011).

For 2010 the total air transport movements per hour of the day are presented in figure 7. This picture shows the pattern of busiest moments per hour of the day.





In 2010 the pattern of flights per month showed that the busiest moment was in July and August, in figure 8 the graph with flights per month 2010 is shown. The busiest days with 1235 flights per day were the 6th and 7th of July 2010. Followed by the 12th of July with 1230 movements and the 27th of July and 16th of August with 1224 movements.



Figure 8 Flight pattern 2010 per month (Schiphol Group ASF, 2011)

2.2 Planning Horizon versus detail of information

For longer horizons it is harder to gather detail on traffic demand and flight characteristics, especially in the aviation sector with its dynamics and multiple stakeholders. This section will describe the planning horizons for the planning of the aircraft stand area at AAS, forecast uncertainty and the information details of flight schedules.

2.2.1 Planning horizons of the stand allocation process at AAS

At AAS Airside Operations the planning is done on different horizons:

- Seasonal, Operational and Daily Planning
 - Seasonal: summer- and winter a season planning is made which serves as basis for the operational planning. Input for this planning is the available flight schedule from all carriers and is planned according to the 'best-fit' policy⁹.
 - Operational planning: this planning is called the one-day ahead planning. According to changes, preferences of airlines and more detail of flight schedule the gate planner will change the seasonal planning for the next day. Input for this planning is the seasonal planning.
 - Daily planning: during the day the planning is adjusted due to changes in arrival or departure times or other incidents at airside. Input for this daily planning is the one-day ahead planning.

⁹ Flights are planned according to the 'best-fit' policy, which means that flights of category X are planned on a stand with that same category X.

- Midterm Planning: this planning is done every year for the business plan period of 5 years (in this report called midterm planning). Furthermore at this level AAS is analyzing scenarios for changes in infrastructure or procedures on variously periods.
- Strategic planning at AAS is done by Airport Development and focuses on the >5 year airport master planning.

2.2.2 Forecast uncertainty

Almost every midterm or strategic decision taken stems ultimately from a forecast. At the same time, forecasting is the area in which mistakes are most frequently made and the one about which is least certainty. Yet forecasts have to be made since so many decisions flow from them (Doganis, 2010). Uncertainty in forecast will influence decision makers, however as Doganis (Doganis, 2010) describes forecasts are needed in order to notify capacity imbalances in an early stage and to start action to minimize those imbalances. Uncertainty is a key source of problems in the mid-term development of an airport; uncertainty in terms of aviation demand, regulatory context, technological breakthroughs and stakeholder behavior (Kwakkel, 2008).

When using forecasted flight schedules demand uncertainty must be considered. Currently ASF is generating flight schedules for a high, medium and low scenario. In their demand model market demand is based on six key drivers: gross domestic product (GDP), oil price, market share catchment area, percentage low cost at AAS, market share transfer and percentage transfer at AAS. Furthermore Emission Trading Scheme (ETS) regulation is taken into account. The dimensions of the forecast model is twofold, namely at marco-economic level; explaining the size of the market and at market position; explaining the market share.

Not only demand uncertainty brings forecast failure, forecasters' bias contributes to forecast failures in several ways as well. Forecasters often have a poor database that has internal biases caused by the data collection system and forecasters often integrate political wishes into their forecasts (Flyvbjerg, Bruzelius, & Rothengatter, 2003). The flight schedules for the midterm planning activities (5 yr) are developed by ASF in cooperation with process owners (e.g. owner of the baggage process, or aircraft stand process). However, forecasts by project promoters may be even more biased, since the promoter has an interest in presenting the project as in as favorable light as possible (Flyvbjerg, Bruzelius, & Rothengatter, 2003).

It can be concluded that ASF does not incorporate uncertainty levels on regulatory context and stakeholder behavior in their demand model. Moreover, it should be noted that forecast failure can exists due to forecasters biases.

2.2.3 Airline planning and slots

In figure 9 the reliability of information – so uncertainty in information – during the planning horizon is visualized. The reliability of information grows when the day of operation comes closer because airlines know what demand is more accurately when approaching the season and the day of operation. The difference between the midterm and operational planning is large due to the difference in detail of information. When the planning horizon is growing towards the day of operation the detail of information on operating flights, arrival and departure times, fleet characteristics, number of passengers, delays, peak moments grows.



Figure 9 Planning Horizon and reliability of information

Airlines do design their flight schedules based on demand factors such as oil prices, technological development, economy, etcetera. Airlines create flight schedules fitted on the demand, and those schedules create demand for aircraft stands. However, the demand is influenced by many uncertainty factors as described in the previous section. And demand is more accurate when reaching the day of operation. Airlines decide in more detail when approaching the season on destinations, frequency and usage of particular aircrafts from their fleet.

Airlines need to request for landing or take off slots for AAS. A slot is defined by IATA as "a scheduled time of arrival or departure on a specific data/time at an airport". The final detailed flight schedules (with allocated slots) are available on April for next Winter season and on September for next Summer season¹⁰. Until 2015 slot capacity will not increase and not all slots are used in operation, therefore slot capacity does not need to be increased (Schiphol Development Plan 2012-2016, April 2011). Total slots allocated for Summer 2011 were 278.378 slots, for Winter 2011/2012 allocated slots are 168.773.

Differences on the day of operation versus the midterm planning are late or early arrivals, longer or shorter handling times and drop-out of flights. The assignment procedure of the flight-to-gate during operation is influenced by those changes and currently when a difference in planning occurs operation managers do re-assign flights manually¹¹. This re-assignment is based on how the planning appears on that day, what buffers are left and expert judgment.

Detailed planning of flight-to-gate is getting less important for the longer the planning horizon, inputs will change. However, to make grounded decisions for infrastructural or procedural changes the developments and possible scenarios of the demand should be known way ahead before the day of operation. Therefore, AAS is creating a forecast flight schedule 5 years ahead for the planning of

¹⁰ Winter season starts at the end of October until end March, Summer season is from April till end of October.

¹¹ Interview operational gate planner control tower AAS, 5th of May 2011.

resources. However planning based on a forecast should be taken into account demand uncertainty and forecasters biases as described in the previous section.

When midterm capacity planning is done with quantitative analysis and a bottleneck is the outcome of the analysis it is often the case that operation managers have some idea of meeting the demand during operation without changes in procedures or infrastructure. This human and organizational element is important in the decision making procedure.

So, there is a strong relation between the midterm and operational planning. To support decision making at midterm level it is needed to take into account this relation and the possibilities of reassignment during day of operation.

2.3 Airport planning process: decision making and aggregation level

The rational planning model assumes the existence of a powerful, unitary actor (Goetz & Szyliowicz, 1997). Decision-making power is centralized in top-management, and top-management works with specifiable long-range goals. Only in a few situations do these assumptions of the previous two sentences hold (Bryson, 1995). In airport operations many stakeholders are involved and therefore decision making from one top-management actor is not accepted. Furthermore, (Mintzberg, 1994) showed that bottom-up processes are essential for successful planning. Airport line managers have access to soft information and knowledge, they are the first to detect opportunities and threats, whereas corporate management can easily become disconnected from reality while relying on hard data. Hard data may inform the intellect, it is largely soft data that generate wisdom, they may be hard to analyze but they are indispensable for synthesis – the key to strategy making (Mintzberg, 1994). This relates to the discussed dilemma in the previous section between the quantitative analysis and the gate planners having the expert knowledge of what happens on airside.

The input data for the support tool is a forecast schedule with one day's forecast at a precision of 5 minutes throughout the day. However, which aggregation level of data (unit of analysis) is needed to enable decision makers to comprehend the necessary information quickly? As described in the problem exploration (introduction) the level of data will differ concerning the scenario that needs to be evaluated. The user of the tool needs to evaluate different scenarios for the following purposes:

- A 5-year ahead estimation for the integrated development plan.
- Various other questions from different organizational levels and departments about the balance between demand and supply of the aircraft stand area.

So, it cannot be said that for one situation a particular aggregation level is needed, it depends on the scenario. The researcher needs to identify and verify the levels of aggregation of variables in an existing data set.

2.4 Demand for and supply of aircraft stands

The demand for aircraft stands is determined by the number of flights – number of flights is determined by the air traffic demand and size of the aircrafts – and therefore the number of aircrafts expected to require services from an airport. This demand is set out in a flight schedule. As stated in

the previous section peak patterns and runway capacity determine demand as well. Supply of aircraft stands can be easily defined as the number of gates and remote stands at airside.

2.4.1 Flight Schedule – forecast of demand

Due to the unpredictable and dynamic nature of the aviation industry AAS has a central department who act as an advisor forecasting for all divisions. Department Aviation Statistics and Forecasts (ASF) creates scenarios – see figure 1 – which are the input for other departments responsible for processes to perform integrated capacity planning. On a yearly basis the flight schedule serves as an input for the midterm planning which is called 'Schiphol Development Plan' for all the airport process departments, e.g. for Passenger Services, Baggage, Terminal and Airside. The purpose of this document is to provide an integrating plan within AAS and to facilitate investment decisions by giving a complete overview of the most important processes at the airport for the coming five years.

The integration and adjustment of capacity of all processes is of importance because the passengers, aircrafts and baggage will flow through all processes. If airside can accommodate a number of aircrafts with a certain amount of passengers but the terminal can accommodate less passengers AAS is limited to the process with the least capacity. It is assumed that ASF takes the capacity of different processes into account when developing the flight schedule, so that the flight schedule is a solid basis for capacity planning for all processes.

A forecast model is used by the department ASF to come to the flight schedule with an explanation of the market demand based on six key drivers: gross domestic product (GDP), oil price, market share catchment area, percentage low cost at AAS, market share transfer and percentage transfer at AAS. Furthermore Emission Trading Scheme (ETS) regulation is taken into account. The dimensions of the forecast model is twofold, namely at marco-economic level; explaining the size of the market and at market position; explaining the market share.

ASF provides the capacity demand in flight schedules for high, medium and low scenarios. The weight of the key drivers is determined by Management Team Aviation. KLM/Air France is not always involved in the forecasting procedure.

The flight schedule consists of the following data:

- Flight number
- Start and End date of the flights (based on season)
- Weekdays that the flight is operational
- Number of seats
- Type of aircraft
- Destination airport or Airport of origin
- Departure or arrival time
- Flight type

A screenshot from flight schedule Summer 2016 can be found in appendix 2. It is important to notice that this flight schedule is the mandatory input for capacity planning for all processes.

2.4.2 Regulation Aircraft Stand Allocation Schiphol (RASAS) Policies

The daily allocation of aircraft to an aircraft stand is done according to the directive Regulation Aircraft Stand Allocation Schiphol (RASAS), preferences of airlines and other parties such as ground handlers and according to the knowledge and experience of the gate planner. The policies from RASAS influence the number of aircraft stands available for flights. This section will give an overview of the policies described in (AAS - RASAS, 2007).

First boundary conditions such as physical limitations and governmental rules are of influence on the allocation of flight-to-gate. Number 1-3 are relevant for both demand and supply characteristics.

- (1) Physical limitations: aircraft stands can only handle a certain category of flights, obviously dimensions of the aircraft are limitations for the allocation to a stand. In the aircraft stand table the maximum category per stand and deviations per stand are set.
- (2) Border status: separation of Schengen and Non-Schengen countries. Passengers travelling within Schengen countries are exempted from border controls. Aircraft stands are divided into Schengen and Non-Schengen stands because in the terminal customs are only available where Non-Schengen passengers are arriving/departing. Next to this difference there is a difference made in the Non-Schengen area, namely passengers from European Union (EU) and passengers not from the European Union (NEU).
- (3) Security Rules: flights which need to be checked 100%, Israeli flights, American Airlines for profiling (an interview at check-in or at the gate for every passenger)

AAS strives for a planning in such a way that the processes of all parties involved can be done in the most efficient way and that safety is secured at all times. The following policies are of relevance and are taken into account when planning is done:

Transfer Central

To empower the mainport function of AAS the airport has decided to separate the total area in two area's namely: 'Common-Use' and 'Transfer Central'. The hub-carriers which deliver the biggest number of transfer carriers get the chance to increase the reliability of transfer connections because all flights of that carrier are allocated in the 'Transfer Central' area and walking distances are minimized. Carriers with no or less transfer passengers are allocated in the 'Common-Use' area.

Robustness of Planning

Between two visits¹² a buffer time of 20 minutes is planned. Gate planners will maximize the buffer time between two visits were possible.

Clearance of stand when delays occur

Delays of departing flight can have a severe effect on carriers with a punctual flight schedule. The aim of this policy is to minimize the effects on the punctual carriers. After the 20 minutes buffer time the departing flight needs to clear the stand, if not the aircraft needs to be handled further at a remote stand.

¹² A visit can be described as an aircraft the same for an arriving and departing flight. For example, flight KL0892 arrives at 13:00, all handling is done and departs at 15:40, this is one visit.

Allocation of passenger handling

Connected handling of passenger flights is preferred over handling at a remote stand.

Best-Fit

Flights are planned according to the 'best-fit' policy, which means that flights of category X are planned on a stand with that same category X.

Passenger Numbers

Flight with the highest number of passengers are planned near to the terminal. The carrier or handling agent is responsible for reporting the number of passengers.

Remote stand allocation

Flights without passengers are planned on a remote stand. Arrival flights with the lowest passenger numbers are allocated at a remote stand if passenger flights need to be handled remote due to capacity shortage.

Towage movements

If a widebody aircraft with a turnaround time larger than 210 minutes or a narrowbody with a turnaround time larger than 170 minutes will stay at AAS the aircraft will be towed to a remote stand temporarily.

Maximum of gate occupation time widebody: Arrival – 75 minutes, Departure – 85 minutes Maximum of gate occupation time narrowbody: Arrival – 55 minutes, Departure 65 minutes

Cluster

Flights with the same handling agent are clustered in one area, in such a way the handling agents can operate more efficiently.

Preferred use of piers

Per season airlines or handling agents can make agreements with AAS to allocate their flights at preferred piers. Reasons for those agreements can be operational or commercial and are only allowed if enough capacity available.

Switch Flights

Flights with a switch status (Schengen-Non-Schengen or Non-Schengen-Schengen) will be allocated at switch gates. If a switch gate is not available the flight will be planned on a gate with the status of the departing flight, the arriving passengers will be transferred by bus to a bus injection point.

For carriers allocated at the H-pier an adjusted policy is considered. This pier is only suitable for carriers which have point-to-point connections from and to Schiphol. Only suitable for flights with a turnaround time of 30 minutes. The buffer time at the H-pier is 10 minutes instead of 20 minutes.

2.4.3 Airside: aircraft stands

The gates and remote stands with numbering at AAS currently can be visualized as in figure 10. The blue parts of airside are the Schengen gates and the red parts are Non-Schengen. At AAS airside 99 connected and 103 disconnected gates are available. This was the situation at the beginning of 2011, however changes will occur during the midterm planning of 5 years. Changes which will be made to

the gates and remote stand in the 5 years coming are outlined in section 2.3 and need to be taken into account when planning the coming years.



Figure 10 Supply of Aircraft Stands July 2011 – Print of Airside Operation (Schiphol Group PMA, July 2011)

2.5 Schiphol Development Plan 2012-2016: Narrowbody and Widebody Gates

The development plan gives an overview of capacity analysis and coming changes in infrastructure or policy. Per NABO and WIBO gates a description will be given of shortages and changes in the coming 5 years.

2.5.1 Narrowbody gates

In the CAT 4 segment the fleet changes of KLM will lead to a shortage of CAT 4 gates and an overflow of CAT 3 gates. The number of CAT 4 remote stands is not enough to accommodate the overflow of CAT 4 gates.

The solution to this problem are planned in finding an upgrade in CAT 3 gates to CAT 4 gates. At the D-pier 12 CAT 3 gates are planned to be upgraded to 10 CAT 4 gates before 2013.

2.5.2 Widebody gates

The shortage of CAT7/8 gates will grow. Handling passengers by bus is required and this service level must be accepted in this situation.

The solution to this problem is planned to be found in upgrading CAT 5/6 gates to CAT 7/8 gates. At the D-pier and at the E-pier 6 CAT 5/6 gates are planned to be upgraded to 4 CAT 7/8 gates, consequently downgrading of 2 gates to CAT 4 gates.

Airlines are using more often larger aircrafts. For the future it is expected that fleet changes will lead to larger airports which will visit AAS. ICAO code F (CAT 9) is the highest category for the largest aircrafts, A380 and Boeing 747-800 are in this category. It is expected that A380 will visit AAS and therefore gates E18, G9 and F08 will be flexible usable and can allocate A380 aircrafts.

2.6 Current capacity planning aircraft stand area: tools

This section will highlight the methods and procedures currently used for the midterm planning of the aircraft stand area.

2.6.1 Capacity planning and peak characteristics

As discussed in section 2.1.2 AAS has chosen to perform midterm capacity planning for all airport processes on a week in the Summer usually in July or August for planning activities on a midterm. The question is if infrastructural capacity such as gates need to be built according to this specific moment and what alternatives are available to cope with the demand.

2.6.2 Capacity planning method: Excel Spreadsheet

With the flight schedule as input (based on a 5 minutes schedule) an Excel list is created with the following characteristics: flight number, prefix, arrival or departure, from day till day in season, operational per day (monday-sunday), seats, aircraft type, category, HHMM flight, HHMM gate/remote stand (which means HHMM flight minus 10 minutes for buffer time), origin, destination, type, pax/cargo, Schengen/Non-Schengen, European / Non-European, European / Intercontinental flight, maximum of gates needed per category (CAT 1-3, CAT 4, CAT 5-6, CAT 7, CAT 8) per day for one season. This static capacity is compared to the available gates and remote stands in 2016. Available gates and remote stands including renovations and up- or downgrading of gates and/or remote stands already planned until 2016 are taken into account.

The information needed for this planning activity is arrival or departure, from day till day in season, operational per day (monday-sunday), HHMM flight, HHMM gate/remote stand (which means HHMM flight minus 10 minutes for buffer time), category, type (cargo, passenger), pax/cargo. With this information the maximum number of gates needed per category is calculated. However, the flight schedule contains much more detailed information such as the flight number, prefix, seats, aircraft type, Schengen/Non-Schengen, European / Non-European, European / Intercontinental flight. Those characteristics are needed when planning is done with the policies discussed in section 2.2.2. Those policies will lead to a loss in capacity. Currently this loss is reported in a qualitative matter.

The following graphs are the output of this analysis done in spring 2011 for 2016. The dotted line is the supply of gates and remote stands (in the graphs indicated as VOPs) and the red line is the demand.



Figure 11 Dashboard Output analysis 2016 static capacity gates and remote stands - Excel method - (Schiphol Development Plan 2012-2016, April 2011)

2.6.3 Operational model GMS

For the operational planning the Gate Management System (GMS) is used. The operational assignment model has a rule-based method with mandatory, costs and benefits rules. For every one-day-ahead planning is determined how the capacity will be distributed, first of all the day is planned with the constraints (physical limitations, security and border status rules) and then the gate planners will determine which rules and which scores the correct planning is made with.

2.6.4 Project OPAS: new system Inform Groundstar

Because the GMS has several limitations such as no management information output and a complex planning system the OPAS – Operational Planning and Allocation Services – project is started initiated by the department ICT / Enterprise & Strategic Services. The tender is finalized on March 2011 and in Summer 2011 the first part of the system produced by Inform GmbH and named Inform Groundstar is started with the implementation phase, this part is for the bus handling process. The system is rule-based and initially purchased for the operational planners. For capacity planning – midterm and strategically planners - it can be used, however in the purchase phase requirements for this purpose are not taken into account. The strategic module is part of the system and can be used for capacity analyses, however the exact functionality and interfaces are not yet known.

2.6.5 Enterprise Dynamics: GCM

In 2006 an allocation model is developed in Enterprise Dynamics – Gate Capacity Manager (GCM) – in cooperation with the company INCONTROL, this model can allocate a flight schedule rule-based. The GCM makes use of a flight schedule for a certain day and the available capacity of stands. Based on a user defined rule set, the GCM assigns the flights to the available stands. Rules have a certain

priority and can reflect a requirement, preference or avoidance. However, this model is currently not in use. This model was intended to use occasionally to run the allocation process of aircrafts to flights with changes in parameters in order to analyze capacity. The functionality of this model is analyzed and output can be found in subsequent phases and chapters.

GCM is part of the Incontrol simulation set SAMANTHA – Simulation Application for Modeling and Analysis of a Total Airport. This product is an airport simulation and capacity management product and provides insight in individual airport processes and in the relation between different processes. Samanta is an object oriented simulation product, built in Enterprise Dynamics.

2.7 Benchmark: How do other airports cope with planning the gate and remote stands?

To answer questions like 'When do we need an extra pier or gate?' or 'Can we accommodate future demand at current gate and remote stand infrastructure?', elaborated analyses of the aircraft stand area is needed. Planning activities and balancing between demand and capacity is a challenging task and for this research it would be an added value to know how other airports cope with this task. To make a comparison between the activities at Schiphol Group and other airports, several airports who needs to focus on this balance as well are contacted by e-mail and telephone to answer the following question: "Do you use a (simulation) model as tool for decision making for policy changes and/or infrastructural changes/investments of the aircraft stand area (gates and remote stands)?".

Frankfurt Airport

Several tools are necessary to combine the processes and explore the capacity of the gate and remote stands. Employees responsible for gates and remote stands at Frankfurt Airport answer questions like 'When do we need the first pier for operational handling?' with the use of AirTop simulation software for aircrafts and the simulation software CAST vehicle for traffic of aircrafts at airside. Besides the pure quantity question the question of quality plays a significant role. Quality in terms of waiting times for aircrafts and passengers, driving times for aircrafts at airside and terminal configuration. Steffen Wendeberg – responsible person at Frankfurt Airport – discussed the attempts to develop and validate tools covering both landside and airside. The last attempt was the SPADE-2 initiated by the European Union (EU) completed at the beginning of 2010, however the system failed and would have led to incorrect decisions. Joyce Groot participated in this project as representative of AAS, and Joyce Groot shares the opinion of Steffen Wendeberg about Spade-2 project¹³.

Aéroports de Paris (ADP)

For the operational planning of flight-to-gates ADP uses a tool called OSIRIS. The tool depends on specific and detailed flight schedules which are known short time before day op operation and therefore the tool is only used for operational planning. For tactical planning ADP uses standard sizing methods, based on gate and remote stand productivity and forecasts.

Dubai International Airport

Dubai Airport uses the Inform GmbH stand planning tool, Dubai recently purchased this tool. This tool is used to built a future stand layout and with the forecasted flight schedule for that same period

¹³ Interview Joyce Groot, September 2011, Senior Advisor Analysis, Development and Innovation, AAS – Aviation.

of time it is simulated if the capacity can accommodate the demand. The tool identifies: 1) what is needed to build to accommodate the demand 2) what processes could be altered to accommodate the demand 3) limiting the demand by imposing capacity constraints 4) move airlines between terminals to accommodate demand.

Unfortunately London Heathrow and Copenhagen Airport did not respond to the attempts of contacting. The tools which are used by other airports – AirTop, CAST and Inform Stand Planning – will be discussed in coming chapters.

2.8 Current decision making process aircraft stand area for development plan AAS

Every year different departments from Schiphol Group cooperate to create a development plan for the coming five years. This procedure is started at November and ends with a development plan in May. The purpose of this document is to provide an integrating plan within Schiphol and to facilitate investment decisions by giving a complete overview of the most important processes at the airport for the coming five years.

The cycle of decision making is visualized in figure 12. The input for capacity planning is delivered by the department ASF¹⁴. Capacity planning is done by the department Process Management Airside (PMA) – department of the division airside operations. PMA is responsible for the development and control of the flight and aircraft handling processes and that enough capacity is offered to perform those handling activities. PMA is the department with the knowledge and skills to analyze aircraft stand area. The integration of capacity, safety, finance, environment and noise is crucial.

With the flight schedule as input PMA is performing the impact of those demand figures on capacity of gates and remote stands. With the method discussed in section 2.6.2 bottlenecks are described in a qualitative matter and those bottlenecks are recorded in the development plan for the coming five years. This plan is coordinated by the Unit Capacity Management. Capacity Management has as main goal to provide timely sufficient, reliable and sustainable capacity for AAS its airlines and passengers and is responsible for the alignment of all important processes of the airport to offer sufficient capacity ..



¹⁴ For an overview of the organizational structure and position of the different departments, units and divisions see appendix I.

Based on the plan investment decisions are made to tackle the bottlenecks. In previous years KLM collaborated with Schiphol Group to make the forecast flight plan. In the investment decision procedure discussions with KLM are done to align the decisions and the visit costs which will increase due to the investments.

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2.9 Concluding remarks capacity aircraft stand area

This chapter discusses the need for capacity planning of aircraft stand area because AAS wants to provide connected gates – which increases the service level – for current and future air traffic demand and would like to safeguard the availability. The aim of capacity management in this project is to reach a balance between the amount and size of aircraft stands and current and future air traffic demand. This balance must be reached without overruns in costs and/or neglected service levels to the customer. To avoid building infrastructure on peak moments and therefore overrun costs scenarios can support decision making when decisions should be made on costs for infrastructure versus service level and procedural policies.

For longer planning horizons it is harder to gather specific details on demand and flight characteristics. At AAS Airside Operations the planning is done on different planning horizons: strategic, midterm, seasonal, one-day-ahead and daily planning. In order to make midterm or strategic decisions forecasts are needed. However, forecasts embody a lot of uncertainty and forecast failures exists due to forecasters biases. It can be concluded that ASF does not incorporate uncertainty levels on regulatory context and stakeholder behavior in their demand model when creating the forecasted flight schedules. A strong relation exists between the midterm and operational planning, during the day of operation the level of detail of information is far larger than during midterm planning. Possibility of re-assignment during day of operation should be taken into account when making decisions based on midterm planning. The dynamics of flight-to-gate allocation should be taken into account and due to the uncertain elements in capacity planning on the long horizon scenarios can be used to support decision making.

At AAS airside 99 connected and 103 disconnected gates are available, this is the static capacity. Dynamic capacity is the number of aircraft per hour at a gate or remote stand and is determined by several factors: time an aircraft is scheduled to spend at a stand, positioning time of the aircraft and buffer time between two visits. Total capacity of stands at AAS is determined by:

- the number of stands;
- the type of aircraft each stand can accept;
- mix of aircraft types that uses the airport;
- minimum handling time;
- governmental rules;
- and preferences of airlines.

The assignment of aircraft to an aircraft stand is done based on the directive Regulation Aircraft Stand Allocation Schiphol (RASAS), preferences of airlines and other parties such as ground handlers and according to the knowledge and experience of the gate planner. The restrictions security rules, border status rules and physical limitations are always taken into account when planning. Furthermore some other policies are taken into account when planning.

Demand for stands during the day is determined by

- air traffic demand in general;
- peak pattern;

- slot capacity;
- runway capacity;

• and fleet developments.

Department Aviation Statistics and Forecasts (ASF) creates high, medium and low flight schedule scenarios for Summer season over 5 years which are the input for all departments within AAS responsible for processes (passenger service, terminal, baggage, airside) to perform integrated capacity planning. The integration and adjustment of capacity of all processes is of importance because the passengers, aircrafts and baggage will flow through all processes.

Currently AAS is performing midterm capacity planning for aircraft stand area with an Excel spreadsheet. With flight schedule information the maximum number of gates needed per category per day is calculated. This static capacity is compared to the available gates and remote stands in the year of analysis. In 2006 an allocation model is developed in Enterprise Dynamics – Gate Capacity Manager (GCM) – in cooperation with the company INCONTROL, this model can allocate a flight schedule rule-based. This model was intended to use occasionally to run the assignment process of aircrafts to flights with changes in parameters in order to analyze capacity and run scenarios, however this model is currently not used.

To make a comparison between the activities at Schiphol Group and other airports, several airports who needs to focus on this balance as well are contacted by e-mail and telephone to answer the following question: "Do you use a (simulation) model as tool for decision making for policy changes and/or infrastructural changes/investments of the aircraft stand area (gates and remote stands)?".

• Frankfurt Airport uses the AirTop simulation software for aircrafts and the simulation software CAST vehicle for traffic of aircrafts at airside. Besides the pure quantity question the question of quality plays a significant role. Quality in terms of waiting times for aircrafts and passengers, driving times for aircrafts at airside and terminal configuration.

- Aéroports de Paris (ADP) uses for the operational planning of flight-to-gates a tool called OSIRIS. The tool depends on specific and detailed flight schedules which are known short time before day op operation and therefore the tool is only used for operational planning. For tactical planning ADP uses standard sizing methods, based on gate and remote stand productivity and forecasts.
- Dubai Airport uses the Inform GmbH stand planning tool, Dubai recently purchased this tool. This tool is used to built a future stand layout and with the forecasted flight schedule for that same period of time it is simulated if the capacity can accommodate the demand.

The decision making cycle is visualized from forecasting the flight schedule, performing capacity analysis, integrating all processes in a development plan and finally investment decisions. For every step in the cycle the responsible department is indicated. It can be concluded that based on the flight schedule a static capacity analysis is made and with qualitative insight of the department PMA the forecast for shortages or overflow of aircraft stands is made. Management team Aviation is responsible for making decisions based on this information to safeguard the balance between demand and supply. Furthermore, shortcomings in the cycle are described.

3. Stakeholder Analysis: stakeholders involved in gate and remote stand planning

In order to implement the tool in the decision making procedure with the different stakeholders within Schiphol Group and the external stakeholders an overview of interests and objectives is needed. When interests of different stakeholders are known conflicts can be minimized or even avoided. By studying the logistics at an airport, it will be found that the large number of actors involved in every flight, in combination with the time critical processes, are the main reasons for the complexity of airport logistics. In the decision making process whereby the midterm planning tool plays a role different stakeholders are involved. The departments within Schiphol Group have all the same main objective namely the objective of the airport. First, the objective and interest of the airport will be explored. The responsibilities – and thus their interests – of the departments will be outlined. Furthermore the objectives and interests of airlines and handling agents will be discussed shortly.

3.1 Stakeholders objectives and interests

In this section the identified stakeholders and their objectives and interests will be discussed with the use of objective trees. The aim of an objective tree is to specify an actor's objective and to give an insight into the causal relationships between the aim and sub-objectives (Bots, 2002).

3.1.1 Amsterdam Airport Schiphol

The main task of Schiphol Group – the exploiter of AAS – is to provide infrastructure for handling aircrafts, passengers and baggage and facilitate the processes of the airlines. To accommodate the growing market demand the airport needs to offer sufficient capacity at competitive prices. The business area Aviation provides services and facilities to airlines, passengers and handling agents. To enhance the competitive position of AAS, Aviation is looking forward and invest when needed to provide sufficient operational capacity, be cost efficient , to have enough airspace and environmental capacity, have an efficient operation and that the accessibility of the airport is good (www5).

AAS wants to accommodate growth now and in the future to enhance competitive positions as Europe's preferred airport. To do so, the airport needs to be cost efficient and needs to maximize the attractiveness of the airport and the surroundings. To accommodate the growth it is needed to know what demand figures will look like in the future and to provide sufficient capacity for all processes. To provide sufficient capacity and minimize infrastructural investments the infrastructure must be used in an efficient way. The productivity of gates must be maximized, so the number of aircrafts the gate can accommodate per hour must increase (dynamic capacity). To do so, efficient allocation of flightto-gates is an important factor in operation. The airport is responsible for the planning of aircraft stands, assigning aircraft to an aircraft stand. This task has to be done within several constraints such as border status, security rules and physical limitations. Furthermore the allocation of flight-to-gate and the service level to the carriers have a direct link. When carrier X wants to be allocated in the peak morning to a particular gate and this is not authorized by airport operation the service perception of this carrier will decrease.

The objective tree in figure 13 is validated with the problem owner.



Figure 13 Objectives AAS

3.1.2 Airlines

At AAS 88 airlines are operational. Air – France / KLM and their partners of the worldwide SkyTeam alliance are the biggest airlines at AAS. Low cost carriers such as EasyJet and Bmibaby operate from Schiphol, using the low-cost pier H.

In figure 14 an overview is given of the percentages of air transport movements per airline segment.



Figure 14 Air transport movements per airline segment (Schiphol Group, Traffic Review 2010, February 2011)

In general airlines would like to offer a reliable and high quality service to satisfy customers and attract new customers. Reliability is often described as punctual flight performance, which means

that on-time performance is high. On the other hand airlines would like to be cost efficient and offer good and competitive prices to their customers, therefore visit costs must be competitive. In this project airlines have a stake due to the planning of their aircrafts to specific places at the terminal or not-connected to the terminal and the costs for towing movements, parking charges and customer satisfaction (walking distances, transfer possibilities, etcetera). The airline itself is responsible for managing the aircraft handling process – from arrival till departure – or can hire a handling agent to perform this task. The objectives for low-cost airlines will be slightly different because these types of airlines focus more on competitive prices, punctual flight schedules and fast turnaround time and less on high quality of service.





3.1.3 Handling agents

At AAS several handling agents are active that are hired by airlines to perform the handling activities of an aircraft. The handling agent can minimize its costs by an efficient use of the handling equipment and crew. An efficient use of the handling equipment and crew is possible when handling activities are concentrated to one specific place at airside. By grouping of flights this can be arranged, however this can have major impact on the capacity and availability of the gates. Handling agent is responsible for providing sufficient equipment and crew needed to perform the aircraft handling process. Therefore the handling agent would not except if flights are allocated apart from each other and not concentrated to one spot.

3.2 Schiphol Group: internal stakeholder engagement

Within Schiphol Group several departments may be affected when a new support tool for aircraft stand capacity analysis is implemented. For the clarity the organizational diagram (with only indicating the departments involved in this project) is visualized in the following page.

First of all the department Airside Operations (AO) is of relevance. The primary process of AO is to direct and facilitate the flight- and aircraft handling in a 24/7 operation. The objective and responsibility of AO is to offer sufficient operational capacity at airside in the coming 5 years and has the fundamental knowledge of the processes at airside. Within AO the employees with the job function Process Manager Airside (PMA) are responsible to offer sufficient capacity the coming 5 years. The unit Capacity Management (CAP) is indicated as stakeholder and has as main goal to provide timely sufficient, reliable and sustainable capacity for AAS its airlines and passengers. Furthermore management team Aviation (MT-A) will be affected by the support tool because MT-A makes decisions for investment and changes in procedural policies. And the department Aviation, Statistics and Forecast (ASF) are involved due to their task of delivering the forecasted schedule. The responsible employees for offering sufficient capacity of other processes may be affected by the new support tool due to the alignment of capacity planning for all processes. Passenger services (PS) for the passenger flow, terminal configuration and baggage. At last the department ICT / Enterprise & Strategic Services (business Manager ICT Airside Operations) is a stakeholder due to the centralized position for the support for new software and tools. However this department does not participate in the decision making.



Figure 16 Responsibilies visualized in organization chart Aviation

At the end MT-A is responsible for providing sufficient capacity, however OPS is the unit who needs to perform the analyses and inform and notifies MT-A in a timely manner. During this project there were several discussions about changes in the organizational diagram. CAP will be abolished and the ADI department will be a part of OPS and will play an advisory role. In November 2011 MT-A will take a final decision on how the OPS organization will look like with the integration of the ADI employees. The proposed suggestions for the tool and decision making procedure in this thesis will not be affected enormous by those changes.

The stakeholders and their position in the decision making cycle – the cycle introduced in the previous chapter – can be visualized according to figure 17.





The current capacity planning approach for gate and remote stand capacity is not sufficient for the dynamics of the aircraft to gate planning and the current occurring critical balance between demand and supply of gates and remote stands. The suggestions for improvements and the 'sense-of-urgency' for using simulation tools in midterm planning need support of all internal stakeholders. Stakeholder engagement is the process by which an organization involves people and/or groups who may be affected by the decisions it makes or can influence the implementation of its decisions. For this project the 'decisions' are related to the implementation of a computational support tool and improvements to the decision making cycle, the 'project'.

Steps in Engaging Stakeholders:

- (1) Identify important stakeholders and their interests
- (2) Assess the power and influence of stakeholders in relation to the project
- (3) Determine appropriate project response to each stakeholder
- (4) Plan which stakeholder will participate in the project cycle
- (5) Develop strategy for building participation and stakeholder commitment

The important stakeholders are identified. Assessing the power and interest of each internal stakeholder can be analyzed using the power versus interest grid from (Eden & Ackermann, 1998) as described in (Bryson J., 2004). Deciding which stakeholder has what kind of power and interest is based on experiences in the organization and their objectives. Obviously AO-PMA have interests in the project because this department initiated the project, this department also needs to take care for budget for improvements on the support tool. Their power in that case is high. AO-PMA has the knowledge of the gate and remote stand system and also has experiences with operational gate planning. Not to forget that AO-PMA took the responsibility the last years for facilitating sufficient capacity of gate and remote stands based on their current method of analysis. However, their power in deciding on investments needed to accommodate future demand is not that high. CAP needs to provide timely sufficient, reliable and sustainable capacity for AAS its airlines and passengers and depends on the analyses of AO-PMA. Their interest is high, however not that high as the interest of AO-PMA, after all AO-PMA is responsible for performing the correct analyses and delivery of validated capacity conclusions. CAP has high power when considering their position in the decision making cycle. MT-A makes the final decisions for investments based on information inputs of AO-PMA and CAP. However, their interests in the improvements for capacity planning will not be that high but their influence on providing budget is large. ASF will have significantly high interest in performing better capacity analysis because ASF does want to avoid building infrastructure on assumptions, however will have influence on implementing the improvements in the decision making cycle. ICT did not participated in the development of the GCM tool in 2006, AO-PMA initiated this project themselves. However, considering their knowledge and integration with other processes it is recommended to use their advice. ICT has no large power in this project but will have a significant interest. In figure 18 the stakeholders are placed in the power versus interest grid.



Power (Influence)

Figure 18 Internal stakeholders in power versus interest grid

Different engagement tactics are available according to the level of power and contribution a stakeholder makes to the successful implementation of the project: inform, needs-based solutions,

engage in groups or engage 1:1. The more power and interest (contribution), the more time spent with the internal stakeholder (Copeman, 2010).



Figure 19 Stakeholder engagement matrix (Copeman, 2010)

Before identifying which tactic must be applied to what stakeholder the goal of the project must be communicated. The key to engagement for this project is clarity about what the project is designed to achieve and the advantages of the project in relation to current capacity analysis.

3.3 Concluding remarks stakeholder analysis

Three important stakeholders are analyzed and internally the responsibilities of departments are described. This analysis has given insight in some important objectives and interdependencies between stakeholders that need to be taken into account during all phases of decision making procedure. Some important conclusions are bullet-wise reported:

- AAS wants to accommodate growth now and in the future to enhance competitive positions as Europe's preferred airport.
- The airport is responsible for the planning of aircraft stands, assigning aircraft to an aircraft stand. This task has to be done within several constraints such as border status, security rules and physical limitations.
- Department AO PMA is responsible for providing reliable numbers on demand and supply balance for midterm planning horizon. Capacity management needs to provide timely sufficient, reliable and sustainable capacity for AAS its airlines and passengers. Management team Aviation is responsible for taking decisions on infrastructural or procedural changes on aircraft stand area.
- AAS wants to deliver a high service level to its customers the airlines.
- Airlines wants punctual service, convenience for their passengers and lower visit costs. In relation to the planning of aircraft stands airlines would like to see that their preferences are taken into account when planning.

• Handling agents wants that their resources such as crew and equipment are efficiently and cost-effectively usable. Therefore they would like to see that aircrafts the handling agent is handling are clustered and this preference influences the planning of aircrafts to gates.

For the success of implementation of the improvements of mid-term capacity planning (support tool and organizational issues) stakeholder engagement is necessary. For this purpose the power and interests for the project of internal stakeholders of different departments within Schiphol Group is analyzed by using the power versus interest grid. It can be concluded that engagement of MT-A, CAP, management of AO-PMA and ASF is needed. Several engagement tactics are known and described. How to engage the important internal stakeholders is explained in the last phase, the implementation phase.

4. Key performance indicators aircraft stand area

During interviews, observations and discussions with AAS employees it became clear that there is a need for a tool which can analyze different scenarios or in other words perform what-if analyses for the allocation of flight-to-gate. However, analyzing different scenarios is a very broad activity and detail level and output indicators should be defined more clearly. Important to know what kind of scenarios and detail level, the indicators needed to support decision making for the match of demand and supply on aircraft stand area and the factors to evaluate the output on.

4.1 **Possible scenarios for analysis**

After discussions with the problem owner several examples for what-if analyses were discussed:

- changing the characteristics of the gates/buffer stands in terms of Schengen / Non-Schengen status (border status) in order to measure the influence of this restriction on the capacity;
- possibility to add more gates/buffer stands;
- possibility to allocate 100% flights from flight schedule elsewhere to investigate impact or treat 100% flights as normal flights (security);
- investigate the impact of upgrading / downgrading in terms of category of gates;
- investigate the impact of changes in rule setting.

Due to the uncertain elements in midterm planning and the dynamic nature of forecasting in the aviation industry, as discussed in section 2.2, scenario planning is a good instrument to explore the future. Scenario planning (sometimes called "scenario and contingency planning") is a structured way for organizations to think about the future (www8). Scenario generation is already applied within Schiphol Group by the department ASF for generation of the forecast flight schedule, three scenarios are generated (high, medium and low) by changing input on the different key drivers for demand¹⁵.

For capacity planning it will be of relevance to perform sensitivity and what-if analyses. Sensitivity analysis is a technique for systematically changing variables in a model to determine the effects of such changes. What-if analysis can be defined as inspecting behavior of a complex system under some given scenario. But not the kind of scenarios in changing the key drivers for demand, but changing the factors which influence the demand for gates and remote stands such as fleet characteristics, peak pattern and arrival and departure patterns (delay).

For AAS it could be the issue if a particular investment should be made. Should AAS put millions in more gates, or should it invest in a more efficient allocation of flights by changing policy?

The variables for scenarios can be defined as:

(1) Infrastructural

The assessment of implications on airport operations as a result of supply-side interventions.

(2) Policy The assessment of implications on airport operations as a result of new types of aircraft, procedures, concepts like CDM and different rule setting.

¹⁵ Economic development, emission trading scheme, oil price developments, market share of AAS in catchment area and market share in the transfer market.

(3) Uncertain elements

The assessment of implications on airport operations as a result of demand changes affecting the volume of traffic.

From the discussions and examples it became clear that the analyses are rather detailed in nature. Creating scenarios with changes in characteristics of flights and stands will lead to a microscopic level of planning.

4.2 Performance indicators aircraft stand area

To be able to get an overall picture of the performance at the airport, it has to be divided into measurable parts, called indicators. Those indicators are of influence on decisions higher management will make on aircraft stand area, so it is needed to define the indicators in order to know what the tool needs to bring forward.

Eurocontrol defined key performance areas (KPA) and the indicators selected to these areas are called key performance indicators (KPI) and aim to reflect the goals, be key to the success and be measurable. The defined areas are: safety, capacity, cost effectiveness, efficiency, environmental sustainability and harmonization of operational procedures and practices (www7). Others can be availability, robustness and security. Those defined areas can be indicated as objectives. In most cases an airport has the ambition to fulfill all these objectives, at least to some degree. This is often complicated as some of these objectives are contradicting. These contradictions can be illustrated by a high degree of safety and security that is not always profitable or by effectiveness and robustness which sometimes are contradicting.

The research project SESAR Joint Undertaking is divided into sub-projects called work packages (WP), one of the WP is to identify airport KPIs and performance drivers for the selected KPAs (SESAR Joint Undertaking – WP 6.5.1, September, 2010). For this project the focus is on the defined KPA capacity:

KPA capacity addresses the ability of the airport to cope with air traffic demand (in number and distribution through time and space). It relates to the throughput of that volume per unit of time, for a given safety and quality level.

The defined objective is:

Manage the airport capacity (runways, taxiways and aircraft stands) in such a way that the capacity imbalances are notified in the earliest stage possible and the occurrences of capacity imbalances kept to a minimum.

The KPI for this area is the stand capacity shortage, in the planning phase this is represented by the stand allocation mismatch and can be measured in number of aircrafts and unit hour. To measure capacity shortage the total number of aircraft for which no stand is available at the scheduled inblock time (SIBT) can be evaluated during the stand allocation process in planning phase. Performance drivers for this KPI are: stand allocation procedures (rules, priorities set by airlines), aircraft stand lay-out, turnaround performance of the aircraft and disruptions or external events. AAS should define – based on their acceptable service level – the X and Y for the following target: not more than Y aircraft waiting more than X minutes for a parking position during a maximum of Z hours within a predefined time frame.

This defined KPI by the SESAR work package (1) - with cooperation of Schiphol employees - is an output criteria for the tool. Because AAS has the aim to handle as most aircrafts as possible at an connected stand the KPI became more detailed (2). In the planning phase the predefined set of rules (RASAS) are taken into account when allocating the aircrafts to a stand. So, the towing rules are taken into account as well. However towing movements must be paid by the airline and are in their perspective not convenient and more expensive than staying at the stand from arrival till departure. Therefore the third KPI are the number of towing movements. To support decision making on midterm level it is needed to know what the capacity shortage is, this can be done by KPIs (1) and (2), following it is needed to know what needs to be changed to the stand lay-out in order to offer a particular service level to the airlines visiting AAS (4). On cost effectiveness level the occupation of the gates and remote stands per category needs to be measured per time unit, so which percentage of the capacity is used at a particular time. The stand resources should have a reasonable high utilization; high enough to be considered effective, but without compromising the airport robustness. For the handling agents – and thus for the airlines who pay the handling agents as well – it is of great importance that the activities for one handling agent are concentrated as much as possible on aircraft stand area. Therefore the concentration level of handling agents is an important indicator as well.

KPIs:

- (1) the total number of aircraft for which no stand is available at the scheduled in-block time (SIBT) MINIMIZE
- (2) the total number of aircraft for which no connected stand is available at the scheduled inblock time (SIBT) - MINIMIZE
- (3) the total number of towing movements MINIMIZE
- (4) the total number and characteristics of stands needed to be built in order to offer service level X MINIMIZE INFRASTRUCTURAL COSTS, MAXIMIZE SERVICE LEVEL
- (5) assigned flight-gate preferences in % taken into account during planning
- (6) the stand occupation in % per category per 5 minutes MAXIMIZE
- (7) concentration level of handling agents (number of handling objects which are concentrated for one handling agent) MAXIMIZE

In appendix III a system diagram can be found with causal relations determining the indicators and influences by external factors and instruments of AAS.

Furthermore the KPA financial costs and benefits, delays and robustness and level of service are of relevance. Delays do play a particular role in this project because delays have a major impact on the utilization rate of the gates and remote stands. Airport authorities would like to see robustness in gate planning in order to limit the amount of gate changes during the day of operation, a robust planning is not sensitive for disruptions.

Service level which offered by the airport to its customers – the airlines and their customers the passengers – can be comprehended in several ways. For determining the service level the International Air Transport Association (IATA) level of service can be used. IATA established norms and are presented in the level of service (LOS) framework consisting of six categories from LOS "A" to "F" (Neufille & Odoni, 2003).

LOS	Flows	Delays	Comfort
A – Excellent	Free	None	Excellent
B – High	Stable	Very few	High
C – Good	Stable	Acceptable	Good
D – Adequate	Unstable	Passable	Adequate
E – Inadequate	Unstable	Unacceptable	Inadequate
F – Unacceptable	System breakdown		Unacceptable

Table 5 Level of service framework – IATA (de Neufville & Odoni, 2003)

The manager of a process at the airport needs to determine based on the strategic goals of AAS which service level the airport wants to offer to its customers in which situation, e.g. a standard minimum or a LOS for peak hours. If preferences of airlines or handling agents for particular stands or stand areas are taken into account when planning the flight-to-gate the service level increases. However, service level and capacity level are in contradiction with each other because preference of stakeholders do decrease capacity. So, decisions should be made for providing or not providing a particular service level - benefits for the airport and airlines – during a particular time in the year and on the day versus the costs for infrastructural changes.

4.3 Concluding remarks indicators

This section started with examples of what-if analyses. The what-if analyses can be categorized in infrastructural or procedural changes, e.g. a change in the number of available gates or a change in the rule-setting. The concept of scenario planning is introduced as instrument to explore the future and assist decision making. Experts set out a number of possible stories and use the tool as support to analyze the outcomes. Furthermore the section discussed the performance indicators which are on influence on decisions that have to be made. First KPAs as objectives were outlined, the defined KPAs of an airport are safety, capacity, cost effectiveness, efficiency, environmental sustainability, harmonization of operational procedures and practices, availability, robustness and security. Those objectives can be contradicting. An important area for the aircraft stand area is capacity, to measure capacity shortage the total number of aircraft for which no connected stand is available at the SIBT can be evaluated during the stand allocation process in planning phase. The contradicting objectives of airline and airport are the towing movements, AAS wants to maximize the number of aircrafts handled per gate per hour, however if towing movements increase the airline have more costs because airlines are responsible for the towing costs. The service level can be represented by the preferences of airlines and handling agents taken into account when allocating an aircraft to a gate, however the more preference the lower dynamic capacity of gates will be, again a contradicting objective. The area delays and robustness is also an important indicator for airport authorities because a robust planning is not sensitive to disruptions and leads to a minimization of gate changes.

5. Evaluating methods for modeling flight-to-gate assignments

In decision making support can be given by computational technologies. After several meetings with the problem owner and other experts it was clear that the tool is needed to perform what-if analyses on the aircraft stand area for infrastructural or procedural changes on gate and remote stand capacity. At present, airport decision makers at AAS lack decision support models and tools able to provide a view of gate area and analyze at a reasonable effort the various trade-offs among different airport performance measures.

This chapter will highlight the difference between analytical models and simulation tools with reference to detail level for each part of the planning horizon. Furthermore from literature an outline of the solution methods for the flight-to-gate assignment problem is given. In the subsequent section the solution methods used in commercial models is described and the choice for a solution method for the decision support tool for the aircraft stand area at AAS is argumented. The last section describes the uncertain elements and how to cope with uncertainty in the planning cycle is discussed.

5.1 Modeling: analytical models & simulation tools

A model is an abstraction of a real situation, a model presents a simplified version of something. The level of simplification depends on the detail level needed for decision making. Modeling allows the user to better understand the problem and presents a means for manipulating the situation in order to analyze the results of various inputs - "what if" analysis - by subjecting it to a changing set of assumptions. Different modeling methods are used in several businesses, methods such as simulation, analytical models and mathematical approaches.

Analytical models can provide effective support for strategic level decisions, and generally require more aggregate description of the process/flow they analyze, while being less labor intensive as compared to simulation counterparts. In terms of their computational accuracy, analytical models are sufficiently accurate for the types of decisions that are suitable to support (Zografos & Madas, 2006). On the other hand Zografos & Madas described in their 2006 article (Zografos & Madas, 2006) that simulation models can provide effective support for operations related decisions, and in general require more detailed description of the process/flow they analyze, while being more labor consuming and computationally expensive than their analytical counterparts. An essential pre-requisite for the use of the simulation models is the availability of a complete, reliable, and consistent set of data needed to calibrate the simulation model for the specific airport and scenario analyzed (Odoni, 1991), (OPAL, Consortium 2003).

Mathematics is used to develop and study analytical models of systems and are built using numbers and symbols that can be transformed into functions, equations and formulas. In mathematical programming, a problem is modeled as an objective function with constraints on the possible solutions, then the resulting model is optimized. Optimization models are used to find an optimal solution (www9). However, if the problem cannot be expressed in a mathematical equation, function or formula other decision making techniques have been utilized such as expert systems or heuristic methods. In those alternative techniques it is possible to implement restrictions such as allocation rules that are not expressible as mathematical equations, functions or formulas, however difficult to guarantee optimality and difficult to guarantee unverified cases (Kitagawa & Takenaka, 2004). For capacity planning for gates and remote stand usually simulation rule-based models are used because the allocation rules specific for every airport cannot be easily expressed using mathematical formulas, equations or functions.

Simulation is a widespread technique for the exploration, design and optimization of complex systems, it replicates a dynamic process in a model. It offers facilities to model real systems by means of computer programmes and to analyze and describe their behavior by changing the simulation parameters (Nyhuis, Cieminksi, & Fischer, 2005).

It can be said that analytical models are capable of doing macroscopic aggregated analyses to support decision making at strategic level and simulation models are able to support decision making at tactical/midterm level with more detailed and microscopic description of the process. In case of this project analytical models – optimization models – can help more efficiently assign daily flights to gates. On the other hand simulation models can imitate the system in order to do what-if analyses by changing the parameters, so simulation models do not calculate what the most optimal allocation is.

5.2 The flight-to-gate assignment: a scheduling problem

The flight-to-gate assignment problem is encountered by gate managers and process managers at an airport on a periodic basis. This assignment should be made in such a way so as to balance the perspectives of the airport, airlines and other stakeholder simultaneously, while providing buffers for disrupting unexpected events and having costs and benefits balanced considering the indicators. However, it is important to distinguish between real-time operation and planning activities. Real-time operation needs more elaborated tools to plan the aircraft to a gate in an efficient way. Midterm planning activities need to evaluate capacity issues and does not need to perform exact aircraft to gate allocation. In literature often models are proposed to support in effective and efficient decision making during the real-time flight-to-gate assignment and re-assignment.

The gate assignment problem can be seen as a scheduling problem. The problem is the type of job shop scheduling problem in which generally a job (a flight) is served once by an available machine (an idle gate), with various constraints and objectives in matching the jobs to machines. Scheduling is a decision making process and it concerns the allocation of the limited resources to tasks over time. The performance of the aircraft stand area is highly dependent on the efficient allocation of the limited resources, and it is strongly affected by the effective choice of scheduling rules.

The details of the problem change with its constraints, objectives, time horizon, solution methods (i.e. optimization, rule-based techniques, meta-heuristics¹⁶, simulation), and purpose (i.e. planning or real-time dispatching) (Murty, Wan, Yu, Dann, & Lee, 2008). The basic gate assignment problem is a quadratic assignment problem¹⁷ and was shown to be NP-hard by (Obata, 1979). In computational complexity this problem is categorized under NP-class of problems. When assigning *m* flights to *n* gates/buffers then a Non-Polynomial (NP) number of combinations are possible $(m!)^n$.

¹⁶ A meta-heuristic is a higher level algorithm, a heuristic method for solving a very general class of computational problems by combining user given black-box procedures. Meta-heuristics can be applied to many different types of problems.

¹⁷ The total passenger walking distance is based on the passenger transfer volume between every pair of aircrafts and the distance between every pair of gates. Therefore, the problem of assigning gates to arriving and departing flights at an airport is a Quadratic Assignment Problem (QAP).

As the gate assignment is a type of job-shop scheduling problem, its complexity increases exponentially if constraint size such as number of flights, available gates, aircrafts, flight block time etcetera. changes which is a very realistic assumption in airport operation. The NP-hard characteristic of the problem implies that there is no known algorithm for finding the optimal solution within a polynomial-bounded amount of time. In practice, AAS may handle more than 1000 daily flights at more than 100 gates which results in billions of variables (Wipro Technologies, 2009).

A well-constructed schedule must satisfy a set of strict rules and constraints (Dorndorf, Drexl, Nikulin, & Pesch, 2007):

- (1) one gate can process one aircraft at the same time;
- (2) service requirements;
- (3) space restrictions with respect to adjacent gates must be fulfilled;
- (4) minimum ground time of the aircraft;
- (5) and minimum time between subsequent aircraft have to be assured.

The multiple criteria and multiple constraints of the problem make it very unlikely that an optimal solution can be found and verified (Dorndorf, Drexl, Nikulin, & Pesch, 2007).

5.3 The flight-to-gate assignment problem: solution methods

During an elaborated literature review on the gate assignment problem it became clear that several methods, algorithms and heuristics (and combinations) are used to solve the gate assignment problem. The following sections will describe the solution methods, however this description is not exhaustive. First the terms heuristics and algorithm will be described.

5.3.1 Heuristics and Algorithms

An algorithm is a finite set of well-defined instructions for accomplishing some task. It starts in some initial state and seeks for an exact solution or approximation that is close to the true solution. For some complicated problems, such as the flight-to-gate assignment problem ,no straightforward solution technique is known. For these problems, heuristic solutions techniques may be the only alternative. Heuristic refers to experience-based techniques for problem solving. Heuristic methods are used to speed up the process of finding a satisfactory solution, where an exhaustive search is impractical.

Approximation algorithms are an approach to attacking difficult optimization problems. Approximation algorithms are often associated with *NP*-hard problems. Since it is unlikely that there can ever be efficient (Polynomial Time) exact algorithms solving *NP*- hard problems, one settles for non-optimal solutions, but requires them to be found in polynomial time. Unlike heuristics, which usually only find reasonably good solutions reasonably fast, one wants provable solution quality and provable run time bounds.

5.3.2 Solution methods

An optimization problem is the problem of finding the best solution from all feasible solutions. Engineers, analysts, and managers are often faced with the challenge of making tradeoffs between different factors in order to achieve desirable outcomes. Optimization is the process of choosing these tradeoffs in the 'best' way (Onwubolu & Babu, 2004). However, an optimal solution for the gate assignment problem cannot be found.

Optimization makes use of maximization or minimization of objective(s) under a set of constraints in the form of mathematical variables. For instance minimize walking distance of passengers or maximize total flight gate preferences. The single objective gate assignment problem with the objective minimize passenger walking distance is widely been studied. Methods such as branch-and-bound algorithms, integer programming, linear programming, expert systems, heuristic methods, tabu search algorithms and various hybrid methods were reported to minimize the distance (Hu & Di Paolo, 2007).

Dorndorf et al. (Ding, Lim, Rodriques, & Zhu, 2005), (Dorndorf, Drexl, Nikulin, & Pesch, 2007), (Yan & Tang, 2007) and (Yan, Tang, & Hou, 2010) discuss developments in solution methods for the gate assignment problem. A number of gate assignment models have been developed and tested. For example, (Babic, Teodorovic, & Tosic, 1984) formulated the gate assignment as an integer programming, and uses branch and bound technique, with some enhancements to accelerate computation, in order to determine a solution of the gate assignment problem. The objective is to reduce the number of passengers who have to walk maximum distances. (Mangoubi & Mathaisel, 1985) take into account transfer passengers as well by using greedy heuristics and lineair programming relaxation to solve the gate assignment problem. (Bihr, 1990) uses 0–1 integer programming to solve the minimum walking distance gate assignment problem for fixed arrivals in a hub using a simplified formulation as an assignment problem.

(Diepen, van de Akker, Hoogeveen, & Smeltink, 2007) is optimizing the idle time between all consecutive flights in order to find a robust schedule for the daily planning. The problem is formulated as an integer lineair program (ILP) and the authors use an alhorithm based on column generation to find a good approximation for the optimum of the model. Experiments show good results, however those experiments did not incorporate complex rule settings which are used by gate planners to plan the aircrafts to a gate.

However, the gate assignment problem has a multi-objective¹⁸ nature. Objective functions often used are the minimization of the total passenger waiting time, the total passenger walking distance, the number of off-gate events, the range of unutilized time periods for gates, the variance of idle times at the gates, or a combination of the above. All these objectives can be divided into two big classes: passenger-oriented and airport-oriented objectives. It is difficult to cope with multiple objectives in the complex gate assignment problem.

(Dorndorf, Drexl, Nikulin, & Pesch, 2007) propose two new optimization models for gate scheduling, the models they propose are multi objective and therefore take into account the real multiple criteria nature of the problem. Computational experiments showed the effectiveness of the proposed technique especially in comparison with the results of a modern rule based decision support system. However there are still open research directions. One problem consists in developing solution techniques for gate scheduling with

¹⁸ The solving method provides a trade-off between several objectives which are usually in conflict. Finding a compromise between several goals may positively influence passenger satisfaction and save extra money for airport operator and airlines companies.

multiple criteria and including all technical and temporal requirements. (Dorndorf, Drexl, Nikulin, & Pesch, 2007) describe a technique most frequently used in practice for dealing with multiple objectives. This technique is criteria aggregation by adding new parameters – weights or goals – to the problem. These parameters can be interpreted as values of decision makers' preferences, and the partial criteria can be ordered by importance due to preference values. The authors are optimistic that multiple criteria meta-heuristics like Pareto Simulated Annealing and Genetic Local Search, can be efficiently applied to the criteria aggregation technique.

• (Yan & Huo, 2001) proposes a multiple objective model and is formulated as a multiple objective 0-1 integer program. To efficiently solve large-scale problems in practice, they used the weighting method, the column generation approach, the simplex method and the branch-and-bound technique to develop a solution algorithm. The first objective tries to minimize passenger walking time while the second objective aims at minimizing passenger waiting times. The authors argue that, e.g. during peak hours, an aircraft might have to wait for an available gate, and hence passengers have to wait on the aircraft until a gate is available.

The problem is an integer program with multiple objectives and quadratic constraints. Such a problem is inherently difficult to solve. Scheduling theory and multicriteria optimization are a topic of growing interest both in theory and practice. However, those topics were not researched a lot in combination. (Drexl & Nikulin, 2008) tackle the problem by Pareto simulated annealing. Due to the fact that computational experiments show good results, the tests with the designed algorithm contained relatively small data and were not applicable to real-life situations at an airport. Taking into account fyzzyness of flight arrival and departure times is also an area for further research (Drexl & Nikulin, 2008).

The analytical models described in literature define the problem in several ways and use exact solution methods or heuristics to solve the model.

While traditional operations research techniques have difficulty with uncertain information and multiple performance criteria and do not adapt well to the needs of operation support, many researchers focus on the design of the so-called rule-based expert systems (Dorndorf, Drexl, Nikulin, & Pesch, 2007). The rule based technique uses a set of rules and the production rule (if <condition> THEN <conclusion>) to produce assignments of flights to gates/buffers. To find a near-optimal solution heuristics scheduling methods can be chosen to satisfy constraints. The number of factors to be taken into account is large in the expert system. The most crucial task is to identify all the rules, order them by importance and list these rules appropriately (Dorndorf, Drexl, Nikulin, & Pesch, 2007).

In their book about rule based expert systems Sasikumar and Ramani (Sasikumar & Ramani, 2007) discuss the advantages and drawbacks of rule based systems. Meaning and interpretation of each rule can be easily analyzed due to the uniform syntax, the syntax is simple and it is easy to understand the meaning of the rules, modifying and adding new rules is easy to perform and data and control are separated which creates possibilities that the same control can be used with different rule bases and the other way around. However, there is no systematic procedure for creating rule based systems, most systems are built based on intuition, prior experience, and trial

and error. Another drawback is that rule based systems provide no mechanism to group together related pieces of knowledge and that all rules at the same level in hierarchy. A limitation of rule based systems is that human experts do not always give explanations by describing rules they have applied.

5.4 The solution methods used in available commercial tools

The planning tools used at AAS and other airports (Frankfurt Airport, Dubai International Airport and Aéroports de Paris (ADP)) are described below.

- The current used Gate Management System for operational planning activities of the flightto-gate planning is done based on a rule setting, *if...then* rules and a score list for each gate.
- AirTop is a rule-based gate-to-gate fast time simulator, has a scenario editing module, simulation run and playback module.
 - AirTop is used by Frankfurt Airport
- The CAST Aircraft traffic generation is based on a central flight schedule handling system. Following the chronological course of the schedule, flights are performed. Delays and schedule deviations can be considered based on probabilities. Several functions enable the user to consider specific conditions and quickly generate scenarios. Several restrictions and priorities may be defined in order to get the real life stand utilization.
- Quintiq (Den Bosch, the Netherlands) provides advanced planning and scheduling software that supports airports to optimize resource utilization. Quintiq offers aviation solutions for planning issues; including gate and stand planning. The software takes into account all applicable rules and constraints, such as airport specific rules, arrival patterns, and airline and handler rules and preferences. For assigning arrivals and departures to stands, the planner gets decision support via scores and colors indicating suitability.
 - Brussels Airport is using this software for the tactical and operational gate planning.
 By implementing the software solution Brussels Airport wants to support expected growth and improve the service to its airline customers.
- Inform Groundstar Stand Planning plans a flight schedule rule based. The business rules are defined in the base data of the system. A user interface called Base Data Editor makes it possible to maintain in a comfortable way the set of rules for the allocation.
 - o Inform stand planning is used by Dubai International Airport

5.5 Solution method for the decision support tool for the aircraft stand area at AAS

The 'sense of urgency' for notifying and managing the imbalances at the aircraft stand area of AAS in an early stage grows due to the higher occupation rate of the stands and the time needed to act on those imbalances. For this matter AAS needs a tool in which what-if analyses can be done which give insight into the dynamics and interdependencies of the system. The system of assigning aircraft to gates has multiple constraints, multiple criteria, multiple objectives and conflicting objectives. Moreover, the complexity increases due to the stakeholders involved in the flight-to-gate assignment and the amount of assignments which have to be planned each day.

At AAS there are many allocation rules that need to be taken into account when planning the aircrafts to a gate, next to the allocation rules known by the gate planner and which are not

documented the most important documented allocation rules are recorded in the Regulation Aircraft Stand Allocation Schiphol (RASAS). The level of detail in the allocation rules depends on the scenario which the researcher wants to run with the decision support tool. Therefore, the tool must be flexible in terms of adding, changing or deleting constraints/rules.

Since the gate assignment problem has the characteristic of a NP-hard class of problem – as described in the previous sections – there is no known algorithm for finding the optimal solution within a polynomial-bounded amount of time. The multiple criteria and multiple constraints of the problem make it very unlikely that an optimal solution can be found and verified. Several attempts are made to develop and test solution methods for the problem, however often those tests are done with a small set of data. Computational experiments showed the effectiveness of the proposed technique in (Dorndorf, Drexl, Nikulin, & Pesch, 2007), especially in comparison with the results of a modern rule based decision support system. However, the airports researched in the benchmark and the described software tools use the rule-based technique with heuristics scheduling methods to satisfy constraints. AAS is also focusing on the rule-based approach on operational level, the new purchased software tool for their operational planning (which also embeds a strategic planning module) uses the rule-based approach.

5.6 Uncertain elements in planning

Uncertainty can have different sources. In this case the following three sources are most important:

- uncertainty due to incomplete knowledge: in decision making decisions have to be taken without knowing all the relevant parameters (input data uncertainty);
- in expert systems uncertainty can arise due to multiple knowledge sources: different experts with expertise on different aspects and levels of the problem;
- in expert systems uncertainty can arise due to shallow reasoning for using rules provided by an expert.

In airport operations there are usually two interdependent stages in the gate assignment process: the planning and the real-time stages. In the planning stage, gate assignment is proposed in advance based on a forecasted flight schedule as discussed in previous chapters. In the real-time stage, AAS may need to reassign flights to gates to meet changes in flight departure/arrival times. It is often the case that departure/arrival times vary in actual operations, making gate reassignment is an ongoing responsibility for airport authorities (Yan, Tang, & Hou, 2010). This project is focused on the midterm planning and not on real-time decisions. However, the uncertain elements in arrival and departure times can have a major impact on the capacity of the gates and buffers and thus the variability in arrival and departure times should be taken into account in midterm planning as well. After all capacity is defined as the ability of the airport to cope with the throughput of air traffic demand per unit of time for a given safety and quality level. The level of uncertainty can be introduced in two manners, namely defined deterministically and where it is given stochastically with some probability measure.

A gate schedule should be insensitive to small changes of input data; in other words schedule flexibility is required. Input data uncertainty in gate scheduling may have a couple of reasons: (1) flight or gate breakdown, (2) flight earliness or tardiness, (3) emergency flights, (4) severe weather
conditions, (5) errors made by staff and many other uncertain elements are possible (Dorndorf, Drexl, Nikulin, & Pesch, 2007). Other causes of input uncertainty can be economic incentives of the airlines to hold an aircraft at the ground (hub-concept) and technical problems (refueling, fast maintenance, etcetera)¹⁹. The predictability of flight operations is of major importance in airport scheduling. Tightening the distribution of arrival times allows time buffers in block times to be reduced while maintaining punctuality. The cost of one minute of buffer time for an A320 is estimated on 49€ per flight (EUROCONTROL, 2005). Cutting buffer time will save money and be more cost effectiveness. For the purpose of this project it can be said that a scenario with less buffer time can be analyzed with the tool.

The punctuality of AAS from 2001-2010 is visualized in figure 20. Arrival punctuality is defined as percentage of passenger aircrafts that arrive no more than 15 minutes after the scheduled arrival time. Departure punctuality is defined as percentage of passenger aircraft that depart no more than 15 minutes after the scheduled departure time. Those figures show the delay in terms of late arrival, however for the gate planning the early arrivals are of relevance as well.





5.7 Concluding remarks modeling flight-to-gate assignment

This section discussed three main topics, namely the difference of detail in analytical and simulation models, solution methods for the flight-to-gate assignment problem and uncertain elements in planning. Analytical models are capable of doing macroscopic aggregated analyses to support decision making at strategic level and simulation models are able to support decision making at tactical/midterm level with more detailed and microscopic description of the process.

The gate assignment problem can be seen as a scheduling problem. The basic gate assignment problem is a quadratic assignment problem²⁰ and was shown to be NP-hard by (Obata, 1979). In computational complexity this problem is categorized under NP-class of problems. As the gate assignment is a type of job-shop scheduling problem, its complexity increases exponentially if

¹⁹ Interperation of interview Lotte Harbers, March 2011, at that time Process Manager Airside.

²⁰ The total passenger walking distance is based on the passenger transfer volume between every pair of aircrafts and the distance between every pair of gates. Therefore, the problem of assigning gates to arriving and departing flights at an airport is a Quadratic Assignment Problem (QAP).

constraint size such as number of flights, available gates, aircrafts, flight block time etcetera. changes which is a very realistic assumption in airport operation. The NP-hard characteristic of the problem implies that there is no known algorithm for finding the optimal solution within a polynomial-bounded amount of time.

In literature the problem is formulated as integer programming, integer linear programming, multiobjective 0-1 integer program, etcetera. The problem is solved using several methods to develop a solution algorithm, e.g. branch and bound techniques, column generation algorithm, meta-heuristics like Pareto Simulated Annealing and Genetic Local Search. However, the attempts described in literature do not show computational test results which incorporate the complex rule settings which need to be used when planning the aircraft stand area at AAS.

While traditional operations research techniques have difficulty with uncertain information and multiple performance criteria and do not adapt well to the needs of operation support, many researchers focus on the design of the so-called rule-based expert systems (Dorndorf, Drexl, Nikulin, & Pesch, 2007). The rule based technique uses a set of rules and the production rule (if <condition> THEN <conclusion>) to produce assignments of flights to gates/buffers. To find a near-optimal solution heuristics scheduling methods can be chosen to satisfy constraints.

The airports researched in the benchmark and the described software tools use the rule-based technique with heuristics scheduling methods to satisfy constraints. AAS is also focusing on the rule-based approach on operational level, the new purchased software tool (Inform Groundstar) for their operational planning (which also embeds a strategic planning module) uses the rule-based approach as well.

For this project no argumentation can be found to use the solution methods researched in literature because it is not proved that those solution methods can tackle the dynamics and the nature of the problem in the real-life situation at AAS and commercial tools do not incorporate the latest developments in algorithms and solution methods.

Sources of uncertainty can be input data uncertainty, multiple knowledge sources and shallow reasoning for using rules in rule-based systems. Uncertain elements in arrival and departure times can have a major impact on the capacity of the gates and buffers and thus the variability in arrival and departure times should be taken into account in midterm planning.

6. Concluding remarks Analysis Phase

In the analysis phase several aspects are researched in order to map out the context of the problem. The current situation and problems/drawbacks of the situation is visualized and described in the following figure. This figure shows the decision making cycle and the problems circled in red.



Drawbacks / Problems current situation (indicated with a red circle):

 the dynamics of the flight-to-gate assignment system are not taken into account when notifying imbalances on aircraft stand area;
 imbalances are notified merely based on expert judgement of the AO-PMA

employee; (3) decision making process steps are not followed when looking for alternatives to solve imbalances;

(4) there is a lack of standardized measures of performance indicators;

(5) forecast uncertainties and forecast failures are not taken into account

elaborated when planning on the midterm level;

(6) and there is no optimal cooperation between the departments.

As a result investment decisions for procedural and infrastracture changes are made based on a weak analyses on the imbalances of the aircraft stand area and potential solutions.

Design Phase I & II

This phase will outline requirements for a midterm capacity analysis tool for aircraft stand area from user perspective and design criteria. In the analysis phase current and potential tools are discussed and in this phase the tool Gate Capacity Manager (GCM) will be evaluated and improvements will be suggested. The GCM tool version 1.0 is developed in 2006 with the aim of supporting in the decision making on midterm level about the capacity of gates and remote stands. The functionality and heuristics of GCM 1.0 will be highlighted, subsequently the drawbacks of the current 1.0 version are outlined. Improvements are made to develop the GCM 1.1 tool. And suggestions for improvements are done for GCM version 2.0. The purpose for the development of GCM 1.0 is identical to the question of the problem owner and therefore the process at that time is evaluated to map out possible improvements needed for implementation. An example of a scenario is given and this run is performed with the GCM version 1.1.

7. User requirements for support tool aircraft stand area

Finding out what users really want or need is difficult for several reasons. Users often think they know what the problem is and they ignore evidence to the contrary. Another difficulty is the failure to generalize, this occurs when people treat related problems as though they were separate (Sage & Armstrong Jr., 2000). To understand users requirements – user is the responsible person for midterm capacity planning of gates and remote stands – several techniques are used.

7.1 User requirement sessions and the outcome

During the user requirement session the discussion was tried to be structured to compensate for the user's biases. Secondly, existing systems are observed that are very similar in nature and purpose. Furthermore, the system of the allocation of flight-to-gate is intensively observed by field trips and interviews. During a second user requirement session the aggregation level of which characteristics of the system are needed for planning is determined using post-its and an open discussion with the user. In appendix IV this poster can be found. The final aggregation level is decided to be level 3.

After several discussions and interviews the following requirements are the outcome:

- 1. The tool must create a planning on gate and remote stand level.
- 2. Visualization output characteristics:
 - a. Nice to have: Airside: visualization with moving objects during the period of planning
 - b. Nice to have: Gantt charts
 - c. Need to have: Excel export possibilities
- 3. The tool must communicate if there is sufficient capacity for the day chosen to schedule, if yes, what the shortage is and if not show where the capacity shortages lies.
- 4. The input for the tool must be the flight schedule delivered by ASF in .sir format or if .sir format is not possible .xls format.

- a. Flight schedule has the following input data per flight: Flight number, Arrival / Departure, Scheduled time of arrival/departure, Which days per week when flight is operational, Start and end date of this operational period, Arrival: origin, Departure: destination, CAT type, Number of chairs, Passenger/Cargo, ICA/EUR, S/NS arrival, S/NS departure, Segment
- b. Not in the schedule but needed for the analysis: 100% arrival yes/no
- 5. The assignment of flight-to-gate must be based at least on the following fixed parameters:
 - a. Wingspan Categories: CAT 1, CAT 2, CAT 3, CAT 4, CAT 5, CAT 6, CAT 7, CAT 8, CAT 9
 - b. Country Regions: Schengen, Non-Schengen, EU, NEU
 - c. Security Categories, Normal, 100% control (only on arriving flights and characteristic of gate/buffer), USA: profiling (only on departing flights and characteristic of gate/buffer), Israel flights
- 6. The assignment of flight-to-gates must be done according to these allocation rules (according to RASAS document):
 - a. Transfer / Common use area
 - b. Towage
 - c. Segment allocation: Skyteam & partners, Leisure, Low-cost carriers, legacy carriers ICA, legacy carriers Europe, full freighter carriers
- 7. It must be possible to turn off /on or change or add allocation rules.
- 8. The number of gates/buffers and if operational or not must be easy to change.
- 9. The infrastructure characteristics of gates/buffers (wingspan categories, country region, security categories) must be variables and easy to change.
- 10. Strategy push-back Connecting arrival and departure flights must be able in the tool before planning
- 11. Reasonable computing time per operational scenario.
- 12. Data to run the software tool must be easy accessible (preferably accessible internally and not dependent on data of e.g. KLM).
- 13. The flight-to-gate assignment must be reliable.
- 14. All flights have to be assigned to a gate, buffer or dummy gate (dummy gate if capacity of gates/buffers is not sufficient).
- 15. User must be able to test randomly the assignment and zoom in on how the decision for that particular assignment is made.

- 16. The assignment must be valid
- 17. The assignment can be a near optimal solution
- 18. The tool must be user-friendly, which means that :
 - a. Easy import and export functionalities
 - b. Easy to run a scenario with new variables (operational scenario)
 - c. Scroll down menu for changing variables of supply, strategy push-back and policy rules. Shows the current status of the variable and possibility to change/add/turn off or on.
- 19. The tool is understandable and usable after a short description of the usage by an expert or an user manual.

The user, without the help of a programmer, must be able to request information from the database – in this database data is stored such as airline prefixes, country codes, stand characteristics, etcetera – change data in the database, specify parameters and input data for a specific run, run a model and request specific output displays.

7.2 Concluding Remarks User Requirement Analysis

With the help of several techniques the user requirements were derived during two user sessions. During the first session the discussions was tried to be structured to compensate for the user's biases, during the second session a more open discussion was leading in order to define the aggregation level of the tool. And the system of flight-to-gate planning during daily operation is observed during a field trip and existing planning tools are explored. The user requirements can be categorized, the tool must be:

- Usage of the tool:
 - o User-friendliness and easy to understand
 - o Data fully deliverable by AAS
 - o User must be able to zoom in on an assignment and see how decisions are made
- Functionality
 - o Planning on gate level
 - Fixed parameters for the assignment: wingspan, country regions, security
 - o Possibility to turn off/on or add allocation rules
 - Supply (stand lay-out) must be changeable
 - o Communication of capacity shortages
- Performance and output
 - o The assignment can be a near optimal solution
 - The assignment must be reliable
 - o Excel export possibilities of output

8. Design criteria for support tool aircraft stand area

In the previous chapter the requirements are discussed derived from user sessions. The input, output and data criteria will be discussed in this chapter. Furthermore the most appropriate method for matching demand and supply for this project is discussed. This chapter ends with a conceptual model of the support tool, this model shows in a qualitative manner what the tool has to do.

8.1 Input, Output criteria and data availability

Capacity is the ability of the airport to cope with the throughput of air traffic demand per unit of time for a given safety and quality level. So, when the airport is not able to perform this activity a capacity imbalance will occur. Those capacity imbalances should be notified in the earliest stage possible and the occurrence should be kept to a minimum.

Department PMA is responsible for notifying the capacity imbalances for aircraft stand area. Air traffic demand is determined in a high, medium and low flight schedule scenario by ASF for capacity calculation for all processes of the airport. This flight schedule is a detailed forecast and based on a 5-minute schedule and is the demand input for the model. Such flight schedules are used for operational planning as well. The supply component of the model must be formed by databases with stand characteristics and policy rules. The databases should be updated according to the chosen scenario, e.g. if a forecasted flight schedule of 2016 is chosen as demand input the supply must be conform the status as in 2016.

It is recommended to implement In the sourcing module of the tool an option for a level of uncertainty on the input data to run scenarios. This option can be used in several scenarios in order to get insight in the performance of the system. The level of uncertainty can be introduced in two manners, namely defined deterministically and where it is given stochastically with some probability measure. In deterministic scenario analysis there is no uncertainty on the values of the variables, however input parameters are changed and evaluated next to the baseline scenario. The deterministic uncertainty analysis can be seen as a simple sensitivity analysis method. The stochastic analysis will introduce variables which cannot be described with certainty, those variables will be defined as statistically distribution and show variability.

Variables for schedule flexibility:

- Fleet characteristics
 - Changing parameters: e.g. 20% of 73W will be replaced by type 737NG
- Peak pattern
- Arrival and departure times
 - Stochastic analysis: arrival times for Trans-Atlantic flights are distributed conform a particular distribution for a particular time chosen in users scenario

Due to the presence of the uncertain elements in simulating the flight-to-gate planning based on a forecasted flight schedule and the use of heuristics one single simulation is not representative. The initial values do have an expected variance and when this variance can be quantified this must be incorporated in the simulation. The Monte-Carlo method can be used to simulate the process many times with different starting values (arrival, departure times). The result of this collection of simulations will be a probability function which represents the whole area of possible outcomes.

The data needed for running scenarios in the tool should be available within AAS. In the past the planning of flight-to-gate was depended on KLM data for the coupling of flights. However, this will influence the process in a negative way because AAS is not able to perform analysis independently.

The tool must create an output based on the indicators defined in the analysis phase.

- the total # of aircraft for which no connected stand is available at the scheduled in-block time (SIBT)
- the total # of towing movements
- the total # and characteristics of stands needed to be built in order to offer service level X
- assigned flight-gate preferences
- the stand occupation in % per category per 5 minutes

The planning must be visualized in a Gantt chart in order to qualitatively assess the robustness of the planning. Furthermore the stand occupation, number of towing movements and the total number of aircrafts for which no connected stand is available must be able to export to Microsoft Excel.

It is recommended to have a cost and benefit module in the tool which evaluates the total costs for implementing a particular service level.

The tool must avoid the 'black-box' idea, the user should know how the model and method makes the decisions and should incorporate wizard or other option which tells the user which constraints played a role if for example a visit cannot be assigned to a gate.

8.2 Which solution method is best for the support tool?

In the analysis phase the characteristics of and solutions methods for the gate assignment problem are discussed. The basic gate assignment problem is a quadratic assignment problem²¹ and was shown to be NP-hard by (Obata, 1979). In computational complexity this problem is categorized under NP-class of problems. The NP-hard characteristic of the problem implies that there is no known algorithm for finding the optimal solution within a polynomial-bounded amount of time. The multiple criteria and multiple constraints of the problem make it very unlikely that an optimal solution can be found and verified (Dorndorf, Drexl, Nikulin, & Pesch, 2007).

During an elaborated literature review on the gate assignment problem it became clear that several methods, algorithms and heuristics (and combinations) are used to solve the gate assignment problem. See chapter 5 for an elaborated, however not exhaustive, review on literature about solution methods for the gate assignment problem.

Several attempts in operation research are made to develop and test solution methods for the problem, however often those tests are done with a small set of data. Computational experiments showed the effectiveness of the proposed technique in (Dorndorf, Drexl, Nikulin, & Pesch, 2007), especially in comparison with the results of a modern rule based decision support system. However, the airports researched in the benchmark and the described software tools use the rule-based

²¹ The total passenger walking distance is based on the passenger transfer volume between every pair of aircrafts and the distance between every pair of gates. Therefore, the problem of assigning gates to arriving and departing flights at an airport is a Quadratic Assignment Problem (QAP).

technique with heuristics scheduling methods to satisfy constraints. AAS is also focusing on the rulebased approach on operational level, the new purchased software tool for their operational planning (which also embeds a strategic planning module) uses the rule-based approach.

The airports researched in the benchmark and the described software tools use the rule-based technique with heuristics scheduling methods to satisfy constraints. AAS is also focusing on the rule-based approach on operational level, the new purchased software tool (Inform Groundstar) for their operational planning (which also embeds a strategic planning module) uses the rule-based approach as well. For this project no argumentation can be found to use the solution methods researched in

Rule based systems with heuristics scheduling methods will be the answer as method for the midterm capacity support tool. Considering the what-if examples and the complexity of the system the aggregation level should be detailed.

Heuristics are intended to gain conceptual simplicity, potentially at the cost of accuracy or precision. However, it should be noted that statistical analysis should be conducted when employing heuristics to estimate the probability of outcomes.

8.3 Conceptual model support tool

To conceptualize and clarify the modules of the support tool a conceptual model with inputs from previous described analysis is made, see figure 21. The yellow document box is the input of the forecasted flight schedule. This flight schedule can be manipulated by adding several levels of uncertainty to the three categories. At the left side the supply data can be found, this data and parameters should be easily changeable in order to generate scenarios. The planning heuristic and rule based method will lead to the choices for assigning a particular flight with characteristics to a particular stand with its own characteristics. The most crucial task lies in this planning heuristic. How does the tool make the decision to assign a flight? The output must be evaluated on a quantitative and qualitative manner, the tool does only support decision making and will not give the 'final' answer. Experts must analyze the system and several scenarios in order to recommend decision makers.

8.4 Concluding Remarks Design criteria

In this chapter it became clear that the support tool needs certain functionalities to perform elaborated analysis and to fit in the problem environment.

- A flight schedule as demand input data
- Stand characteristics which are easy to change
- Production rules which are easy to change
- An option to implement a level of uncertainty on the input data to run scenarios.
- Output module: on the measurable indicators as described in the analysis phase

Furthermore it is recommended to have a cost and benefit module in the tool which evaluates the total costs for implementing a particular service level and the tool must avoid the 'black-box' idea. The method for planning the flight-to-gates is recommended to be a rule based systems with heuristics scheduling methods. Considering the what-if examples and the complexity of the system the aggregation level should be detailed.



Figure 21 Conceptual model midterm gate planning tool

9. Functionalities of original 'Gate Capacity Manager (GCM)' version 1.0

There are several options to deal with the dilemma of the problem owner, that is the need for computational support in the decision making on midterm level about the capacity of gates and remote stands. A new model can be developed, the current Gate Capacity Manager (GCM) model which had the same purpose a few years ago can be improved or the heuristics of the operational model can be used at a higher abstraction level highlighting properties of the model itself which is called meta-modeling. Due to the fact that many of the user requirements and functional requirements can be found in the GCM tool the decision is made to analyze and recommend on improvements for a second version of the GCM tool.

This chapter will highlight the functionalities and heuristic of GCM version 1.0. This chapter starts with an introduction of the simulation platform Enterprise Dynamics and the Enterprise Dynamics Airport Suite. Subsequently the functionalities of the GCM tool and the different steps that need to be taken before the GCM tool can perform a run will be outlined. Furthermore the process and program of requirement used in 2006 to develop the tool will be discussed. The differences and equalities of the GCM tool and the operational planning tool are outlined in the subsequent section.

9.1 The Enterprise Dynamics Airport Suite

The Enterprise Dynamics (ED) Airport Suite is developed by Incontrol ED and is an integrated simulation platform with three main modules, namely ED Airport BaxSim, ED Airport PaxSim and the already introduced in section 2.6.5. the ED Airport Gate Capacity Manager. This suite provides quantitative insight on individual airport processes and their interdependencies, it provides an integrated environment covering both airport airside and landside simultaneously for aircraft, passenger, baggage and cargo operations (Zografos, Madas, & Salouras, 2010). ED Airport Suite is a simulation platform at the detailed microscopic level, so aggregated macroscopic analyses with the use of analytical models are not realizable. GCM is part of the Airport Suite and has a microscopic nature. AAS has the licenses for this Airport Suite, however it is not used in its integrated form.

Enterprise Dynamics (ED) is a discrete event simulation platform for logistics & business processes. ED is object-oriented combined with an event-oriented approach. The user can select standard simulation objects (Atoms) in which the behavior of their real life equivalents is captured, from a library and create a model by clicking and dragging the objects into the model space. For each simulation object, parameters can be altered to change its behavior (Hillen, 2000). In discrete event simulation the operation of a system is represented as a chronological sequence of events. Each event occurs at an instant in time and marks a change of state in the system. Event-based mechanism is one of the mechanisms which can carry out discrete event simulation (Pidd, 1998). ED has 2D and 3D visualization possibilities. The library and the atoms for the GCM tool are all created by company Incontrol Simulation Solutions. In the simulation model, aircraft objects are generated for each individual visit.

9.2 Functionality and heuristics GCM tool 1.0

Functional analysis addresses the logic structure that the system must achieve in order to achieve its desired outputs. In other words, functional analysis addresses the transformations that are needed in order to turn the available inputs into the desired outputs. As approach the IDEF-0 – integrated

definition language – is used to describe the functional elements of the GCM 1.0 tool. IDEF-0 is an approach which is focused on the functional models of a system and uses a numbered activity represented in a box (Sage & Armstrong Jr., 2000). IDEF-0 diagrams make it possible to decompose the processes in sub-activities until a desired level of detail. In the diagram each activity transforms an input into an output, has a control that specifies how this transformation occurs and specifies a mechanism that is needed to perform the transformation (Bots, 2002).

The GCM tool exists of a priority heuristic, parameters, databases as input and assigns flights to gates based on required, preference and avoidance rules. The preference and avoidance rules have a score, with those scores the end score of a stand is determined. The Enterprise Dynamic module embodies the heuristic and parameters, however the databases are imported from Microsoft Access databases. Changing the databases must be done in Access.

In the total process from input to output there are several important processes which are outlined in this section. In appendix V the IDEF-0 diagram – starting at A0 – is shown.





9.2.1 Input: flight schedule, visit generator, user input and databases (IDEF-0: A1, A2)

The planning starts with the midterm flight schedule forecast in Microsoft Excel. This input data is a given and must be used to perform capacity analysis at AAS. This schedule consists of arrival and departure flights for a season. In the GCM tool a particular day can be simulated, so a particular day must be chosen from the flight schedule in Excel. This can be done by using formulas and filters in Excel – see chapter 9 for GCM version 1.1. For the planning of gates and remote stands it is needed to know the visits, so the coupled arrival and departure flights on one aircraft. This is necessary because the entity which flows through the model is the aircraft and not a loose arrival or departure flight. It cannot be said that an arrival and departure flight can be coupled based on numerical characteristics, e.g. arriving flight KL1146 can be coupled automatically with departing flight KL1147²². During the development of the GCM tool in 2006 data availability and cooperation with KLM was more elaborated than nowadays. Therefore the visits of KLM where known and only the visits of other carriers needed to be coupled. Nowadays no data from KLM is provided. This will lead

²² Interview Joyce de Groot, June 2011, Senior Advisor Analysis, Development and Innovation, AAS – Aviation.

to making more assumptions and uncertainty, however to run a scenario AAS is not depended in this case on data availability and supply by KLM.

Because the numerical strategy is not the answer another strategy is chosen and converted into a heuristic. With the help of macros in Microsoft Excel visits are generated with the flight schedule as input data and based on following criteria:

- a. turnaround time >= minimum turnaround time
- b. same carrier for arriving and departing flights
- c. same aircraft type for arriving and departing flights

Subsequently the arrival and departing flight are coupled with the First-In-First-Out (FIFO) strategy. The turnaround time can be adjusted and there is a minimum turnaround time which can be implemented. This minimum turnaround time is the minimum time in minutes that has to be taken into account between the arrival time of an arriving flight and departure time of a departing flight. Per airline the minimum turnaround time can be implemented. For instance for KLM a minimum turnaround time of 180 minutes. The visits are categorized by B, A, or D. The result can be only an arrival (A), only a departure (D) or both (B).

A part of the results of a particular generation of visits is shown in table 7. This list must be pasted in the database Input_Visits in the Microsoft Access databases. In table 8 a screenshot is shown of the first rows of the Input_Flights data. This data needs to be pasted to the database Input_Flights in Microsoft Access. For this run it is chosen to simulate on the 22nd of July 2016, departure day and time is of no relevance for the run if it is an arriving flight.

VisitID	FlightIn	FlightOut	Туре
1	OR0290	OR0511	В
2	HV0494	HV0447	В
3	HV0700	HV0293	В
4	HV0458	HV0555	В
5	OR0494		A

Table 6 Result of Input_Visits from the visit generator in Excel

ID	SubTyr -	FlightNr 💌	DepDay 🔽	DepTim 🝷	ArrDay 🚽	ArrTime 🔻	Dep 🗾	Arr 💌	Carrier 💌	ServTyp
1	320	AAN1412	0-jan-00	0:00:00	22-jul-16	8:30	TLV	AMS	AAN	С
2	320	AB9265	0-jan-00	0:00:00	22-jul-16	12:15	PMI	AMS	AB	J
3	CRK	AF1156	0-jan-00	0:00:00	22-jul-16	6:40	LYS	AMS	AF	J
4	321	AF1240	0-jan-00	0:00:00	22-jul-16	6:40	CDG	AMS	AF	J
5	318	AF1256	0-jan-00	0:00:00	22-jul-16	11:35	LYS	AMS	AF	J
6	321	AF1340	0-jan-00	0:00:00	22-jul-16	7:15	CDG	AMS	AF	J
7	CRK	AF1356	0-jan-00	0:00:00	22-jul-16	17:30	LYS	AMS	AF	J

Table 7 Input_Flights from flight schedule

Until now the databases Input_Visits and Input_Flights are described. For running a simulation in the GCM tool more databases are required. And other databases in Microsoft Access are required to 'feed' the data needed to run a simulation.

Feeding databases in Microsoft Access

- Data_Aircraft_Type
- Data_Airport_and_Country_Codes
- Data_Carriergroups
- Data_Carrier
- Data_CarrierSegment
- Data_Countries
- Data_Handlers
- Data_StandAreas
- Data_StandStatus

Databases used by GCM tool

- Input_Rules
- Input_Stands
- Input_Visits
- Input_StandConflicts

The data from Input_Visits and Input_Flights are combined in a new Input_Visits database which can be imported by ED-GCM. This new data sheet consist of the following data which is fed by the different databases: visitnumber, Type (A,D,B), Subtype aircraft, paxnumber, CAT, Carrier, GroupName, Segment, Handler, arrival flightnumber, arrival time, origin, Schengen/Non-Schengen/S-NS, CustomsCheck yes/no, departure flight number, departure time, destination, Schengen/Non-Schengen/S-NS, EU or NEU inbound, profiling yes or no and which service type.

So, the user can configure the data in Access and import all the databases in the GCM tool.

9.2.2 Input_Stands and Input_Rules Databases (IDEF-0: A2)

In the previous section databases Input_Visits (derived from Input_Visits and Input_Flights from Excel) is discussed. The database Input_Stands is a database with the characteristics of the stands and must be updated according to the year the user wants to perform a planning, e.g. if the user would like to plan a schedule forecasted for 2016 all the updates to gates and remote stands scheduled until that time should be changed and be aligned with the data in the database. For every stand following characteristics are saved: Stand_Id, Stand, Connected yes/no, Category, Schengen/Non-Schengen/Switch status, Stand_Area (pier), Profiling yes/no, Customs yes/no, Exist? yes/no, InUse yes/no, Pax yes/no.

The planning rules that are used by the GCM tool are stored in the Input_Rules database. In the following figure the column characteristics – data type and description – are given.

	Veldnaam	Gegevenstype	Beschrijving
►	RuleType	Numeriek	Number to identify the criteria type.
	Flight	Tekst	Flight number, this can refer to the arriving OR the departing flight of a visit.
	Carrier	Tekst	Carrier name.
	CarrierGroup	Tekst	Carrier group name.
	CarrierSegment	Tekst	Carrier segment name.
	Handler	Tekst	Handler
	AC_category	Tekst	Aircraft category number from 1 until 8.
	AC_Type	Tekst	Aircraft type
	AC_schengenInd	Tekst	Schengen indication of a visit.
	CustomCheck	Numeriek	1=yes, 2=no, 0 = irrelevant
	Profiling	Numeriek	1=yes, 2=no, 0 = irrelevant
	EU_NEU_Inbound	Tekst	
	RuleServiceType	Numeriek	Rules can be defined for cargo and passenger flights, $1 = passenger$, $2 = cargo$, $0 = both$.
	RuleSign	Numeriek	The rule can have a sign, like $=$ (1) or $<>$ (0).
	RequirementLevel	Tekst	Requirementlevel of a rule, this can be 1_required, 2_preference, 3_avoid.
	Score	Numeriek	A number to indicate the relative significance for a preference or avoid rule.
	Rule_active?	Numeriek	1=yes, 2=no
	Connected?	Tekst	1=yes, 2=no, 0 = irrelevant
	Stand_schengenInd	Tekst	
	MinimumCat	Numeriek	Minimum category stand, numbered from 1 until 8.
	Custom?	Numeriek	1=yes, 2=no, 0 = irrelevant
	Profiling?	Numeriek	1=yes, 2=no, 0 = irrelevant
	IndividualGate	Tekst	Possiblity to assign flights to individual gates. If more gates can be chosen, separate them with comma.
	StandArea	Tekst	Assign flights to a certain standarea.
	AssignmentType	Numeriek	Number to identify the assignment type.
	Explanation	Tekst	Free text.

Figure 23 Column charactertistics from Input_Rules database

For every new rule all the columns need to be filled in, if a column is not specific for that rule a * can be filled in.

- RuleType:
 - o 0=multiple
 - o 1=Flight
 - o 2=Carrier
 - 3=CarrierGroup
 - o 4=CarrierSegment
 - o 5=Handler
 - o 6=ACCategory
 - o 7=ACType
 - o 8=ACSchengen
 - o 9=CustomsCheck
 - o 10=Profiling
 - o 11=EUNEU Inbound

This characteristic is given to structure the rules and to make it more easy and faster for the heuristics to find the rule.

- Flight: flight number of the arriving or departing flight from a visit
- Carrier until AC_SchengenInd and EU_NEU_Inbound: on those columns scroll down menus can be found fed from the Data_ databases.
- CustomCheck and Profiling: yes, no or * can be filled in
- RuleServiceType: rules can be defined for cargo and passenger flights, 1=passenger, 2=cargo
- RuleSign: the rule can have a sign like = or <>
- RequirementLevel: this is an important part of the rule set-up, here the user determines if the rule must be taken into account (required), if the rule gets a preference or an avoidance

- Score: for the preference and avoidance rules a score is needed, this is a number to indicate the relative significance
- MinimumCat: here the user can define the aircraft type minimum needs a particular type of category stand, e.g. CAT6 a/c needs minimum CAT6 stand
- IndividualGate: the user can assign flights to individual gates by indicating the flight number in the column Flight and the stand in this column
- GateGroup: assigns flight to a certain StandArea, e.g. flight KL1167 must be assigned to B_pier

This Input_Rules database is an important database, with the data stored in this database the user decides on which requirements and preferences or avoidances will be taken into account for the planning.

9.2.3 Build model (IDEF-0: A31-A33)

After configuring, adding or deleting characteristics in the databases the databases can be imported by the GCM tool in Enterprise Dynamics. When the library and the model is opened in ED the model layout appears in the model space. The model layout consists of a the planning module and a visualization of airside. In the following figure screenshots are shown of the model layout during planning.



Figure 24 Model layout GCM tool

Different colors can be allocated to the stands, when red the stand is occupied, when green the stand is available and when yellow the stand is not yet used at that time. The aircrafts have different



colors as well. The colors are categorized by segment, e.g. blue is hub segment and orange is low cost segment.

Figure 25 Model layout GCM tool – airside

A zoom in on the three atoms 'database import', 'initialization' and the 'planningengine'.



Figure 26 Model lay-out Enterprise Dynamics GCM tool

First the databases from Microsoft Access should be imported, this can be done by double clicking on the blue Database atom. Then building of the model is needed, this can be done by double clicking

on the purple atom Initialization. Important to notice is that the parameters can be changed. The atom Parameters is a table that contains the constants and parameters, the values can be changed by the user. In figure 27 the parameters built in are shown.

🕖 Table ol	Parameters			
File Edit	View			
-Dimensions				
Bows [.]	15 Columns:	4 S	et	
<u></u>	,	· · · · ·		
	Name Constant	Value	Unit	Description
1	SlackTime]10	Minutes	Standard Slack Time between two visits at a stand.
2	MaxCategory	9	Number	The maximum possible aircraft category
3	HandlingTimeNaboArr	55	Minutes	Handling time for arriving Narrow Body aircraft
4	HandlingTimeNaboDep	65	Minutes	Handling time for departing Narrow Body aircraft
5	HandlingTimeWiboArr	60	Minutes	Handling time for arriving Wide Body aircraft
6	HandlingTimeWiboDep	75	Minutes	Handling time for departing Wide Body aircraft
13	HandlingTimeCargoArr	90	Minutes	Handling time for arriving cargo aircraft
14	HandlingTimeCargoDep	90	Minutes	Handling time for departing cargo aircraft
7	TowMinVisitTimeNabo	170	Minutes	Minimum ground time narrow body aircraft for optional towing
8	TowMinVisitTimeWibo	210	Minutes	Minimum ground time wide body aircraft for optional towing
	TowMinVisitTimeCargo	210	Minutes	Minimum ground time cargo aircraft for optional towing
9	MaxCatNabo	4	Number	Maximum category of narrowbody aircrafts
10	ReservationTime	10	Minutes	Reservation time for a stand before arrival or after departure.
11	TowingPreference	110	Score	Preference value for towing (minimum 0, maximum 500)
12	MatchPI	75	Percentage	Performance Indicator match between visit and stand

Figure 27 Parameters in ED GCM tool

The SlackTime and ReservationTime together is the buffertime between a departing and arriving flight at one gate, in this case 20 minutes. For the handling time of aircrafts permanent values are chosen. After the planning round a stand receives a score, the highest score is a 100% match and has preference. However, if the stand with the highest score is not available the tool will seek for a stand available with the score after the highest score, if the stand has less than a 75% match – determined by the MatchPI – the allocation will be marked as red. So, the MatchPI is the performance indicator match between visit and stand.

The towing characteristics (TowMinVisitTimeNabo, TowMinVisitTimeWibo, TowMinVisitTimeCargo and TowingPreference) will be discussed in the following section.

9.2.4 PlanningEngine (IDEF-0: A34)

After the import of databases and determining the parameters in the GCM tool the planning of the visits to the stands can be performed. This can be done by double clicking on the green atom PlanningEngine. A visit is divided into three parts by the planning engine: handling time arriving flight with a preceding reservation time, time between arriving and departing process and handling time departing flight followed by a reservation time. The planning engine has functions to create a planning and assign all flights to an available stand. The assignment of a visit to a stand depends on the availability of a stand in combination with the score (Incontrol Enterprise Dynamics, 2006). In the Access database the visits were already sorted on aircraft category descending then on arrival time ascending and departure time ascending. **This sorting heuristic will lead to a planning where the largest aircrafts are planned first.**

The loop starts and evaluates every visit if it is a passenger or cargo flight and on the requirement rules. Every stand without those characteristics will be deleted from the potential stand list, the so-

called standscorelist. Remaining stands get a higher or lower score according to the rules and scores from the database Input_Rules. Subsequently the function 'choose available stand' will evaluate the standscorelist until an available stand is found. This process is outlined in the flowchart scheme followed by the IDEF-0 box A344. Three options are possible when searching for a stand. Before the three options will be outlined the term towingpreference should be explained. In the RASAS document AAS has determined that WIBO and NABO aircrafts can be allocated to a gate a certain time and if longer the aircraft has the possibility to be towed to a remote stand if capacity is needed at that particular time. In the GCM tool it is possible to park the aircraft during the time between arrival and departure on a remote stand. When it is not possible to plan the visit on a stand with a score which is higher than the towingpreference, the PlanningEngine searches for a towing option on one of these stands (Incontrol Enterprise Dynamics, 2006).

- (1) One stand is available for the required period. The visit will be assigned to that particular stand.
- (2) More stands with the same score are available for the required period. The visit will be assigned to the stand with the shortest time between already planned visit and visit to assign.
- (3) No stand is available with a score higher than the towingpreference score. The tool will search for towing options.
- (4) No stands available with a positive score and no towing options. The visit is moved to the list with visits cannot be assigned.

9.2.5 Output: Gantt Chart, Excel

In the current version of the GCM tool it is possible to export the stand planning to Excel and to visualize the planning per pier in ED in a gantt chart. In the gantt chart each carrier segment has its own color. In figure 28 a screenshot can be found of the first rows of a planning exported to Excel. In figure 29 a gantt chart can be found visualized in ED GCM tool.

Stand	🔻 Area 🔻 C	AT	- V	isit 🔻	ArrFlig 🔻	De 🔻	ArrTin 🗸 De	pTin 🐺 Carri 🔻	CarrierGro	CarrierSe -	Stat -	Aircraf -	AircraftC -	BusArriv -	BusGa 🔻	Towir 🔻	Conne 🗸	Custor -	Profilin - Buffe	rs 🔻
B16	B_pier		2,4	784	KL1165	0	0:00	0:00 KL	Skyteam	Hub	S	E90	2,4	0	0	0	1	(0 0	
B20	B_pier		2,4	791	KL1477	0	0:00	0:00 KL	Skyteam	Hub	S	E90	2,4	0	0	0	1	(0 0	
B24	B_pier		2,4	785	KL1953	0	0:00	0:00 KL	Skyteam	Hub	S	E90	2,4	0	0	0	1	(0 0	
B28	B_pier		2,4	782	KL1791	0	0:00	0:00 KL	Skyteam	Hub	S	E90	2,4	0	0	0	1	(0 0	
B35	B_pier		4	824	HV0329	0	0:00	0:00 HV	Indep	Leisure	S	73H	4	0	0	0	1	(0 0	
B31	B_pier		4	828	HV6583	0	0:00	0:00 HV	Indep	Leisure	S	73H	4	0	0	0	1	(0 0	
B27	B_pier		4	829	HV0683	0	0:00	0:00 HV	Indep	Leisure	S	73H	4	0	0	0	1	(0 0	
B23	B_pier		4	815	HB0023	0	0:00	0:00 HB	Indep	*	S	73H	4	0	0	0	1	(0 0	
B17	B_pier		4	830	HV0459	0	0:00	0:00 HV	Indep	Leisure	S	73H	4	0	0	0	1	(0 0	
B15	B_pier		4	833	HB0027	0	0:00	0:00 HB	Indep	*	S	73W	4	0	0	0	1	(0 0	
B13	B_pier		4	826	HB0031	0	0:00	0:00 HB	Indep	*	S	73W	4	0	0	0	1	(0 0	
C04	C_pier		4	825	KL1705	0	0:00	0:00 KL	Skyteam	Hub	S	73H	4	0	0	0	1	(0 0	
C06	C_pier		4	817	KL1395	0	0:00	0:00 KL	Skyteam	Hub	S	73W	4	0	0	0	1	(0 0	
C08	C_pier		4	734	HV0201	0	0:00	0:00 HV	Indep	Leisure	S	73H	4	0	0	0	1	(0 0	
C10	C_pier		4	736	HV0563	0	0:00	0:00 HV	Indep	Leisure	S	73H	4	0	0	0	1	(0 0	
C12	C_pier		4	735	HV0531	0	0:00	0:00 HV	Indep	Leisure	S	73H	4	0	0	0	1	(0 0	
C14	C_pier		4	759	HV0415	0	0:00	0:00 HV	Indep	Leisure	S	73H	4	0	0	0	1	(0 0	
C16	C_pier		4	731	HV0741	0	0:00	0:00 HV	Indep	Leisure	S	73H	4	0	0	0	1	(0 0	
C15	C_pier		4	760	KL1223	0	0:00	0:00 KL	Skyteam	Hub	S	73H	4	0	0	0	1	(0 0	
C18	C_pier		4	730	HV0103	0	0:00	0:00 HV	Indep	Leisure	S	73H	4	0	0	0	1	(0 0	
C13	C_pier		4	732	HV0897	0	0:00	0:00 HV	Indep	Leisure	S	73H	4	0	0	0	1	(0 0	
C11	C_pier		4	756	HV0883	0	0:00	0:00 HV	Indep	Leisure	S	73H	4	0	0	0	1	(0 0	
C09	C_pier		6	823	OR0395	0	0:00	0:00 OR	Indep	Leisure	S	763	6	0	0	0	1	(0 0	
C05	C_pier		4	755	HV0129	0	0:00	0:00 HV	Indep	Leisure	S	73W	4	0	0	0	1	(0 0	
D02	D_Comm		4	768	SK0550	0	0:00	0:00 SK	Star Alliantie	Euro	S	319	4	0	0	0	1	(0 0	
D12	D_Comm		5	733	HV0149	0	0:00	0:00 HV	Indep	Leisure	S	73H	4	0	0	0	1	(0 0	
D16	D_Zuid		4	748	HV5131	0	0:00	0:00 HV	Indep	Leisure	S	73W	4	1	1	0	1	(0 0	

Figure 28 Planning GCM tool exported to Excel





Figure 29 Visualized gantt chart planning GCM tool

9.3 GCM tool versus operational planning tool: differences and equalities

The aim of operational and midterm planning differs and therefore the planning techniques and evaluation can also differ. Gate planners at operational level would like to see an exact planning of aircraft to a particular gate and would take into account the exact restrictions of the supply of infrastructure. The latter means that for the operational planning also plans according to characteristics like if the gate is connected to the hydrants system²³, if the aviation bridge fits the aircraft, pax numbers for passenger and baggage flow in the terminal and particular preferences of carriers and handling agents. So, the operational planning is detailed and needs an exact planning for the day of operation. On the other hand the midterm planners would like to question if the supply capacity is sufficient for a forecasted flight schedule. This midterm capacity question does not need an exact planning of aircraft to gate taken into account all the details such as hydrants systems and aviation bridges. Midterm planning aims at answering the question if the forecasted flight schedule can be accommodated and under which changes in infrastructure.

For both the operational Gate Management System (GMS) tool and midterm planning GCM tool the method rule based is used. The GCM tool is more flexible in running scenarios and changing the rule setting. It is also more convenient for the midterm planner to have an own operating tool and not having to ask the operational gate planner over and over to run scenarios. Furthermore to understand the sensitivity of factors in the system and the overall interdependencies in the system it is recommended to have a tool managed by the midterm planner.

²³ At AAS airside several gates are connected to the hydrants system for fuelling of the aircraft.

9.4 The GCM tool versus the user requirements and design criteria

The functionalities of the GCM tool are described. The arguments described in this section will reason the choice for the GCM tool by analyzing if the GCM tool version 1.0 incorporates the user and design criteria. The assessment is done by answering the question: (1) Is the criteria present in GCM V1.0?. If not present the following two questions will be answered as well: (2) Why (not) present?, (3) Is improvement possible in order to incorporate the criteria?.

Criteria (user and design)	Assessment GCM 1.0 tool
User-friendliness and easy to understand	1. Not present
	2. For a total planning activity three programs
	(Excel, Access and ED) are needed, this
	creates confusion and is complex.
	3. Yes, user-friendliness can be incorporated by
	GUIs.
Data needed to perform analysis fully	1. Present
deliverable by AAS	
Zoom in option on decision making by the model	1. Not present in a user-friendly manner
for the user to avoid 'black-box' idea	2. Currently assignment decisions can only be
	analyzed by a complex overview of the
	production rules that played a role in the
	assignment.
	3. Yes, can be incorporated by GUIs.
Planning possible on gate level	1. Present
Possible to turn off/on or add production rules	1. Present
Supply of stands and characteristics of stands	1. Present
must be possible to change	
Capacity shortages are communicated in a clear	1. Not present
overview	2. Currently the visits which cannot be
	accommodated are assigned to a scratch list,
	nowever it is not clear why those visits
	cannot be assigned.
Event event executivities of evenut	3. Yes, can be incorporated.
Excel export possibilities of output	1. Present
A flight schedule (unit 5 minutes) as input data	1. Present
An option to implement a level of uncertainty on	1. Not present
the input data	2. Unly possible when in excel the input data is
	adjusted.
Clear output modulo on porformance indicators	5. res, can be incorporated.
Clear output module on performance indicators	1. NOL present
	2. Currently it is complicated to analyze the
	Vec. can be incorporated
	5. res, can be incorporated.

9.5 **Concluding remarks functionalities GCM version 1.0**

This chapter describes the functionalities of the original GCM tool version 1.0 developed in Enterprise Dynamics in 2006. The choice is made to analyze and generate suggestions for improvements for the

GCM tool because the user and design criteria can be found in the GCM tool or it is possible to implement the criteria as an improvement.

The GCM tool exists of a priority heuristic, parameters, databases as input and assigns flights to gates based on required, preference and avoidance rules. The preference and avoidance rules have a score, with those scores the end score of a stand is determined. The Enterprise Dynamic module embodies the heuristic and parameters, however the databases are imported from Microsoft Access databases and the visits (coupled arrival and departure flights) are generated in Microsoft Excel. The planning starts with the midterm flight schedule forecast in Microsoft Excel. In the GCM tool a particular day can be simulated, so a particular day must be chosen from the flight schedule in Excel. The stand is chosen according to a standscorelist which contains all stands and their scores. The scores are determined by the preference and avoidance rules. The output can be exported to Excel or shown in a Gantt chart. Finally the difference between planning in the operational tool and on midterm level is discussed.

The GCM tool with the current functionalities (V1.0) is not sufficient to implement as decision support tool for notifying and management the imbalances at the aircraft stand area. However, if adjustments are made the GCM tool is a tool which offers good support when analyzing the aircraft stand area.

10.The development of GCM version 1.1

The GCM version 1.0 is used the latest in 2009. The databases were not up-to-date and the visitgenerator was built on data delivery by KLM. So, changes are made to the visitgenerator in Excel and the visitgenerator is made more user-friendly. Furthermore, the feeding databases in Access are updated. First, this chapter will describe the program of requirement and the process as in 2006/2007 when the GCM 1.0 was developed in cooperation with Incontrol. Then the drawbacks and shortcomings of the GCM 1.0 tool are described. Subsequently improvements which are implemented (creation of version 1.1) are outlined in the last section.

10.1 Process aspects: How did the process of development and implementation of GCM 1.0 in 2006 looked like?

The GCM tool is initiated by the responsible person at 2006 for the midterm gate capacity Joyce Groot. Cooperation was started with Incontrol on the GCM tool in 2006. A program of requirement and description of airside/gate simulation was written. In this document the following aspects were described:

- Aim of the gate simulation airside is insight in demand development of gate and remote stands for just-in-time investments on aspects as number, category, peak pattern and segment.
- Aim of the gate simulation airside is doing analyses on scenarios with expansion and/or changes to current infrastructure on aspects as number, category and segment allocation.
- It must be possible to create a planning on gate-level and pier-level.
- The tool must communicate for which flights no capacity is left or the amount of capacity needed to allocate the demand.
- Planning rules must be changeable and possibility must exist to turn-off/on.
- Output should be possible: export to Excel in order to perform analyses on gate occupation, occupation degree, visiting time of visits, etcetera.

Furthermore the initiator highlighted that the aim of the GCM tool was not only the gate/remote stand capacity but as well the allocation of flight-to-gate. This allocation is the starting point for other processes such as the terminal flows.

During development AAS and Incontrol worked closely together. Validation and verification was guided by the initiator. Verification is the act of determining of a product meets its specific requirements. Validation is the act of determining if a product satisfies its users and stakeholders (Sokolowski & Banks, 2009). Most important task was to aggregate the rules used in operational planning (±500) in order to plan on midterm level. This task is performed by the initiator and a number of required, preference and avoidance rules are used for the midterm planning cycles at that time, see for the list of rules chapter 11. The score per rule and score for towing preference is determined by the initiator through the method trial and error. However, it must be noticed that changing the set of rules is possible.

After the switch in position and responsibilities the task of performing midterm planning activities on aircraft stand area changed from the initiator to the problem owner of this project. Due to the lack of reliability and user-friendliness the problem owner was not satisfied with the GCM tool.

10.2 Functionality aspects: drawbacks of the GCM 1.0 tool

There are several reasons why the GCM tool is currently not in use by the responsible person for the midterm planning. First, the tool was not considered as being valid and it is not known how the tool makes the decisions for planning an aircraft to a gate. Secondly, the tool is very complex in use and needs much proceedings.

After an analysis and running several scenarios the following drawbacks of the tool can be concluded:

- The use of Microsoft Excel, Microsoft Access and Enterprise Dynamics makes it complex and not user-friendly to work with.
- The set-up of feeding databases and input databases in Microsoft Access is not clear and errors are easily made.
- There is no computational check on the input data, such as a check if every column is filled in or if the correct data type and unit is used.
- The input database for rules is complex and it is not clear what to fill in for every column.
- The match PI the performance indicator for the match between visit and stand can be set in %, however if a match is lower than this % the visit is still planned on the stand.
- Tool familiarity for Enterprise Dynamics and simulation in general is needed to understand the steps that has to be taken to run a planning.
- The output indicators are not clear:
 - o It is not clear what the reason for an unassigned visit is.
 - \circ $\;$ Total number of towing movements is not communicated by the tool.
 - o Assigned flight-gate preferences is not communicated
- There is no guidance through the planning in order to perform and run a scenario in a fast and easy way.
- The handling times are indicated as permanent values in the parameter table. However, it should be possible to add a distribution or stochastic element on those values due to the differences in handling times at operation.
- Furthermore there are currently no possibilities to implement stochastic elements in the input data or statistical indicators for the fleet composition or peak pattern.
- Departure flights are directly planned on a gate. E.g. when a flight has only a departure (no visit) the entity aircraft is made at 0:00 and is directly planned at a gate, so this flight will occupy the gate, until the departure time. It would be recommended to add in the heuristic the possibility to assign the flight first to a remote stand.

10.3 Improvements implemented: GCM tool version 1.1

The visitgenerator in Microsoft Excel as it was in 2006 is currently not usable due to input data differences. For the new version 1.1 a user guide is written. The improvements which are made are generating the correct day from the season forecasted flight schedule, subsequently check that data on duplicate flight numbers through a formula.

	G3	- (9	f _≭ =ALS(M	AX(AANTA	AL.ALS(\$B\$2:	\$B\$3000;\$B\$2:\$	B\$3000)>1);"Duplicate";"N	loDuplicate	≥")
	A	В	С	D	E	F	G	Н	
1	ArrDep 💌	FlightNr 💌	AircraftTy -	Carrie 💌	DepTim 💌	ArrTime 💌	Duplicates/No Duplicat 💌		
2	A	AAN1412	320	AAN	0:00	8:30	NoDuplicate		
3	A	AB 9265	320	AB	0:00	12:15	NoDuplicate		
4	A	AF 1156	CRK	AF	0:00	6:40	NoDuplicate		
5	A	AF 1240	321	AF	0:00	6:40	NoDuplicate		
6	Α	AF 1256	318	AF	0:00	11:35	NoDuplicate		

Figure 30 Improvements for GCM version 1.1: Check duplicated in flight schedule

In Microsoft Access the feeding databases are updated in such a way that the databases can feed the rule, stand, visit and flight databases. The airline prefixes, aircraft types, airport codes are updated. Furthermore the output analysis Excel spreadsheet is updated by implementing macros and formulas in order to assess several KPIs from the planning.

The code in Enterprise Dynamics is not changed.

10.4 Concluding remarks toward version 1.1

The program of requirement and process is described which are used in 2006 to develop, design and built the original GCM 1.0 tool. The requirement set up at that time can be compared to the requirements described by the problem owner of this project. The initiator described the functionalities of the tool. A drawback of the design and validation process in 2006/2007 is that only one person at AAS participated in the design and validation of the tool. The successor did not rely on the tool and described the tool as not user-friendly to work with. Several drawbacks of the GCM 1.0 tool are described after the author of this thesis worked with the tool and with the knowledge of the analysis phase.

Drawbacks in the use of the tool:

Generating a planning is complex due to the use of Excel, Access and ED and the complex set up of databases in Access. Tool familiarity and understanding simulation in general is needed to understand the steps that has to be taken to run a planning. There is no guidance through the planning in order to perform and run a scenario in a fast and easy way.

Functional drawbacks:

There is no computational check on the input data. The match PI can be set in %, however if a match is lower than this % the visit is still planned on the stand. The output indicators are not clear communicated. The handling times are indicated as permanent values in the parameter table. Furthermore there are currently no possibilities to implement stochastic elements in the input data or statistical indicators for the fleet composition or peak pattern. Departure flights are directly planned on a gate. E.g. when a flight has only a departure (no visit) the entity aircraft is made at 0:00 and is directly planned at a gate, so this flight will occupy the gate, until the departure time.

The last section of this chapter comprehend the improvements made to GCM 1.0 which created GCM 1.1. The visitgenerator in Excel is improved, the feeding databases in Access and the output analysis Excel spreadsheet are updated. The ED code is not changed.

11.Experiment: a run with forecasted flight schedule **2016** with GCM V1.1

This chapter will described the run in the GCM v.1.1. tool. First, the input data and the scenario is described. In that section the planning activities are described step-by-step as well. Section two describes the output analysis.

11.1 Input data and planning activities

The forecasted flight schedule of Summer 2016 is available and from this schedule the input data will be generated. The 5th of August 2016 is chosen to plan. The planned upgrades for the infrastructure is taken into account and therefore the databases with stand characteristics are updated according to those upgrades of infrastructure.

11.1.1 Excel visitgenerator

First the flight schedule for that particular day is filtered. The data in this flight schedule consists of:

- Prefix code
- Flight number
- Seat capacity
- Aircraft type
- Origin airport code (if arrival) Arrival airport code is AMS
- Destination airport code (if departure) Departure airport code is AMS
- Arrival/Departure time (unit 5 minutes)
- Type (Passenger, Cargo or Freight)

The macro in the visitgenerator uses this data to create visits. The output of this visit generating is as follows:

Results Visit Generator		
Number of visits type B	624	
Number of visits type A	99	
Number of visits type D	114	
Average turn around time visits B	102,0 (mins)	

The list with visits has 837 rows. The first rows are visualized in the following spreadsheet:

VisitID		FlightIn	FlightOut	Туре	TurnAroundTime
	1	OR 0290	OR 0511	В	175
	2	HV 0494	HV 0447	В	120
	3	HV 0700	HV 0293	В	120
	4	HV 0458	HV 0555	В	100
	5	OR 0494	OR 0503	В	115
	6	HV 0328	HV 0287	В	90
Table 8 G	ono	rated visit ev	periment		

Table 8 Generated visit experiment

This list will be copy/pasted in the Input_Visits database in Access. Furthermore the data of the flight schedule is adjusted in such a way that it will fit the requirements of the Access database

Input_Flights. The list with flights has 1461 rows. The first rows are visualized in the following spreadsheet.

ID	AircraftType	FlightNr	DepDay	DepTime	ArrDay	ArrTime	Departure	Arrival	Carrier	ServType
1	320	AAN1412		0:00		8:30	TLV	AMS	AAN	С
2	320	AB 9265		0:00		12:15	PMI	AMS	AB	J
3	CRK	AF 1156		0:00		6:40	LYS	AMS	AF	J
4	321	AF 1240		0:00		6:40	CDG	AMS	AF	J
5	318	AF 1256		0:00		11:35	LYS	AMS	AF	J
6	321	AF 1340		0:00		7:15	CDG	AMS	AF	J
7	CRK	AF 1356		0:00		17:30	LYS	AMS	AF	J
8	321	AF 1640		0:00		10:55	CDG	AMS	AF	J
9	320	AF 1740		0:00		12:0	CDG	AMS	AF	J

Table 9 Input_Flights database experiment

11.1.2 Access databases

Because this flight schedule consists aircraft types which were not recorded in the feeding databases, those missing data was updated in the databases Vliegtuigtypes_algemeen. The data from the Excel visitgenerator is copy/pasted in the Access databases Input_Visits and Input_Flights. The stand characteristics are recorded in the database Input_Stands and is updated according to the situation in 2016. In the following table the first rows of this databases is shown.

Stand_Id Stand	Connected? Category	Capacity	Status	x_loc	x_loc2	y_loc	y_loc2	StandArea	Profiling	Customs	Exist?	InUse?	Pax	Explanation Exc	eptions	Limitations	Туре
1 B16	WAAR 2.4	1	S	20	1468	2	1106	B_pier	ONWAAR	ONWAAR	WAAR	WAAR	WAAR				pier
2 B20	WAAR 2.4	1	S	20	1488	4	1134	B_pier	ONWAAR	ONWAAR	WAAR	WAAR	WAAR				pier
3 B24	WAAR 2.4	1	S	20	1508	6	1162	B_pier	ONWAAR	ONWAAR	WAAR	WAAR	WAAR				pier
4 B28	WAAR 2.4	1	S	20	1528	8	1190	B_pier	ONWAAR	ONWAAR	WAAR	WAAR	WAAR				pier
5 B32	WAAR 2.4	1	S	20	1548	10	1218	B_pier	ONWAAR	ONWAAR	WAAR	WAAR	WAAR				pier
6 B36	WAAR 2.4	1	S	20	1568	12	1246	B_pier	ONWAAR	ONWAAR	WAAR	WAAR	WAAR				pier
		r												Plu	s MD90-		
7 B35	WAAR 4	1	S	20	1648	14	1200	B_pier	ONWAAR	ONWAAR	WAAR	WAAR	WAAR	30			pier

Table 10 Input_Stands database in Access for experiment

The x_loc and y_loc numbers are the locations of the stands in the visualization in Enterprise Dynamics. The x_loc2 and y_loc2 are the locations of the stands on the airside picture in Enterprise Dynamics. The assignment of the visits to the stands is done based on the standscore list, this list is created according to the required, preference and avoidance rules. Those rules are specified in the GCM_Rules database. The rules in this database can be changed according to the users scenario. For this scenario 102 rules are taken into account. All the rules have characteristics which are indicated in the database.

The required rules can be categorized in the following categories:

- Physical Limitations
 - e.g. CAT5 a/c needs minimum CAT5 stand
- Required remote handling
 - e.g. CAT2 always remote on B-platform
- Security check
- Customs check
 - e.g. flights requiring customs check always on custom checks gates
- Profiling
 - e.g. flights requiring profiling always on profiling gates

The preference rules can be categorized in the following categories:

- Preference carrier on particular pier
 - e.g. Non-hub carriers preference on G-pier
- CAT3-CAT8 preference for connected gate
- Segment preference on particular pier
 - e.g. Euro segment preference on B-pier
- Switch flight preference
 - e.g. Switch flight NS-S preference on switch gate
- NS/S and EU/NEU preference on particular gate
 - e.g. NS preference on NS gate

The avoidance rules can be categorized in the following categories:

- Border status
 - e.g. avoid NEU inbound at H-pier clean area
- Avoidance carrier on particular pier
 - e.g. Non-hub carriers avoidance on E-pier
- Segment avoidance on particular pier
 - e.g. Leisure avoidance on B-pier
- NS/S avoidance on particular gate
 - e.g. S avoidance on NS gate

11.1.3 Enterprise Dynamics: GCM tool

The databases from Access are imported in the GCM model. Initialization is done and the stands are built. The parameters for this scenario are set as shown in the following figure.

	• - · ·			
🕖 Table o	Parameters			
File Edit	View			
-Dimensions				
	15 0.1		. 1	
Hows:	Loiumns:	4 5	et	
	Name Constant	Value	Unit	Description
1	SlackTime]10	Minutes	Standard Slack Time between two visits at a stand.
2	MaxCategory	9	Number	The maximum possible aircraft category
3	HandlingTimeNaboArr	55	Minutes	Handling time for arriving Narrow Body aircraft
4	HandlingTimeNaboDep	65	Minutes	Handling time for departing Narrow Body aircraft
5	HandlingTimeWiboArr	60	Minutes	Handling time for arriving Wide Body aircraft
6	HandlingTimeWiboDep	75	Minutes	Handling time for departing Wide Body aircraft
13	HandlingTimeCargoArr	90	Minutes	Handling time for arriving cargo aircraft
14	HandlingTimeCargoDep	90	Minutes	Handling time for departing cargo aircraft
7	TowMinVisitTimeNabo	170	Minutes	Minimum ground time narrow body aircraft for optional towing
8	TowMinVisitTimeWibo	210	Minutes	Minimum ground time wide body aircraft for optional towing
	TowMinVisitTimeCargo	210	Minutes	Minimum ground time cargo aircraft for optional towing
9	MaxCatNabo	4	Number	Maximum category of narrowbody aircrafts
10	ReservationTime	10	Minutes	Reservation time for a stand before arrival or after departure.
11	TowingPreference	110	Score	Preference value for towing (minimum 0, maximum 500)
12	MatchPl	75	Percentage	Performance Indicator match between visit and stand

The planning engine is started and the tracer is opened which shows the visits that cannot be assigned.

11.2 Output analysis

The planning is generated and the output is analyzed by analyzing the gantt chart per pier in ED and the standplanning list in Excel. It can be concluded that the planning is not robust on several piers, time between two succeeding flights (in the gantt charts) is to such a degree that robustness cannot be guaranteed. The standplanning list is exported to an Excel spreadsheet. The following conclusions can be drawn:

- 56 towing movements have taken place;
- 5 visits cannot be accommodated and are allocated on the scratch list, two 2,4 CAT flights and three 6,7 CAT flights;

The following graphs are drawn from the standplanning list:



Stand occupation

Occupation All Gates and Stands per Aircraft Category



12.Suggestions for improvements: towards GCM version 2.0

According to the drawbacks of the GCM tool described in chapter 10 and the user requirements and the conceptual model for the support tool several developments for the current GCM tool are proposed in this chapter. The further development are categorized in category +++, ++ and +. Category +++ means that the adjustment categorized in this category are needed before the GCM tool can be used. The adjustments proposed in category ++ will lead to a better understanding of the system and are a added value for scenario development. Category + are adjustments that are 'nice to have'.

12.1 Category +++ adjustments

An integrated solution whereby input databases, modeling and output evaluation is
integrated in one wizard, which will increase the easiness and user-friendliness of the tool.
Incontrol proposed a wizard look and feel for this adjustment. The wizard will be
programmed in Enterprise Dynamics but will only show the functionalities important for
running a scenario. The following screenshots of wizards are examples and are wizards of
other Incontrol tools.

Ē	Sakura Finetek Simulator - Wizard	
	SMART ANALYSIS TOOL powered by sakura	ep 2 of 11
	ntroduction General Laboratory Layout	
	Model Selection	General
	Edit current model C:\Projects\SakuraFinetekSimulator\Models\Default.mod	Current Set-up
	🚺 💿 Load an existing model	
		SMART
	💼 💿 Load a default model	Set-up
	Settings	Inbound Flow
	Laboratory Name: Default Laboratory	
		Comela
		Graphs
		Run

Figure 31 Adjustment +++ GCM tool: integrating input data, modeling and output evaluation

With the help of data entry fields the user is guided through the data needed for the run. So, for the input rules, flights, visits and stands this lay-out will guide the user to adjust the data for a particular scenario. The wizard will also include a feedback mechanism which will directly generate feedback when the input is not according to specified requirements, for

instance a warning pop-up when the user implements the numerical values for time as 0:00 instead of 00:00.

-	akura Finetek Sir	mulator - Wiz	ard				
		SM		OOL iy sakura		Step 8 of 11	
inb -L	ist of H-numbers	: per time inte	erval			General	
	Arrival time 07:00 08:00 08:30 09:00	Number p 0 11 11 11	f Biopsy H-Nrs Number of Other H-N U B 3 3 3	rs *	Add Edit Delete	Current Set-up	
	09:30 10:00 10:30 11:00 11:30 12:00 12:30 13:00 13:30	11 11 11 11 11 11 11 11 11 11	3 3 3 3 3 3 3 3 3 3	*	Settings Arrival time: 09:00 Number of biopsy H-Nrs: 11 Number of other H-Nrs: 3		
S F C	ettings Percentage fat ma Greate initial con	aterial in H-n tent processi	rs of type other (%): 50		Ok	: Cancel App	NV
2					S 🗸 🖬		

Figure 32 Adjustment +++ GCM tool : guidance for the user during input of data I

During the simulation the user is able to follow the performance indicators as described in previous chapters. In figure 33 a wizard is shown of how the indicators can be analyzed.

Workflow					
Current SMART Automation					
	Current - Biopsy	Current - Other	SMAAT Automation - Biopsy	SMAAT Automation - Biopsy SMAAT Automation - Other	
noductivity					
namenis in process.		42 147	7.04	15	
otal bloc its finis hed:	125.2	840	1432	975	
peed					
g Tarnamound Time (TAT):	25 hr 34 min	ZhrZmù	8 hr 29 min	9 hr9 min	
tin Termano and Time (TAT):	21 hr 1 min	22 h : 2 min	3 hr 4 min	3 Br30 min	
hos Termano and "Time (CAT) :	29 hr/5 min	29 hrS min	20 hr 18 min	20 hr 14 min	
ame Day Diagnosis Rating					
H-net finished within some days	0	0	67.66	65.24	
H-as flabted in 24 km:	25.9	2286	9 209	92.86	
H-nes finished in 45 km;	80	80	9 2.99	92.84	
peed (detailled)					
g time reception :	Ohr 16 min	Ohr 25 min	Ohr16 min	0 hr 25 min	
g time groating:	O he 1.4 min	O hr Stemin	Ohr9 min	Ohr8 min	
eg time greprozens ing	OhrOmin	O hr O min	Ohr25 min	Othr 23 min	
and time more enabling:	20 hr 15 min	20hr11 min	1 hr33 min	1 hr 23 min	
ig time embedding:	Zhr 41 min 4 k.45 min	2 hr 41 min Ch 1/59 min	Zhr1 min 5 ks 1 Mania	1 hr 40 min The 17 min	
er time att in ine .5 covers lingings	O he 25 min	O to 35 min	2 hr ddinnin	Z hr S min	
Stree we veropy	O h r Bi rain	O h / 13 min	Ohr7 min	O for 24 min	
O ocup a solution () () () () () () () () () ()	ncy of shift Current Tech	nici ans (per 60 min)	Occupancy of shift Auton	nation Technicians (per 60 mil	

Figure 34 Adjustment +++ GCM tool : evaluation of output

Finally the following wizard will be shown and the run can be started.

Sakura Finetek Simulator - Wizard	• X
SMART ANALYSIS TOOL powered by sakura	ep 11 of 11
Run	General
Settings	
Run length (max 5): 5 days	Current
Show 2D animation	Set-up
	SMART
Finish Wizard	Set-up
Start simulation	In Lawrence
	Flow
	Graphs
	Run
	00

Figure 33 Adjustment +++ GCM tool: start the simulation run

- All flights have to be assigned to a gate, buffer or dummy gate (dummy gate if capacity of gates/buffers is not sufficient).
 - And this assignment must be communicated in the output wizard.
- Currently in GCM version 1.0 two planningengines are incorporated. According to the developer²⁴ this is not necessary and only creates confustion. The second planningengine was created to search for towing options and to assign visits from the first round which could not be assigned. This option is already incorporated in the first round.
- The following problem should be solved by changing the heuristic: departure flights are directly planned on a gate. E.g. when a flight has only a departure (no visit) the entity aircraft is made at 0:00 and is directly planned at a gate, so this flight will occupy the gate, until the departure time. It would be recommended to add in the heuristic the possibility to assign the flight first to a remote stand and then towed to the gate before departure time + handling time + buffer time.
- The match PI the performance indicator for the match between visit and stand can be set in %, however if a match is lower than this % the visit is still planned on the stand. It is recommended only to plan the visit to a stand lower than the match PI after consultation with the user. The tool must communicate the standscorelist to the user and the user can choose to assign the visit still or puts the visit to the scratch list.

12.2 Category ++ adjustments

- The static allocation is not sufficient for an elaborated analysis of the system and its dynamics. The functionality of the tool should be expanded with the dynamic aspect of variability in arrival and departure times. Enterprise Dynamics is a platform which is meant as simulation platform which can work with stochastic values like variability in arrival and departure times.
 - It should be possible to incorporate distributions on arrival and departure times (this can be further detailed, e.g. distributions for Trans-Atlantic flights) in the input wizard.
 - The baseline (static planning) and the dynamic planning (simulation with chosen values from distributions) will be compared and the effects can be analyzed after sufficient simulation runs. Two options are possible:
 - A new algorithm must be developed for re-planning of flights.
 - If a flight needs to be re-scheduled due to the new arrival or departure times this will be communicated to the user, however the flight will not be replanned.
 - o Indicators for the analysis of the effects should be determined and defined.
- The handling times are indicated as permanent values in the parameter table. However, it should be possible to add a distribution or stochastic element on those values due to the differences in handling times at operation.
- Integration of the GCM tool with other processes such as terminal, baggage.

²⁴ Interview Marlies Wouters, Senior Simulation Engineer Incontrol 26th of June 2011.

12.3 Category + adjustments

- It would be helpful for analyzing the impact of fleet characteristics on the planning. Therefore it is suggested to implement statistical indicators on the following characteristics of the flight schedule:
 - Fleet characteristics: e.g. 20% of 73W will be replaced by type 737NG
- The user can choose between different heuristics which determine the decision making of the tool for planning an aircraft to a gate. Currently the GCM tool first assigns the largest aircrafts, however it would be helpful if the user can choose in those important heuristic characteristics.

12.4 Concluding remarks proposed improvements towards GCM 2.0

This chapter highlights the suggested improvements for GCM version 2.0. The suggestions are categorized according to category +++, ++, +. Planning a scenario in GCM 1.1 is complex and time consuming, therefore the suggestion to create user-friendly GUIs in the form of a wizard are categorized under category +++ improvements. An integrated solution whereby input databases, modeling and output evaluation is integrated in one wizard. This wizard will guide the user from input towards the output analysis. The wizard will also include a feedback mechanism which will directly generate feedback when the input is not according to specified requirements and a performance evaluation screen. The following improvements are also categorized under category +++: all flights have to be assigned to a gate, buffer or dummy gate and this assignment must be communicated in the output wizard; the two planningengines must be combined, departure flights must first be planned on a remote stand before towing to a gate for preparing departure, the match PI – the performance indicator for the match between visit and stand – can be set in %, however if a match is lower than this % the visit is still planned on the stand. It is recommended only to plan the visit to a stand lower than the match PI after consultation with the user. The tool must communicate the standscorelist to the user and the user can choose to assign the visit still or puts the visit to the scratch list. Category ++ suggestions contains the following suggestions. The functionality of the tool should be expanded with the dynamic aspect of variability in arrival and departure times. Enterprise Dynamics is a platform which is meant as simulation platform which can work with stochastic values like variability in arrival and departure times. Category + improvements are the implementation of statistical indicators for fleet characteristics and peak patterns and the possibility for the user to choose between different heuristics.

Implementation

As indicated in the analysis phase not only the lack of a tool which fits the system complexity was missing but also the organizational framework in which the tool must perform. The following chapter will highlight the improvements for the shortcomings on the decision making cycle as visualized in chapter 6. Next to that the engagement matrix as discussed in the analysis phase will be used to recommend how to engage important internal stakeholders in order to implement the improvements for the support tool.

13.Improvements on decision making cycle for aircraft stand area

This chapter highlights the concept of decision making under risk and uncertainty and suggests improvements for the decision making cycle.

13.1 Decision making under risk and uncertainty

Decision making is the act of choosing one alternative from among a set of alternatives. The process of decision making starts with recognizing a decision situation, followed by identifying appropriate alternatives, choosing and justifying the best alternatives according to indicators and implement the chosen alternative. Baket et al. (Baker & all, 2002) defined efficient decision making as "efficient decision making involves a series of steps that require the input of information at different stages of the process, as well as a process for feedback".

Decision making can adopt different conditions like decision making under certainty, risk, uncertainty and ambiguity. The following factors determine the condition of the decision making:

- If the decision makers knows the objectives they want to achieve
- If alternatives are clear
- If the likelihood of the outcomes is complete, subject to chance or not understood
- If information if available, complete

Currently the decision for procedural or infrastructural changes on the aircraft stand area are decided upon static capacity calculations and expert judgment. The decision makers know which objectives they want to achieve, alternatives to reach those objectives are incomplete, outcomes of analysis is subject to chance and not at any time understood and information is available however sometimes incomplete. Decision making under risk and uncertainty are the conditions of the decision to be made for aircraft stand area.

13.2 Suggested improvement to organization of decision making

Every year the decision making cycle is followed with the aim of notifying capacity imbalances in the earliest stage possible and create action on this notification. However, current decision making cycle has several shortcomings and improvements can create great advantages. In figure 34 the suggestions for improvements are visualized in the decision making cycle. The suggestions are indicated with an orange circle, the already implemented improvements are indicated with a green circle.



Figure 34 Improvements for the yearly decision making cycle for aircraft stand area

The process of decision making as described in the previous section should be followed in order to come to robust decision making. It starts with recognizing a decision situation, this is yearly done by Schiphol Group because the Schiphol Development Plan is made on a yearly basis. This plan looks 5 years ahead and evaluates if all processes can accommodate future demand. The objective for the decision making procedure is known, that is to offer sufficient capacity for handling aircrafts, passengers and baggage at competitive prices. So, sufficient gate and remote stand capacity needs to be offered to accommodate the aircrafts of the future demand. Alternatives for accommodating this demand needs to be identified. However, this is not done in the current static calculations done at midterm capacity planning. So, for point (2) in figure 35 another approach is needed. First point (1) will be discussed.

Suggestion (1):

It is recommended to intensify the cooperation between department ASF and department AO-PMA. ASF creates the forecasted flight schedules and AO-PMA draws conclusions on capacity (im)balances between demand and supply of gates and remote stands based on that schedule. However, due to
the uncertainty factor of the flight schedule and the assumptions made by ASF for creating the flight schedule AO-PMA must ask feedback before drawing conclusions. If for instance AO-PMA concludes that there is a bottleneck and gates are needed to accommodate the future demand, first thing to do for AO-PMA is looking back which input causes this bottleneck. Subsequently, AO-PMA and ASF can discuss the variance of this input and assumptions made when creating this input. In such a way conclusions based on input data with high assumptions are avoided.

Suggestion (2):

For point (2) it is clear that capacity planning on midterm level needs more elaborated views than currently is done. Next to implementing new tools several organizational issues must be addressed. The process for evaluating different alternatives is suggested as follows: create scenarios for input parameters such as airside lay-out, rule setting (service level), governmental regulations, towing procedures, fleet characteristics, peak pattern and arrival and departure variances. Run a baseline scenario and the generated scenarios in the GCM 2.0 tool. Monitor and analyse the output on the defined – with all internal and external stakeholders – indicators and review the output on costs and benefits.

Furthermore there is a need for clear standardized measures of airport effectiveness addressing the performance of the airport in order to justify and evaluate the alternatives. A first initiative is given by defining measurable indicators in chapter 4, however support for creating norms and indicators must grow within Schiphol Group in order to assess the performance of different processes at the airport.

Suggestion (3):

It is suggested to organize expert sessions with experts from different organisational levels – operational gate planners, members management team etcetera – to discuss the different alternatives. In such a way soft and hard information comes together and knowledge from all layers of the organisation will help generating the best alternative for the problem.

13.3 Concluding remarks improvements decision making cycle

The chapter starts with describing the decision making process: start with recognizing a decision situation, followed by identifying appropriate alternatives, choosing and justifying the best alternatives according to indicators and implement the chosen alternative. Subsequently the conditions of decision making are described, for decision making for the aircraft stand area it can be concluded that decision making takes place under risk and uncertainty. Decision makers know which objectives they want to achieve, alternatives to reach those objectives are incomplete, outcomes of analysis is subject to chance and not at any time understood and information is available however sometimes incomplete. In the following section the suggestions for improving the decision making cycle are described. Firstly, it is recommended to intensify the cooperation between department ASF and department AO-PMA. ASF creates the forecasted flight schedules with assumptions and AO-PMA draws conclusions on capacity (im)balances. AO-PMA and ASF must discuss the variance of the input and assumptions made. In such a way conclusions based on input data with high assumptions are avoided. Secondly, evaluating different alternatives is suggested: create scenarios for input parameters such as airside lay-out, rule setting (service level), governmental regulations, towing

procedures, fleet characteristics, peak pattern and arrival and departure variances. Run a baseline scenario and the generated scenarios in the GCM 2.0 tool. Monitor and analyse the output on the defined – with all internal and external stakeholders – indicators and review the output on costs and benefits. Finally it is suggested to organize expert sessions with experts from different organisational levels to discuss the different alternatives and let soft and hard information come together.

14.Stakeholder engagement for organizational and tool improvements

Building incentives and creating support internally for doing more correct and elaborated capacity planning is of great importance for the success of this research. In the analysis phase – chapter 3 – stakeholder engagement is introduced and this chapter will elaborate on this by proposing concrete steps in order to engage the identified internal stakeholders. The identified stakeholders are AO-PMA, CAP, MT-A, ASF, ICT, Passenger Service, Terminal and Baggage processes. After identifying their power and interest in the project it was concluded that AO-PMA, CAP, MT-A and ASF need to be committed to the project.

14.1 Clarity about the aim of the tool and organizational improvements

The key to engagement for this project is clarity about what the project is designed to achieve and the advantages of the project in relation to current capacity analysis. The aim of the project must be communicated in a clear and short description:

To avoid imbalances between traffic demand and supply of gates and remote stands, imbalances must be notified in the earliest stage possible. To do so, a capacity analysis with the dynamics of the flight-to-gate assignment and taking into account input uncertainty is needed. With such analyses the capacity shortages can be calculated more accurate and alternatives can be evaluated in a quantitative matter. Most importantly, decision makers are supported with more accurate planning of gates and remote stands in an early stage and money can be save. The support tool facilitates the decision making process, however tighter cooperation between departments is needed. Between ASF and AO to avoid planning on assumptions in the flight schedule and between AO, PS, Terminal and Baggage to totally assess the capacity of flows of passengers, aircrafts and baggage.

14.2 Internal stakeholder engagement tactics

The project needs budget for improvements for the support tool, support for organizational changes in the decision making cycle and support for changing the current capacity planning. The following figures are derived from chapter 3 and the power versus interest grid and the engagement tactics are combined in one figure (right figure in figure 35).



Figure 35 Power versus Interest grid and the stakeholder engagement tactics

The engagement tactics will be discussed per stakeholder:

- AO-PMA: the problem owner must be convinced of the improvements suggested for the support tool and the decision making cycle. In a 1:1 meeting the GCM tool version 1.1 will be shown and the planning of 2016 compared to GMS planning will be showed. Furthermore the proposals for improvement for the tool will be discussed and the proposal of Incontrol for performing the improvements will be discussed. More concrete agreements will be made for tightening the cooperation between ASF and AO-PMA. Next to the problem owner the manager of AO-PMA needs to commit to the project. After engagement of the problem owner, the author of this thesis and the manager.

- It is suggested to inform CAP and MT-A in a group meeting with AO-PMA manager and the problem owner. Commitment can be created by showing the current situation of capacity analysis and the support tool.

- Firstly, ASF is informed by the problem owner during an informal meeting. Together a plan can be set up to change the procedure at the beginning of the cycle.

14.3 Follow-up: responsibilities, demo GCM tool and user manual GCM V1.1

In section 3.2 the responsibilities were highlighted in the organization chart. For the implementation of the improvements and follow-up for this project it is needed to know the responsibilities and action to take by which department and responsible person. The GCM tool will be used by the AO-PMA employee. CAP will be abolished and the ADI department will be a part of OPS and will play an advisory role. However, it is not known before November 2011 which exact role ADI will play within OPS. Presumably ADI employees will advise the process managers of baggage, PS and airside operation on simulation and forecasting. The new situation is shown in figure 36.

A demo of the GCM tool V1.1 – as currently available – is given to Joyce Groot (employee of ADI) and Jan van Rooijen (AO-PMA employee). During this demo experiments were shown and an experiment is simulated by using the user manual written for the GCM V1.1. This user manual is shown in appendix VI. Both parties were enthusiastic and noticed the added value compared to the current analysis in the Excel spreadsheet. However, it is suggested that the AO-PMA employee will be provided with a demo of the new Inform Groundstar tool – strategic planning module. This new model will be implemented in 2012 at AAS on operational level, but also has a strategic module for capacity planners. Subsequently, it is suggested that the AO-PMA employee will discuss the suggested improvements for the GCM tool as described in this thesis with the simulation engineer of Incontrol Simulation Software.

Concerning the improvements for the cooperation and decision making, management of OPS is responsible for taking initiative in this matter. Currently the expectations for cooperation in terms of discussing the forecasted flight schedule as input and starting point for the decision making cycle seems to be different from each other. ASF does expect that AO-PMA will intensify the cooperation after capacity analyses with the flight schedule on the aircraft stand area are done. To align the expectations it is suggested to organize a brainstorm session with several employees from OPS and from ASF.

At the end MT-A is responsible for providing sufficient capacity, however OPS is the unit who needs to perform the analyses and inform and notifies MT-A in a timely manner.



Figure 36 New situation organization chart Aviation

14.4 Concluding remarks stakeholder engagement

This chapter clarifies the steps to be taken to commit all important identified internal stakeholders to the project. Identified stakeholders of relevance are AO-PMA (problem owner and management), MT-A, CAP and ASF. The key to engagement for this project is clarity about what the project is designed to achieve and the advantages of the project in relation to current capacity analysis. The aim of the project is described in a short paragraph which can be communicated to the stakeholders. The project needs budget for improvements for the support tool, support for organizational changes in the decision making cycle and support for changing the current capacity planning. For those needs engagement is needed and suggestions are done to engage the stakeholders. Proposed engagement tactics are engage AO-PMA manager 1:1, engage CAP and MT-A in a group session and start cooperating and creating a plan with ASF on an informal basis.

Conclusions and recommendations

This closing phase presents the conclusions and recommendations of this research. The last chapter will contain a reflection on this research and project.

15.Conclusions

This research started with the initial assignment 'Gate & Remote Stand Capacity' drawn up by the responsible person for gate and remote stand capacity at that time (February 2011). The assignment described that there is a need for impact analysis on gate and remote stand capacity considering several changes, such as fleet changes in the flight schedule. Because AAS does not receives accurate information about fleet characteristics it is hard to point out when and where capacity shortages will appear. In the assignment the suggestions was made to develop a tool in which parameters which determine the gate and remote stand capacity can change and in which supply and demand characteristics can be changed in order to run scenarios.

At the beginning of this research the following objective and sub-objectives were formulated:

Research objective:

Analyze aircraft stand capacity planning on midterm level at Amsterdam Airport Schiphol in order to suggest improvements for better performing capacity planning and supporting decision making on aircraft stand area.

Sub-design objectives:

- *Re-design computational tools in such a way that the tool is a support for decision making on aircraft stand area.*
- Propose a decision support environment and embed this in the current organizational working processes at Amsterdam Airport Schiphol.

15.1 Analysis Phase

Gates and remote stands can be considered as resources of the airport and a particular capacity is available. In airport operations capacity is an important aspect because when traffic demand exceeds the operational capacity the aim of the airport is at risk. Primary goal of capacity management is to ensure that capacity of the gate and remote stands meets current and future traffic demand. There are serious consequences of getting the balance between demand and capacity wrong. The objective of AAS for capacity is: *Manage the airport capacity (runways, taxiways and aircraft stands) in such a way that the capacity imbalances are notified in the earliest stage possible and the occurrences of capacity imbalances kept to a minimum.* The 'sense of urgency' for notifying and managing the imbalances grows due to the higher occupation rate of the stands. Currently demand is growing and the number of stands doesn't/cannot grow in order to accommodate this demand.

1. What is the situation of the current procedure for midterm planning (decision making) of aircraft stand capacity?

3. Which tools are currently used for capacity cases on aircraft stand area?

6. Which tools are available within AAS to perform capacity planning of aircraft stand area?

Assessing if air traffic demand can be accommodated by AAS and the impact of changes in infrastructure, operational procedures or traffic volume is the objective of midterm capacity management. First, every year Schiphol Group is developing the integrated development plan for the coming 5 years. For this plan AO needs to deliver output of demand-supply analyses on a 5-yearly level. Furthermore, department AO is responsible for performing analyses on the demand-supply balance of aircraft stands for various questions from different organizational levels and departments.

With a forecasted flight schedule as input (based on a 5 minutes schedule) an Excel spreadsheet is created and at the day of analysis on the morning peak the number of demand for gates per category is calculated. Subsequently this amount of gates per category is compared to the supply of gates per category. With common sense and expert judgment of the capacity planner the demand and supply balance is analyzed concerning the loose of capacity due to allocation rules and the winning capacity due to planned upgrades of infrastructure. For gate and remote stand decision making it starts with the forecasted flight schedule from ASF, subsequent AO-PMA performs the capacity analysis of gates and remote stands in the Excel spreadsheet, CAP integrates all processes in a development and investment plan and finally MT-A decides on investment decisions. The shortcomings in this cycle are:

- decisions are based on assumptions made to develop the flight schedule and those assumptions are not taken into account in the output of the analyses;
- the dynamics of the flight-to-gate assignment system is not taken into account;
- there is a lack of standardized measures of performance indicators;
- and there is no optimal cooperation between the departments.

For performing analyses on the demand-supply balance of aircraft stands in 2006 an allocation tool is developed in Enterprise Dynamics in cooperation with the company Incontrol – the Gate Capacity Manager (GCM). This GCM tool allocates a flight schedule rule-based. The tool uses *if...then* rules in order to determine the most wanted stand for a particular flight. The GCM tool is currently not in use by department AO. Enterprise Dynamics (ED) is a discrete event simulation platform for logistics & business processes and is object-oriented combined with an event-oriented approach. The tool is a part of the Enterprise Dynamics (ED) Airport Suite. The Suite has a microscopic nature.

The GCM tool exists of a priority heuristic, parameters, databases as input and assigns flights to gates based on required, preference and avoidance rules. The preference and avoidance rules have a score, with those scores the end score of a stand is determined. The Enterprise Dynamic module embodies the heuristic and parameters, however the databases are imported from Microsoft Access databases and the visits are generated in Microsoft Excel. The stand is chosen according to a standscorelist which contains all stands and their scores. The scores are determined by the preference and avoidance rules. The output can be exported to Excel or shown in a Gantt chart.

The program of requirement of 2006 – for the development of GCM 1.0 – can be compared to the requirements described by the problem owner of this project. A drawback of the design and validation process in 2006/2007 is that only one person at AAS participated in the design and validation of the tool. The new responsible person for gate and remote stand capacity did not rely on the tool and described the tool as not user-friendly to work with.

Drawbacks in use of the tool:

Generating a planning is complex due to the use of Excel, Access and ED and the complex set up of databases in Access. Tool familiarity and understanding simulation in general is needed to understand the steps that has to be taken to run a planning. There is no guidance through the planning in order to perform and run a scenario in a fast and easy way.

Functional drawbacks:

- There is no computational check on the input data.
- The output indicators are not clear communicated.
- The handling times are indicated as permanent values in the parameter table.
- There are currently no possibilities to implement stochastic elements in the input data or statistical indicators for the fleet composition or peak pattern.

2. Which actors are involved in the midterm capacity planning of aircraft stand area and how do they interact?

Every year different departments from Schiphol Group cooperate to create a development plan for the coming five years.

- The flight schedule is delivered by department Aviation, Statistics and Forecast (ASF).
- With the flight schedule as input the process manager of department Airside Operations (AO) is performing the impact of those demand figures on capacity of gates and remote stands. The objective and responsibility of AO is to offer sufficient operational capacity at airside in the coming 5 years and has the fundamental knowledge of the processes at airside.
- The outcome of those analyses is communicated with the Unit Capacity Management (CAP) and CAP integrates the most important processes of the airport into the development plan. CAP has as main goal to plan timely sufficient, reliable and sustainable capacity for AAS its airlines and passengers and is responsible for the alignment of all important processes of the airport to offer sufficient capacity.
- Based on the plan investment decisions are made by Management Team Aviation to tackle the bottlenecks.

In previous years KLM collaborated with Schiphol Group to make the forecast flight plan. In the investment decision procedure discussions with KLM are done to align the decisions and the visit costs which will increase due to the investments.

4. Which variables determine the supply and demand for gates and remote stands?

According to (Janic, 2000) the capacity of any airport component – and thus also for gates and remote stands – can be expressed by four different measures that represent capacity attributes: the physical infrastructure, fluctuations of demand over time, profiles of user entities, and the quality of service provision.

Physical infrastructure AAS

At AAS airside 99 connected and 103 disconnected gates are available. All gates have different characteristics and have restrictions on which aircrafts can be accommodated.

Allocation Rules

The assignment of flight-to-gates is restricted due to governmental rules such as security rules and border status rules (Schengen, Non-Schengen) and therefore capacity is enforced fragmented and is less useful. Furthermore, allocation rules such as rules for towing rules and preferences must/can be taken into account. The capacity of the gates and remote stands during planning stage is also determined by the buffer time taken into account between two succeeding flights. This buffer time is to ensure that there is sufficient time between scheduled departure time of the first aircraft and the scheduled arrival time of the second aircraft to absorb stochastic flight delays.

Demand for aircraft stands

The demand for aircraft stands is determined by the number of flights – number of flights is determined by the air traffic demand and size of the aircrafts – and therefore the number of aircrafts expected to require services from an airport. This demand is set out in a flight schedule. The peak patterns, fleet composition and runway capacity determine demand as well.

5. How do other airport perform analyses on imbalances on aircraft stand area?

- Frankfurt Airport uses the AirTop simulation software for aircrafts and the simulation software CAST vehicle for traffic of aircrafts at airside.
- Aéroports de Paris (ADP) uses for the operational planning of flight-to-gates a tool called OSIRIS. The tool depends on specific and detailed flight schedules which are known short time before day op operation and therefore the tool is only used for operational planning. For tactical planning ADP uses standard sizing methods, based on gate and remote stand productivity and forecasts.
- Dubai Airport uses the Inform GmbH stand planning tool, Dubai recently purchased this tool. This tool is used to built a future stand layout and with the forecasted flight schedule for that same period of time it is simulated if the capacity can accommodate the demand.
- Brussels airport uses the Quintiq planning software. The software takes into account all applicable rules and constraints, such as airport specific rules, arrival patterns, and airline and handler rules and preferences. By implementing the software solution Brussels Airport wants to support expected growth and improve the service to its airline customers.

8. Which indicators are needed to support decision making for investment decisions on aircraft stand area for midterm planning?

The KPI for the capacity area of AAS is the stand capacity shortage, in the planning phase this is represented by the stand allocation mismatch and can be measured in number of aircrafts and unit hour. To measure capacity shortage the total number of aircraft for which no stand is available at the scheduled in-block time (SIBT) should be evaluated during the stand allocation process in planning phase. Currently the capacity planner of the aircraft stand area does not uses specific KPIs for

measuring the performance of the aircraft stand area. It is suggested to develop KPIs for the aircraft stand area, a first idea of KPIs is given:

- (1) the total number of aircraft for which no stand is available at the scheduled in-block time (SIBT) MINIMIZE
- (2) the total number of aircraft for which no connected stand is available at the scheduled inblock time (SIBT) - MINIMIZE
- (3) the total number of towing movements MINIMIZE
- (4) the total number and characteristics of stands needed to be built in order to offer service level X MINIMIZE INFRASTRUCTURAL COSTS, MAXIMIZE SERVICE LEVEL
- (5) assigned flight-gate preferences in % taken into account during planning
- (6) the stand occupation in % per category per 5 minutes MAXIMIZE
- (7) concentration level of handling agents (number of handling objects which are concentrated for one handling agent) MAXIMIZE

Furthermore the performance of the aircraft stand area should be measured on cost and benefits, delays and robustness.

9. Which method/tool is used for the operational flight-to-gate assignment?
10. What does literature say about flight-to-gate assignment?
11. Which methods are available from literature and most appropriate to model the aircraft stand allocation in a dynamic and flexible way for the use by AAS?

For the operational planning the Gate Management System (GMS) is used. The operational assignment model has a rule-based method with mandatory, costs and benefits rules. The model chooses a gate or remote stand with the highest score determined by the rules. For every one-day-ahead planning is determined how the capacity will be distributed, first of all the day is planned with the constraints (physical limitations, security and border status rules) and then the gate planners will determine which rules and which scores the correct planning is made with.

The flight-to-gate assignment problem is encountered by gate managers and process managers at an airport on a periodic basis. This assignment should be made in such a way so as to balance the perspectives of the airport, airlines and other stakeholder simultaneously, while providing buffers for disrupting unexpected events and having costs and benefits balanced considering the indicators.

The gate assignment problem can be seen as a scheduling problem. The basic gate assignment problem is a quadratic assignment problem²⁵ and was shown to be NP-hard by (Obata, 1979). In computational complexity this problem is categorized under NP-class of problems. As the gate assignment is a type of job-shop scheduling problem, its complexity increases exponentially if constraint size such as number of flights, available gates, aircrafts, flight block time etcetera. changes which is a very realistic assumption in airport operation. The NP-hard characteristic of the problem implies that there is no known algorithm for finding the optimal solution within a polynomial-bounded amount of time.

²⁵ The total passenger walking distance is based on the passenger transfer volume between every pair of aircrafts and the distance between every pair of gates. Therefore, the problem of assigning gates to arriving and departing flights at an airport is a Quadratic Assignment Problem (QAP).

In literature the problem is formulated as integer programming, integer linear programming, multiobjective 0-1 integer program, etcetera. The problem is solved using several methods to develop a solution algorithm, e.g. branch and bound techniques, column generation algorithm, meta-heuristics like Pareto Simulated Annealing and Genetic Local Search. However, the attempts described in literature do not show computational test results which incorporate the complex rule settings which need to be used when planning the aircraft stand area at AAS.

While traditional operations research techniques have difficulty with uncertain information and multiple performance criteria and do not adapt well to the needs of operation support, many researchers focus on the design of the so-called rule-based expert systems (Dorndorf, Drexl, Nikulin, & Pesch, 2007). The rule based technique uses a set of rules and the production rule (if <condition> THEN <conclusion>) to produce assignments of flights to gates/buffers. To find a near-optimal solution heuristics scheduling methods can be chosen to satisfy constraints.

The airports researched in the benchmark and the described software tools use the rule-based technique with heuristics scheduling methods to satisfy constraints. AAS is also focusing on the rule-based approach on operational level, the new purchased software tool (Inform Groundstar) for their operational planning (which also embeds a strategic planning module) uses the rule-based approach as well.

For this project no argumentation can be found to use the solution methods researched in literature because it is not proved that those solution methods can tackle the dynamics and the nature of the problem in the real-life situation at AAS and commercial tools do not incorporate the latest developments in algorithms and solution methods.

Unit of analysis and detail level of model

Due to the diversity of the various questions that need to be answered with the decision support tool it cannot be said that for one situation a particular aggregation level is needed, it depends on the scenario. The researcher needs to identify and verify the levels of aggregation of variables in an existing data set.

Analytical models can provide effective support for strategic level decisions, and generally require more aggregate description of the process/flow they analyze, while being less labor intensive as compared to simulation counterparts. Simulation models can provide effective support for operations related decisions, and in general require more detailed description of the process/flow they analyze, while being more labor consuming and computationally expensive than their analytical counterparts. It is suggested to use simulation models for the decision support tool due to the details of the assignment process and the allocation rules.

15.2 Design Phase

12. What are the user requirements for the tool?

Two user requirement sessions are held to document the user requirements for the decision support tool. The user requirements can be categorized, the tool must be:

- Usage of the tool:
 - o User-friendliness and easy to understand
 - o Data fully deliverable by AAS
 - o User must be able to zoom in on an assignment and see how decisions are made
- Functionality
 - o Planning on gate level
 - o Fixed parameters for the assignment: wingspan, country regions, security
 - o Possibility to turn off/on or add allocation rules
 - o Supply (stand lay-out) must be changeable
 - o Communication of capacity shortages
- Performance and output
 - The assignment can be a near optimal solution
 - The assignment must be reliable
 - Excel export possibilities of output

13. What are the design criteria for the tool to perform valid capacity planning for aircraft stand area for midterm planning?

- A flight schedule as demand input data
- Stand characteristics which are easy to change
- Production rules which are easy to change
- An option to implement a level of uncertainty on the input data to run scenarios.
- Output module: on the measurable indicators as described in the analysis phase

Furthermore it is recommended to have a cost and benefit module in the tool which evaluates the total costs for implementing a particular service level and the tool must avoid the 'black-box' idea. The method for planning the flight-to-gates is recommended to be a rule based systems with heuristics scheduling methods. Considering the what-if examples and the complexity of the system the aggregation level should be detailed.

14. Which data are input for the tool and is data availability a problem in this case?

The input for analyzing the demand and supply balance of the aircraft stand area is a forecasted flight schedule or the researcher can implement the details of the flight schedule. Data availability it not a problem due to the heuristic for generating visits (coupled arrival and departure flights), so no details of carriers is needed. It would be of added value if more exact details of the flight schedule are known derived from the carriers operating on AAS. However, due to conflicting interests and unstable supply of information this will be avoided as input requirement for the decision support tool.

15. Which improvements/adjustments must be made to the tool in order to perform aircraft stand 'what-if' analyses?

There are improvements made to GCM 1.0 which created GCM 1.1. The visitgenerator in Excel is improved, the feeding databases in Access are updated and the output analysis Excel spreadsheet is

updated and improved. The ED code is not changed. Currently the GCM tool version 1.1 is able to perform 'what-if' analyses, however running scenarios is complex and the tool need updates and improvements.

The suggestions for improvements are categorized according to category +++, ++, +. Planning a scenario in GCM 1.1 is complex and time consuming, therefore the suggestion to create user-friendly GUIs in the form of a wizard are categorized under category +++ improvements. An integrated solution whereby input databases, modeling and output evaluation is integrated in one wizard. This wizard will guide the user from input towards the output analysis. The wizard will also include a feedback mechanism which will directly generate feedback when the input is not according to specified requirements and a performance evaluation screen. The following improvements are also categorized under category +++: all flights have to be assigned to a gate, buffer or dummy gate and this assignment must be communicated in the output wizard; the two planningengines must be combined, departure flights must first be planned on a remote stand before towing to a gate for preparing departure, the match PI – the performance indicator for the match between visit and stand - can be set in %, however if a match is lower than this % the visit is still planned on the stand. It is recommended only to plan the visit to a stand lower than the match PI after consultation with the user. The tool must communicate the standscorelist to the user and the user can choose to assign the visit still or puts the visit to the scratch list. Category ++ suggestions contains the following suggestions. The functionality of the tool should be expanded with the dynamic aspect of variability in arrival and departure times. Enterprise Dynamics is a platform which is meant as simulation platform which can work with stochastic values like variability in arrival and departure times. Category + improvements are the implementation of statistical indicators for fleet characteristics and peak patterns and the possibility for the user to choose between different heuristics.

15.3 Implementation Phase

16. Which improvements must be made to the current working processes between departments in order to incorporate the dynamics of the aircraft stand area?

The decision making process consists of the following steps:

- recognizing a decision situation,
- followed by identifying appropriate alternatives,
- choosing and justifying the best alternatives according to indicators and
- implement the chosen alternative.

For decision making for the aircraft stand area it can be concluded that decision making takes place under risk and uncertainty. Currently the steps are not followed when making decisions on infrastructural or procedural changes on the aircraft stand area.

To improve the decision making cycle it is recommended:

- to intensify the cooperation between department ASF and department AO-PMA;
- evaluating different alternatives is suggested: create scenarios for input parameters such as airside lay-out, rule setting (service level), governmental regulations, towing procedures, fleet characteristics, peak pattern and arrival and departure variances. Run a baseline

scenario and the generated scenarios in the GCM 2.0 tool. Monitor and analyse the output on the defined – with all internal and external stakeholders – indicators and review the output on costs and benefits;

• and it is suggested to organize expert sessions with experts from different organisational levels to discuss the different alternatives and let soft and hard information come together.

17. How can those improvements be embedded in the current working environment?

A demo of the GCM tool V1.1 – as currently available – is given to Joyce Groot (employee of ADI) and Jan van Rooijen (AO-PMA employee). During this demo experiments were shown and an experiment is simulated by using the user manual written for the GCM V1.1. This user manual is shown in appendix VI. Both parties were enthusiastic and noticed the added value compared to the current analysis in the Excel spreadsheet. However, it is suggested that the AO-PMA employee will be provided with a demo of the new Inform Groundstar tool – strategic planning module. This new model will be implemented in 2012 at AAS on operational level, but also has a strategic module for capacity planners. Subsequently, it is suggested that the AO-PMA employee will discuss the suggested improvements for the GCM tool as described in this thesis with the simulation engineer of Incontrol Simulation Software.

Concerning the improvements for the cooperation and decision making, management of OPS is responsible for taking initiative in this matter. Currently the expectations for cooperation in terms of discussing the forecasted flight schedule as input and starting point for the decision making cycle seems to be different from each other. ASF does expect that AO-PMA will intensify the cooperation after capacity analyses with the flight schedule on the aircraft stand area are done. To align the expectations it is suggested to organize a brainstorm session with several employees from OPS and from ASF.

18. Which aspects should be taken into account when implementing the tool, such that it will receive support of the stakeholders involved in the decision making procedure?

It is important to engage all important identified internal stakeholders to the project of improving the midterm capacity planning. Identified stakeholders of relevance are AO-PMA (problem owner and management), MT-A, CAP and ASF. The key to engagement for this project is clarity about what the project is designed to achieve and the advantages of the project in relation to current capacity analysis. The project needs budget for improvements for the support tool, support for organizational changes in the decision making cycle and support for changing the current capacity planning. For those needs engagement is needed and suggestions are done to engage the stakeholders. Proposed engagement tactics are engage AO-PMA manager 1:1, engage CAP and MT-A in a group session and start cooperating and creating a plan with ASF on an informal basis.

16.Recommendations

In this chapter recommendations are made with respect to the midterm capacity planning for gates and remote stands by responsible employee Process Manager Airside at department Airside Operations.

Change of midterm capacity planning of gates and remote stands: organization and tool

It can be concluded that the current planning tool and approach (Excel spreadsheet) does not incorporated the dynamics of the system flight-to-gate assignment. Not every flight can be accommodated at a gate, restrictions must be taken into account. The characteristics of the flight-togate assignment problem can be described as multiple criteria, multiple constraints, multiple objectives and conflicting objectives. To generate insight into the system and its interdependencies and to support decision makers it is recommended to integrate a support tool in the midterm planning horizon. Decision makers need to know if current infrastructure can accommodate future demand and if not which alternatives are available considering several indicators. The capacity imbalances must be notified in the earliest stage possible.

It is recommended to start using the currently available GCM tool V1.1 by process manager airside of the department Airside Operations. Moreover it is recommended to improve the current GCM tool 1.1 by implementing the suggested improvements. Those improvements must be implemented by a simulation expert. The tasks for improvements are suggested to be outsourced towards Incontrol. This research made clear which functionalities and characteristics the tool must contain.

- Module for capacity input: in this module the user can change the physical lay-out situation of airside, characteristics of gate and remote stand, production rule set (towing rules, preferences, segment allocation)
- Module for demand input: in this module the user can change the initial forecasted flight schedule. Changing the fleet characteristics, adding distribution on arrival and departure times and changing the peak structure.
- Planning heuristic: the assignment of flight-to-gate must be based on production rules and a heuristic which assigns every aircraft to a gate, remote stand or dummy gate and which decided on towing movements.
- Module for evaluation output on performance criteria

Next to recommendations for the support tool it is necessary to change the decision making procedure. The formal decision making process must be applied: start with recognizing a decision situation, followed by identifying appropriate alternatives, choosing and justifying the best alternatives according to indicators and implement the chosen alternative. Department AO-PMA is responsible for identifying alternatives. To evaluate different what-if situations it is suggested to use scenarios for input parameters such as airside lay-out, rule setting (service level), governmental regulations, towing procedures, fleet characteristics, peak pattern and arrival and departure variances. Run a baseline scenario and the generated scenarios in the GCM 1.1 tool (after implementation of improvements V2.0). Subsequently, higher management must be involved in order to choose and justify the alternatives. So, tighter cooperation between different organizational levels is needed. However, clear performance indicators are needed in order to assess the alternatives.

It is recommended to intensify the cooperation between department ASF and department AO-PMA. ASF creates the forecasted flight schedules with assumptions and AO-PMA draws conclusions on capacity (im)balances. AO-PMA and ASF must discuss the variance of the input and assumptions made. In such a way conclusions based on input data with high assumptions are avoided. Finally it is suggested to organize expert sessions with experts from different organisational levels to discuss the different alternatives and let soft and hard information come together.

Stakeholder engagement

AO-PMA needs to create a sense of urgency towards the other internal stakeholders involved. This means that the stakeholders involved need to be convinced that there are problems that need to be solved and that they can only be solved by some form of cooperation (Bruijn, ten Heuvelhof, & in 't Veld, 2002). The key to engagement for this project is clarity about what the project is designed to achieve and the advantages of the project in relation to current capacity analysis. In this thesis a qualitative description is given of the problem and the advantages of the proposed improvements. However, the message will be more clear with quantitative analysis. So, what will deliver a more accurate gate planning (incorporating the dynamics) on midterm level in terms of € and how can it assist in deciding on procedural changes.

Firstly, AO-PMA must be convinced of the improvements suggested for the support tool and the decision making cycle. In a 1:1 meeting the GCM tool version 1.1 and the planning of 2016 compared to GMS planning will be shown.

It is recommended that the responsible employee for gate planning on midterm level will create that 'sense-of-urgency' toward the AO-PMA manager. And it is suggested to inform CAP and MT-A in a group meeting with AO-PMA manager and the problem owner. Commitment can be created by showing the current situation of capacity analysis and the future situation with the support tool.And it is recommended that the problem owner will inform ASF during an informal meeting. Together a plan can be set up to change the procedure at the beginning of the decision making cycle.

Considering other tools

It is recommended that ICT-Business Manager Airside informs the process manager airside on the strategic module of the Inform Groundstar tool which is currently implemented for operational purposes. The Groundstar tool is purchased for operational purposes, however the tool also incorporates a strategic module in which capacity planners can run scenarios and evaluate the output on several indicators.

NLR is developing the airport simulator Airport Operations Center (APOC). APOC offers the possibility to plan airport operations in an effective way and in cooperation with airlines, handling agents, airport authorities and air traffic control. NLR APOC can be used to validate and assess new developments in procedural decision of airport operations. Currently NLR is focusing on the development of the stand management module. This module comprehends a microscopic simulation of airside processes, has multiple planning strategies which can be chosen and has a module for performance monitoring. NLR suggested to develop the stand planning tool in cooperation with AAS.

17.Reflection

This last section provides a reflection on the research approach, the scope of the research and on the project itself.

Research Approach

The original project assignment provided by the problem owner was focused on a tool needed to assess the balance between the capacity available of the gates and remote stands and the demand for gates and remote stands. Furthermore the tool must be able to perform impact analyses, which means that it must be able to analyze the output when changing the input parameters of the tool. In the beginning of this research it was not totally clear if a new tool was needed or if existing tools were capable of performing the needs of the problem owner. Also I wanted to investigate the organizational environment in order to know the context of the tool. In my opinion this was needed to find out the requirements and detail level for the tool as well as the engagement and interest of the internal stakeholders of AAS. So, first I spent time to describe the decision making process for investment decisions which returns every year in the form of the development plan for AAS for the coming five years. The problem owner was not convinced of the need to research the organizational context because this did not changed the final need for the tool. And at the end as the problem owner reasoned, the problem owner is responsible for performing valid analyses on the gate and remote stand area and other internal stakeholders will depend on those analyses and outcomes. After several discussions I convinced the problem owner for the need of the organizational context by describing important decisions that should be made in order to define the criteria for the tool. Gradually, after several informal talks with employees of different departments it became clear to me that capacity planning is not only a concern for problem owner' department but is an issue for all processes at the airport such as baggage handling and passenger handling in the terminal. I noticed that departments such as Analysis, Development and Innovation, ICT, Aviation, Statistics & Forecast, Passenger Services and Baggage all have their own view on how to perform capacity planning analyses. I anticipated on this by defining the interests, objectives and linkages of the internal stakeholders.

However, the original assignment was to provide a tool. I spent time on finding out the current way of performing the analyses on capacity of and demand for gates and how the problem owner determined overcapacity or shortfalls in capacity. To analyze a capacity – demand balance and the sensitivity of its factors norms are needed to determine if there is overcapacity or a shortfall in capacity. Especially because the flight-to-gate assignment encloses many allocation rules which are not mandatory such as preferences for the allocation of a certain airline on a gate. During this research I have noticed that those kind of norms are missing or are not recorded in a formal way and for me it was difficult to understand the moment in time when an urgency will occur for a shortfall in capacity. To avoid in getting stuck on this matter I decided that the tool must be flexible in terms of adding, changing or deleting allocation rules. I cannot decide on whether an imbalance occurs, however the tool must provide certain information in order that the responsible capacity planner can make decisions based on the output of the tool. After several weeks I noticed that in 2006 a project had started with an objective the same as for this project. I analyzed this project and the process of implementation and it became clear that the tool developed at that time is not in use but has the requirements needed to perform the capacity analyses. It was hard to determine the reasons why

this tool is not in use anymore. I anticipated on this by analyzing the added value of the tool by giving demos to the capacity planners and obtain and observe their opinion on the tool. By doing so I found the drawbacks of the current version and could define more detailed user requirements.

Due to the forecast uncertainty I concluded that it is needed to implement stochastic elements in the capacity planning process of gates and remote stands. I was amazed that this was not yet done at in an elaborated way by AAS when performing capacity planning. The way AAS is incorporating uncertainty in forecast is by providing three scenarios of the flight schedule for in 5 years (high, medium and low). I spoke to people from KLM and Schiphol about this matter and I received very positive feedback and they were all enthusiastic about the idea. It was not possible to perform calculations and numerical analyses with stochastic input parameters, however I discussed the need for this and recommend that AAS introduces this stochastic approach.

Looking back at my approach to the original assignment and the context of the problem I would have started earlier with talking to the different departments and employees of AAS with simulation knowledge. Furthermore for me it was very difficult to understand the detail level for the different planning horizons. It would be of added value to look at other large infrastructural branches with forecasting issues such as in the branches rail and road development.

Scope

In the beginning of this research it was not totally clear if a new tool was needed or if existing tools were capable of performing the needs of the problem owner. I default to the assumption that I was building and providing a model which performed capacity analyses on the gate and remote stand area at the end of the project. However gradually it became clear to me that it was not realizable for me as a SEPAM student to build a model which incorporates the complexity and dynamics of the allocation rules. Because of this I realized a program of requirement for the needed tool and assessed if the existing tool developed in 2006 does meet those needs.

At the first few weeks I got stuck on the broad environment of capacity planning, forecasting flight schedules and the norms for the service levels. Due to the forecast uncertainties in forecasting flight schedules and demand for gates and remote stands and the dynamic character of the aviation sector in general I got stuck on scenario development and the way assumptions should/were been made. Furthermore it took some time to map out the interdependencies of the flight-to-gate assignment system.

As said in the previous section many departments within AAS are concerned with capacity planning. Currently a new tool (Inform Groundstar) for the operational flight-to-gate planning is implemented, this OPAS project is aims at operational gate planning purposes. However, I noticed that the tool also has a strategic planning module and is able to serve capacity planners for the longer horizon. Due to the fact that I did not investigated this option in detail I would recommend to the problem owner to analyze this tool (according to the requirements set up in this project) and to take this option into account before improving the GCM tool.

Project and the follow-up

To me it is clear that the current methods and approaches towards midterm gate capacity planning is not sufficient to cope with the high occupation rate of the gates during peaks that is currently the case. So, there is definitely a need for more elaborated capacity planning. Hopefully the process manager airside who is responsible for providing figures on shortages on gate capacity is encouraged to take action on this matter.

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Interviews

Name	Department	Job title	Date		
Etienne van Zuijlen	AAS/CDM	CDM-program manager	14-02-2011		
Koos Ruiter	AAS/A/AO	Senior Gate Planner	08-03-2011		
			08-07-2011		
			12-08-2011		
Martijn van der Meer	AAS/A/AO/PMA	Manager Airside Operations PMA	11-03-2011		
Wouter van Daal	AAS/A/CAP/ADI	Manager Analysis, Development & Innovation			
Joyce Groot	AAS/A/CAP/ADI	Senior Advisor Manager	22-03-2011		
			25-03-2011		
			12-07-2011		
			19-07-2011		
			26-07-2011		
			01-08-2011		
			30-09-2011		
			21-10-2011		
Bob Gimberg	AAS/A/CAP/ADI	Senior Advisor Manager	25-03-2011		
Marlies Wouters	Incontrol	Senior Simulation Engineer	21-04-2011		
	Simulation		27-06-2011		
	Software		04-08-2011		
Ricardo Kallendorf	Air France - KLM	Capacity analyst ground resources KLM	05-05-2011		
Daniel Dos Reis Miranda	AAS/A/MD/ASF	Manager Aviation, Statistics and Forecast	23-05-2011		
Ed Bos	Air France - KLM	Project Manager Air France - KLM	26-05-2011		
Ineke Robertus	Air France - KLM	Capacity analyst ground resources KLM	06-06-2011		
Ron Witteman	Air France - KLM	Gate Planner	07-06-2011		
Sandor Verhoeven	AAS/A/AO/PS	Advisor Passenger Services	14-06-2011		
Michael Keet	AAS/A/AO/PMA	Process Manager Analysist Airside	23-06-2011		
Eric Corten	AAS/ICT	Business Manager ICT Airside Operations	30-06-2011		
Alexander Verbreack	TU Delft	Professor TPM Faculty / Systems Engineering	30-06-2011		
Mamadou Seck	TU Delft	Assistant professor TPM Faculty / Systems	22-07-2011		
Livilia Tar Daala		Engineering	10.00.2011		
нуке тег веек	AAS/A/MD/ASF	Advisor Aviation, Statistics and ForeCast	10-08-2011		
Bert van Wee	TU Delft	Protessor TPM Faculty / Transport & Logistics	18-08-2011		
Jan van Ooijen	AAS/A/AO/PMA	Process Manager Airside	02-09-2011		
			21-10-2011		

Name	Department	Job title	Date		
Lotte Harbers	AAS/A/AO	Process Manager Analysist Airside	Once a week till		
			06-06-2011		
Ronald Grossman	NLR	Senior R&D Manager NLR	Once a month		
Maraat de Bruijn	AAS/A/AO	Process Manager Analysist Airside	Once a week		
			from 06-06-2011		

Field Trips

Activity	Date		
Airside	08-03-2011		
Control Tower – Daily Operational Gate Planner – one evening shift	05-05-2011		

Abbreviations

LIST OF ABBREVIATIONS								
AAS	Amsterdam Airport Schiphol							
Α	Aviation							
ADI	Analysis, Development & Innovation							
AO	Airside Operations							
APC	Apron Planning & Control							
ASF	Aviation Statistics & Forecasts							
ATAP	Air Traffic Control & Airport (department NLR)							
ATM	Air Traffic Management							
CAP	Capaciteitsmanagement							
CAT	Category							
CDM	Collaborative Decision Making							
COO	Chief Operations Officier							
EU	European flight							
ETS	Emission Trading Scheme							
GCM	Gate Capacity Manager							
GDP	Gross Domestic Product							
GMS	Gate Management System							
IATA	International Air Transport Association							
ICA	Intercontinental fligth							
KLM	Koninklijke Luchtvaart Maatschappij							
KPA	Key Performance Area							
КРІ	Key Performance Indicator							
LVNL	Luchtverkeersleiding Nederland (ENG: Air Traffic							
мт	Control Netherlands)							
мт л	Management Team Aviation							
MIT-A	Narrowhody							
NEU	Non-European flight							
NLO	Non-European right							
NP	Non-Polynomial							
NS	Non-Schengen							
OPS	Operations							
PMA	Process Manager Airside							
PT	Positioning Time							
RASAS	Regulation Aircraft Stand Allocation Schiphol							
S	Schengen							
SEPAM	Systems Engineering, Policy and Management							
SIBT	Scheduled In-Block Time							
SIM	Samenwerking Innovatiemainport							
SOT	Scheduled Occupancy Time							
WIBO	Widebody							
WP	Work Package							



Appendix I – Organization chart AAS – Aviation (situation until November 2011)

Appendix II -Screenshot input flight schedule

	A	В	С	D	E	F	G	Н	1	J	K	L	M	N	0	P	Q	R S	T	U	V	V	X	Y
1		Prefix 💽	VINr 💽		van dag/m 💌	tot dag/mr 💌	ma 💌	di 💌	woe 💌	do 💌	vr 💌	za 💌	zo 💌	Seat 💽	Alc	origin1 💽	origin2 🔹	UurA 💽 MinA	💽 HHMM	I A 💽 UurV [MinV	 HHMM V 	💌 dest1 🚺	🔹 dest2 🚺
2	A	AAN	AAN0182		11-apr-16	24-okt-16	1	0	0	0	0	0	0	180	320	NDR	NDR	11	20					
3	A	AAN	AAN0412		21-jun-16	13-sep-16	0	2	0	0	0	0	0	180	320	TLV	TLV	11	45					
4	A	AAN	AAN0784	ł	24-apr-16	23-okt-16	0	0	0	0	0	0	7	180	320	TNG	TNG	15	0					
5	A	AAN	AAN1412		1-jul-16	9-sep-16	0	0	0	0	5	0	0	180	320	TLV	TLV	8	30 8:30					
6	٧	AAN		AAN0137	6-jun-16	24-okt-16	1	0	0	0	0	0	0	180	320					1	4	0	ASR	ASR
7	٧	AAN		AAN0537	24-apr-16	23-okt-16	0	0	0	0	0	0	7	180	320					1	8	0	ASR	ASR
8	A	AB	AB 9265		30-mrt-16	28-okt-16	0	0	3	0	5	0	0	174	320	PMI	PMI	12	15 12:15					
9	٧	AAN		AAN0783	24-apr-16	23-okt-16	0	0	0	0	0	0	7	180	320						7	0	TNG	TNG
10	A	AB	AB 3963		2-apr-16	29-okt-16	0	0	0	0	0	6	0	144	73G	BMI	BMI	16	0					
11	A	AB	AB 9265		28-mrt-16	24-okt-16	1	0	0	0	0	0	0	144	73G	PMI	PMI	12	15					
12	A	AF	AF 1156		27-mrt-16	29-okt-16	1	2	3	4	5	6	7	100	CRK	LYS	LYS	6	40 6:40					
13	A	AB	AB 9265		29-mrt-16	27-okt-16	0	2	0	4	0	0	0	186	738	PMI	PMI	12	15					
- 14	A	AB	AB 9265		2-apr-16	29-okt-16	0	0	0	0	0	6	0	186	738	PMI	PMI	15	5					
15	A	AB	AB 9267		27-mrt-16	23-okt-16	0	0	0	0	0	0	7	186	738	PMI	PMI	8	35					
16	٧	AB		AB 3962	2-apr-16	29-okt-16	0	0	0	0	0	6	0	144	73G					1	6	40	BMI	BMI
17	٧	AB		AB 9264	28-mrt-16	24-okt-16	1	0	0	0	0	0	0	144	73G					1	3	0	PMI	PMI
18	A	AF	AF 1240		27-mrt-16	29-okt-16	1	2	3	4	5	6	7	186	321	CDG	CDG	6	40 6:40					
19	٧	AB		AB 9264	29-mrt-16	27-okt-16	0	2	0	4	0	0	0	186	738					1	3	0	PMI	PMI
20	٧	AB		AB 9264	2-apr-16	29-okt-16	0	0	0	0	0	6	0	186	738					1	5 !	50	PMI	PMI
21	٧	AB		AB 9266	27-mrt-16	23-okt-16	0	0	0	0	0	0	7	186	738						9 ;	20	PMI	PMI
22	A	AF	AF 1256		28-mrt-16	29-okt-16	1	2	3	4	5	6	0	114	318	LYS	LYS	11	35 11:35					
23	A	AF	AF 1340		27-mrt-16	29-okt-16	1	2	3	4	5	6	7	186	321	CDG	CDG	7	15 7:15					
24	A	AF	AF 1356		27-mrt-16	29-okt-16	1	2	3	4	5	6	7	100	CRK	LYS	LYS	17	30 17:30					
25	A	AF	AF 1640		28-mrt-16	28-okt-16	1	2	3	4	5	0	0	186	321	CDG	CDG	10	55 10:55					
26	A	AF	AF 1740		27-mrt-16	28-okt-16	1	2	3	4	5	0	7	152	320	CDG	CDG	12	0 12:0					
27	A	AF	AF 1640		27-mrt-16	29-okt-16	0	0	0	0	0	6	7	152	320	CDG	CDG	10	55					
28	A	AF	AF 2040		28-mrt-16	28-okt-16	1	2	3	4	5	0	0	186	321	CDG	CDG	15	35 15:35					
29	A	AF	AF 1740		2-apr-16	29-okt-16	0	0	0	0	0	6	0	186	321	CDG	CDG	12	0					
- 30	A	AF	AF 2240		27-mrt-16	29-okt-16	1	2	3	4	5	6	7	186	321	CDG	CDG	17	40 17:40					
31	A	AF	AF 3262		28-mrt-16	28-okt-16	1	2	3	4	5	0	0	37	ER3	CFE	CFE	13	50 13:50					
32	A	AF	AF 2040		27-mrt-16	23-okt-16	0	0	0	0	0	0	7	127	319	CDG	CDG	15	35					
33	A	AF	AF 5200		28-mrt-16	29-okt-16	1	2	3	4	5	6	0	88	AR8	BSL	BSL	5	55 5:55					
34	A	AF	AF 5202		27-mrt-16	29-okt-16	1	2	3	4	5	6	7	88	AR8	BSL	BSL	14	20 14:20					
35	A	AF	AF 3262		27-mrt-16	23-okt-16	0	0	0	0	0	0	7	37	ER3	CFE	CFE	17	30					
36	A	AF	AF 5364		28-mrt-16	28-okt-16	1	2	3	4	5	0	0	50	ER4	NTE	NTE	6	25 6:25					
37	A	AF	AF 5366		28-mrt-16	28-okt-16	1	2	3	4	5	0	0	50	ER4	NTE	NTE	14	0 14:0					
38	A	AF	AF 5368		27-mrt-16	28-okt-16	1	2	3	4	5	0	7	50	ER4	NTE	NTE	17	50 17:50					
39	A	AF	AF 5364		2-apr-16	29-okt-16	0	0	0	0	0	6	0	50	ER4	NTE	NTE	6	25					
40	A	AF	AF 5366		27-mrt-16	23-okt-16	0	0	0	0	0	0	7	50	ER4	NTE	NTE	13	35					
41	A	AF	AF 5482		28-mrt-16	28-okt-16	1	2	3	4	5	0	0	50	ER4	SXB	SXB	6	5 6:5					
42	A	AF	AF 5484		28-mrt-16	28-okt-16	1	2	3	4	5	0	0	37	ER3	SXB	SXB	9	40 9:40					
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Appendix III - Causal Diagram capacity gate



Appendix IV – Poster aggregation level: 2nd Brainstorm session user requirement

Appendix V – IDEF-0 diagrams GCM tools

Level A0



Level A1-A3



Level A21-A23



Level A31-A35



Level A341 – A344





Heuristic: Flowchart A344 IDEF-0 scheme choose available stand from standscorelist
Appendix VI – User Manual GCM tool V1.1

User Guide Versie 1.0

Datum 01-10-2011

Gate Planning met de Gate Capacity Manager (GCM) Tool Versie 1.1

De GCM tool is een tool waarmee een gate planning gesimuleerd kan worden. Zo kunnen er 'what-if' analyses gedaan worden betreffende de gate en VOP capaciteit. Voor het jaarlijkse Schiphol development plan kan de 5-jarige forecast gerund worden, echter kunnen er ook analyses gerund worden voor vragen die voortvloeien uit projecten zoals de G-satelliet of de D-stemvork. De tool is flexibel genoeg om deze verschillende analyses uit te voeren en om het detaillevel per simulatie aan te passen.

De algehele simulatie maakt gebruik van de visitgenerator in Excel, de databases in Access en de planning engine in Enterprise Dynamics (ED). ED is een discreet simulatie platform en maakt gebruik van objecten waarin het gedrag van real-life gebeurtenissen is opgenomen, voor iedere visit wordt er een object aangemaakt. De input bestaat uit verschillende data en parameters. In onderstaande lijst worden de activiteiten weergegeven die in iedere fase van de simulatie moeten worden voltooid en in welk programma welke data/parameters aangepast kunnen worden.

Onderdeel Simulatie	Programma	Activiteit	Data / Stappen	Assumpties
Visitgenerator	Excel	Omzetten data uit het .sir bestand naar te gebruiken data voor simulatie van 1 dag.	 .sir vliegschema check duplicates genereer Input_Visits genereer Input_Flights 	 in forecasted vliegschema in het algemeen minimum turnaraound times per airline koppeling volgens FIFO
Databases	Access	Input klaarmaken voor generatie van planning in GCM tool.	 'Feeding Databases'* Input_Rules Input_Stands Input_Visits Input_StandConflicts 	- de planning is gebaseerd op de opbouw van de regels, Input_Rules bevat assumpties
Planning Engine	Enterprise Dynamics – GCM library	Genereren van de gate/VOP planning	 Import databases Model bouwen Set of parameters Run planning Evalueren output 	- Parameters: handling times, towing characteristics, buffer time, matchPl

* De zogenoemde 'Feeding' Databases is de data die zorgt voor een juiste interpretatie van de input databases, de volgende 'Feeding' Databases bestaan in Access:

- Data_Aircraft_Type
- Data_Airport_and_Country_Codes
- Data_Carrier
- Data CarrierSegment

Data Carriergroups

- Data_Handlers
- Data Countries
- Data StandAreas
- Data StandStatus

User Guide – Visitgenerator Excel

Maak data k	daar in data	a uit .sir be	stand (voo	or deze run	sheet S16	.sir)					Extra opme	erkingen		
1. Sorteer d	e data op k	olom A op	Arrival (A)	en Vertre	k (V)									
2. Bepaal op	o welke dag	g de planni	ng moet w	orden uitg	evoerd (vo	oor deze ru	ın is gekoz	en voor vri	ijdag 22 juli	2016)				
3. Voeg in k	olom AB he	et woord 'V	Veek' toe											
4. Voeg in k	olom AC, ri	j 1 de eers	te dag (ma	andag) var	de week	van analys	e in het vo	lgende for	rmat in dd-i	mm-yyyy				
5. Voeg in k	olom AD, ri	ij 1 de laats	te dag (zo	ndag) van o	de week va	an analyse	in het volg	gende forn	nat in dd-m	m-yyyy				
6. Voeg in k	olom AC va	anaf rij 2 t/r	n laatste i	ngevulde r	ij de volge	nde formu	le in =ALS	(E2<\$AC\$1;	;1;0)		Met deze f	ormules w	ordt bekek	en
7. Voeg in k	olom AD va	anaf rij 2 t/ı	m laatste i	ngevulde r	ij de volge	nde formu	ıle in =ALS	(F2>\$AD\$1	;1;0)		of de vluch	t in de gev	venste ana	lyse week
8. Voeg een	autofilter	in op de ee	erste rij								vliegt of nie	et.		
9. Filter alle	en de 1-tje	s uit op ko	lom AC en	AD										
10. Filter op	de kolom	van de gew	venste ana	lyse dag de	e nullen w	eg (voor de	eze run ko	lom vrijdag	g, selecteer	alleen de	5)			
Check dupli	icates													
1. Copy/Pas	te de volge	ende data v	an de .sir	sheet naar	Duplicates	s sheet					Voor de ar	rivals kan	er bij dep.t	ime
ArrDep	FlightNr	\ircraftTyp	Carrier	DepTime	ArrTime						0:00 invgev	uld worde	en,	
											voor depar	rtures kan	er bij arr.	
											time 0:00 ingevuld worden			
2. Voeg in ri	ii G Duplica	tes/No Dui	olicates in	en voeg de	e volgende	e formule i	n van rii 2	t/m laatste	ingevulde	rii	Let op de re	anae van d	de kolom	
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3. Voeg auto	ofilter toe o	op eerste ri	ii		,, 1						staat de gehele dataset hierin?			
4. Filter op r	rii G op Dur	olicate	,								J			
5. Check per	r flightnr of	f de duplica	ate een do	orvlucht of	een ande	re vlucht n	naar zelfde	nummer	is					
6. Indien do	orvlucht pl	aats achter	r het flight	nr van arriv	al het vol	gende teke	en dv							
7. Indien ze	lfde vlucht	nummer m	laar ander	e vlucht (ve	erschil in A	rrtime of [)entime) z	et achter h	net flightnr	van arriva	l het volgen	nde teken	а	
8. Alle vluch	nten hebbe	n nu de sta	atus No Du	plicate - ch	eck via filt	ter kolom e	, ,			· an ann a	. net toige	ue tenen	_"	
				prioace of										
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2. Verander	alle 'V' in k	colom A in	'D'	Deprine	,									
	une e nu		-											
Set paramet	ters and ru	n												
1 Ganaars	heets Parar	neters en 1	FurnAroun	dTimes or	n de naram	eters in te	voeren							
2 Vul een n	ninimum tı	irnaroundt	ime in on	de sheet P	arameters	in F5 (aanl	voolen ?	0 minuten')					
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5. Druk op u			t in sheet	i urunieten	,						ie vinden ir	n de cheet	Roculto	
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		uies Aivis I												

8. Maak in kolom ID nummers aan beginnend bij 1 en eindigt op de laatst ingevulde rij

User Guide – Databases Access

Open Access document										
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1. Update GCM Input Sta	ands en GCM In	put StandCon	flicts confo	rm de gev	venste run					
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	Numeriek	Number to identif	y the criteria l	type.			beschrijving			
Flight	Tekst	Flight number, th	is can refer to	the arriving	OR the departing	, flight	of a visit.			
Carrier	Tekst	Carrier name.								
CarrierGroup	Tekst	Carrier group nar	ne.							
CarrierSegment	Tekst	Carrier segment i	name.							
	Tekst	Handler Aircraft category pumber from 1 until 8								
	Tekst	Aircraft type								
AC_schengenInd	Tekst	Schengen indication of a visit.								
CustomCheck	Numeriek	1=yes, 2=no, 0 = irrelevant								
Profiling	Numeriek	ek 1=yes, 2=no, 0 = irrelevant								
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MinimumCat	Numeriek	Minimum categor	y stand. numh	ered from 1	until 8.					
Custom?	Numeriek	1=yes, 2=no, 0	= irrelevant							
Profiling?	Numeriek	1=yes, 2=no, 0	= irrelevant							
IndividualGate	Tekst	Possiblity to assig	in flights to inc	dividual gate	s. If more gates c	an be	chosen, separat	e them with com	na.	
StandArea AssignmentTurce	Tekst	Assign flights to a	a certain stand	larea.						
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User Guide – Databases Access – Extra Opmerkingen

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User Guide – GCM Entreprise Dynamics Tool

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Appendix VII – *Scientific Article* ' Flight-to-gate assignment: methods and complexities at different planning horizons'

Flight to gate assignment: solution methods and complexities at planning horizons

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Abstract

The flight-to-gate assignment problem is encountered by gate managers and capacity planners at airports in general on a periodic basis. The 'sense of urgency' for notifying and managing the imbalances of demand for and supply of gates in an early stage grows due to the higher occupation rate of gates compared to previous years at Amsterdam Airport Schiphol (AAS). Capacity planners need computational tools for capacity analyses to face the complex decision making process on gate infrastructure and procedures. Current methods described in literature for the flight-to-gate assignment problem are reviewed. Subsequently, the most appropriate method for capacity planning on tactical level is chosen and reasoned. Since the flight-to-gate assignment problem has the characteristics of a NPhard class of problem there is no known algorithm for finding the optimal solution within a polynomial-bounded amount of time. Several attempts to find sub-optimal solutions to the flight-to-gate assignment problem are made and described in literature, however practical usability and tests with a large set of data is missing. Available commercial tools are based on the rule-based technique and a heuristics scheduling method to find a near-optimal solution. Based on the arguments described in the previous two sentences it is suggested to use the rule-based technique with a heuristic method for the decision support tool at AAS.

Keywords

Flight-to-gate assignment, heuristic scheduling method, rule-based techniques, planning horizon, decision support tool

1 Introduction

The airport planning and decision making process contains various trade-offs and complications due to large number of stakeholders having different and often conflicting objectives regarding the performance of airport processes. Infrastructure at the airside of an airport in general must provide enough capacity for current and future demand. At Amsterdam Airport Schiphol (AAS) capacity planners are responsible for providing sufficient capacity in such a way so as to balance the perspectives of the airport, airlines and other stakeholders simultaneously, and having cost and benefits balanced considering the performance indicators. This also accounts for the capacity of gates and remote stands at airside of AAS. At AAS planning is done on daily operation, one-day-ahead, seasonal and tactical basis²⁶. The objective of planning the gates and remote stands on tactical level is to assess if air traffic demand can be accommodated by AAS and to assess the impact of changes in infrastructure, operational procedures and traffic volumes. Flight characteristics and gate characteristics and the constraints must be taken into account when analyzing the balance between capacity of and demand for gates. The planning of flight to gates concerns many issues. The details of the flight-to-gate problem change with its constraints, objectives, time horizon, solution methods (i.e. optimization, rule-based techniques, meta-heuristics²⁷, simulation), and purpose (i.e. planning or real-time dispatching) (Murty, Wan, Yu, Dann, & Lee, 2008). First the multiple objectives of the airport, airlines and other stakeholder must be balanced. Secondly, the planning must provide buffers for disrupting unexpected events and costs and benefits must be balanced considering the indicators. Incorporating buffers will cost capacity and thus money. The cost of one minute of buffer time for an A320 is estimated on 49€ per flight (EUROCONTROL, 2005).

At present, capacity planners and airport decision makers at AAS lack decision support models and tools able to provide a view of gate area and to analyze at a reasonable effort the various trade-offs among different airport performance measures. Before introducing a helpful tool for capacity planners at AAS it must be researched which solution method and approach for the tool is best for the cases they have to answer. This article will review the class of problem of the flight-to-gate assignment problem and solution methods discussed in literature. Furthermore, the difficulty of using forecasts in planning activities will be outlined. Finally, the most appropriate solution method and approach for the decision support tool for AAS is discussed and reasoned.

2 Forecast uncertainty and forecasters' biases

For longer horizons it is harder to gather detail on traffic demand and flight characteristics, especially in the aviation sector with its dynamics and multiple stakeholders. Also, the details on flight schedules²⁸ carry a lot of uncertainty. So, detailed planning of flight-to-gate is getting less important for the longer the planning horizon, inputs will change anyway. Almost every midterm or strategic decision taken stems ultimately from a forecast. At the same time, forecasting is the area in which mistakes are most frequently made and the one about which is least certainty. Yet forecasts have to be made since so many decisions flow from them (Doganis, 2010). Uncertainty in forecast will influence decision makers, however as Doganis (Doganis, 2010) describes forecasts are needed in order to notify capacity imbalances in an early stage and to start action to minimize those imbalances.

At AAS department Aviation, Statistics and Forecast (ASF) creates forecasted flight schedules which serves as input for capacity planning and analyses. Currently ASF is generating flight schedules for a high, medium and low scenario. When using forecasted flight schedules demand uncertainty must be considered. In their demand model market

²⁶ Tactical planning can be defined as planning 1 till 5 year(s) ahead.

²⁷ A meta-heuristic is a higher level algorithm, a heuristic method for solving a very general class of computational problems by combining user given black-box procedures. Meta-heuristics can be applied to many different types of problems.

 $^{^{28}}$ Details such as destination, arrival and departure day/time, number of passengers, type of aircraft, visit time, etcetera.

demand is based on six key drivers: gross domestic product (GDP), oil price, market share catchment area, percentage low cost at AAS, market share transfer and percentage transfer at AAS. Furthermore Emission Trading Scheme (ETS) regulation is taken into account. The dimensions of the forecast model is twofold, namely at marco-economic level; explaining the size of the market and at market position; explaining the market share.

Not only demand uncertainty brings forecast failure, forecasters' bias contributes to forecast failures in several ways as well. Forecasters often have a poor database that has internal biases caused by the data collection system and forecasters often integrate political wishes into their forecasts (Flyvbjerg, Bruzelius, & Rothengatter, 2003). The flight schedules for the midterm planning activities (5 yr) are developed by ASF in cooperation with process owners (e.g. owner of the baggage process, or aircraft stand process). However, forecasts by project promoters may be even more biased, since the promoter has an interest in presenting the project as in as favorable light as possible (Flyvbjerg, Bruzelius, & Rothengatter, 2003).

When the planning horizon is growing towards the day of operation the detail of information on operating flights, arrival and departure times, fleet characteristics, number of passengers, delays, peak moments etcetera grows. The forecasts will become more reliable and contain less assumptions. In figure 1 the reliability of information during the planning horizon and the tools at AAS are visualized. Currently AAS is performing static tactical capacity planning for aircraft stand area with an Excel spreadsheet. With flight schedule information the maximum number of gates needed per aircraft category per day is calculated. This static capacity is compared to the available gates and remote stands in the year of analysis. The constraints on the flight-to-gate assignment which typify the problem are not taken into account in this analysis.



Figure 1 Planning Horizon and reliability of information

To improve this static capacity analysis it is suggested to develop a flight-to-gate planning tool for tactical purposes which takes into account the dynamics of the constraints and will be flexible to run 'what-if' analyses.

3 The flight-to-gate assignment: a scheduling problem

The gate assignment problem can be seen as a scheduling problem. The problem is the type of job shop scheduling problem in which generally a job (a flight) is served once by an available machine (an idle gate), with various constraints and objectives in matching the jobs to machines. Scheduling is a decision making process and it concerns the allocation of the limited resources to tasks over time. The performance of the aircraft stand area is highly dependent on the efficient allocation of the limited resources, and it is strongly affected by the effective choice of scheduling rules.

The basic gate assignment problem is a quadratic assignment problem²⁹ and was shown to be NP-hard by (Obata, 1979). In computational complexity this problem is categorized under NP-class of problems. When assigning *m* flights to *n* gates/buffers then a Non-Polynomial (NP) number of combinations are possible $(m!)^n$.

As the gate assignment is a type of job-shop scheduling problem, its complexity increases exponentially if constraint size such as number of flights, available gates, aircrafts, flight block time etcetera. changes which is a very realistic assumption in airport operation. The NP-hard characteristic of the problem implies that there is no known algorithm for finding the optimal solution within a polynomial-bounded amount of time. In practice, AAS may handle more than 1000 daily flights at more than 100 gates which results in billions of variables (Wipro Technologies, 2009).

A well-constructed schedule must satisfy a set of strict rules and constraints (Dorndorf, Drexl, Nikulin, & Pesch, Flight gate scheduling: State-of-the-art and recent developments, 2007):

- (6) one gate can process one aircraft at the same time;
- (7) service requirements;
- (8) space restrictions with respect to adjacent gates must be fulfilled;
- (9) minimum ground time of the aircraft;
- (10) and minimum time between subsequent aircraft have to be assured.

The multiple criteria and multiple constraints of the problem make it very unlikely that an optimal solution can be found and verified (Dorndorf, Drexl, Nikulin, & Pesch, Flight gate scheduling: State-of-the-art and recent developments, 2007).

4 The flight-to-gate assignment problem: solution methods

During an elaborated literature review on the gate assignment problem it became clear that several methods, algorithms and heuristics (and combinations) are used to solve the gate assignment problem.

²⁹ The total passenger walking distance is based on the passenger transfer volume between every pair of aircrafts and the distance between every pair of gates. Therefore, the problem of assigning gates to arriving and departing flights at an airport is a Quadratic Assignment Problem (QAP).

An optimization problem is the problem of finding the best solution from all feasible solutions. Engineers, analysts, and managers are often faced with the challenge of making tradeoffs between different factors in order to achieve desirable outcomes. Optimization is the process of choosing these tradeoffs in the 'best' way (Onwubolu & Babu, 2004).

For some complicated problems, such as the flight-to-gate assignment problem, no straightforward solution technique is known. For these problems, heuristic solutions techniques may be the only alternative. Heuristic refers to experience-based techniques for problem solving. Heuristic methods are used to speed up the process of finding a satisfactory solution, where an exhaustive search is impractical.

Approximation algorithms are an approach to attacking difficult optimization problems. Approximation algorithms are often associated with *NP*-hard problems. Since it is unlikely that there can ever be efficient (Polynomial Time) exact algorithms solving *NP*- hard problems, one settles for non-optimal solutions, but requires them to be found in polynomial time. Unlike heuristics, which usually only find reasonably good solutions reasonably fast, one wants provable solution quality and provable run time bounds.

Optimization makes use of maximization or minimization of objective(s) under a set of constraints in the form of mathematical variables. For instance minimize walking distance of passengers or maximize total flight gate preferences. The single objective gate assignment problem with the objective minimize passenger walking distance is widely been studied. Methods such as branch-and-bound algorithms, integer programming, linear programming, expert systems, heuristic methods, tabu search algorithms and various hybrid methods were reported to minimize the distance (Hu & Di Paolo, 2007).

Dorndorf et al. (Ding, Lim, Rodriques, & Zhu, 2005), (Dorndorf, Drexl, Nikulin, & Pesch, Flight gate scheduling: State-of-the-art and recent developments, 2007), (Yan & Tang, 2007) and (Yan, Tang, & Hou, 2010) discuss developments in solution methods for the gate assignment problem. A number of gate assignment models have been developed and tested. For example, (Babic, Teodorovic, & Tosic, 1984) formulated the gate assignment as an integer programming, and uses branch and bound technique, with some enhancements to accelerate computation, in order to determine a solution of the gate assignment problem. The objective is to reduce the number of passengers who have to walk maximum distances. (Mangoubi & Mathaisel, 1985) take into account transfer passengers as well by using greedy heuristics and lineair programming relaxation to solve the gate assignment problem. (Bihr, 1990) uses 0–1 integer programming to solve the minimum walking distance gate assignment problem for fixed arrivals in a hub using a simplified formulation as an assignment problem.

(Diepen, van de Akker, Hoogeveen, & Smeltink, 2007) is optimizing the idle time between all consecutive flights in order to find a robust schedule for the daily planning. The problem is formulated as an integer lineair program (ILP) and the authors use an alhorithm based on column generation to find a good approximation for the optimum of the model. Experiments show good results, however those experiments did not incorporate complex rule settings which are used by gate planners to plan the aircrafts to a gate. However, the gate assignment problem has a multi-objective³⁰ nature. Objective functions often used are the minimization of the total passenger waiting time, the total passenger walking distance, the number of off-gate events, the range of unutilized time periods for gates, the variance of idle times at the gates, or a combination of the above. All these objectives can be divided into two big classes: passenger-oriented and airport-oriented objectives. It is difficult to cope with multiple objectives in the complex gate assignment problem.

(Dorndorf, Drexl, Nikulin, & Pesch, Flight gate scheduling: State-of-the-art and recent developments, 2007) propose two new optimization models for gate scheduling, the models they propose are multi objective and therefore take into account the real multiple criteria nature of the problem. Computational experiments showed the effectiveness of the proposed technique especially in comparison with the results of a modern rule based decision support system. However there are still open research directions. One problem consists in developing solution techniques for gate scheduling with multiple criteria and including all technical and temporal requirements. (Dorndorf, Drexl, Nikulin, & Pesch, Flight gate scheduling: State-of-the-art and recent developments, 2007) describe a technique most frequently used in practice for dealing with multiple objectives. This technique is criteria aggregation by adding new parameters - weights or goals - to the problem. These parameters can be interpreted as values of decision makers' preferences, and the partial criteria can be ordered by importance due to preference values. The authors are optimistic that multiple criteria meta-heuristics like Pareto Simulated Annealing and Genetic Local Search, can be efficiently applied to the criteria aggregation technique. (Yan & Huo, 2001) proposes a multiple objective model and is formulated as a multiple objective 0-1 integer program. To efficiently solve large-scale problems in practice, they used the weighting method, the column generation approach, the simplex method and the branch-and-bound technique to develop a solution algorithm. The first objective tries to minimize passenger walking time while the second objective aims at minimizing passenger waiting times. The authors argue that, e.g. during peak hours, an aircraft might have to wait for an available gate, and hence passengers have to wait on the aircraft until a gate is available.

The problem is an integer program with multiple objectives and quadratic constraints. Such a problem is inherently difficult to solve. Scheduling theory and multicriteria optimization are a topic of growing interest both in theory and practice. However, those topics were not researched a lot in combination. (Drexl & Nikulin, 2008) tackle the problem by Pareto simulated annealing. Due to the fact that computational experiments show good results, the tests with the designed algorithm contained relatively small data and were not applicable to real-life situations at an airport.

The analytical models described in literature define the problem in several ways and use exact solution methods and/or heuristics to solve the model. While traditional operations research techniques have difficulty with uncertain information and multiple performance criteria and do not adapt well to the needs of operation support, many researchers focus on the design of the so-called rule-based expert systems (Dorndorf, Drexl, Nikulin, & Pesch, Flight gate scheduling: State-of-the-art and recent developments, 2007). The rule based technique uses a set of rules and the production rule (if <condition> THEN

³⁰ The solving method provides a trade-off between several objectives which are usually in conflict. Finding a compromise between several goals may positively influence passenger satisfaction and save extra money for airport operator and airlines companies.

<conclusion>) to produce assignments of flights to gates/buffers. To find a near-optimal solution heuristics scheduling methods can be chosen to satisfy constraints. The number of factors to be taken into account is large in the expert system. The most crucial task is to identify all the rules, order them by importance and list these rules appropriately (Dorndorf, Drexl, Nikulin, & Pesch, Flight gate scheduling: State-of-the-art and recent developments, 2007). In their book about rule based expert systems Sasikumar and Ramani (Sasikumar & Ramani, 2007) discuss the advantages and drawbacks of rule based systems. Meaning and interpretation of each rule can be easily analyzed due to the uniform syntax, the syntax is simple and it is easy to understand the meaning of the rules, modifying and adding new rules is easy to perform and data and control are separated which creates possibilities that the same control can be used with different rule bases and the other way around. However, there is no systematic procedure for creating rule based systems, most systems are built based on intuition, prior experience, and trial and error. Another drawback is that rule based systems provide no mechanism to group together related pieces of knowledge and that all rules at the same level in hierarchy. A limitation of rule based systems is that human experts do not always give explanations by describing rules they have applied.

5 Commercial tools and practical usability

In the previous section literature on development for solution methods on the flight-togate assignment were described. For the decision support tool at AAS flexibility is needed in such a way to measure the aircraft stand performance indicators such as the number of aircrafts for which no connected stand is available at the scheduled time, the number of towing movements, the number of arrivals/departure which needed a bus gate (arrival on a remote stand), the gate occupation percentages, etcetera. Those performance indicators can be compared after running a different scenario with changed variables. In such a way the impact of infrastructural or procedural changes can be measures and evaluated. Those requirement on practical usability were the input for commercial software companies to built flexible tools.

- The current used Gate Management System for operational planning activities of the flight-to-gate planning is done based on a rule setting, *if...then* rules and a score list for each gate.
- AirTop is a rule-based gate-to-gate fast time simulator, has a scenario editing module, simulation run and playback module.
 - AirTop is used by Frankfurt Airport.
- The *CAST Aircraft* traffic generation is based on a central flight schedule handling system. Following the chronological course of the schedule, flights are performed. Delays and schedule deviations can be considered based on probabilities. Several functions enable the user to consider specific conditions and quickly generate scenarios. Several restrictions and priorities may be defined in order to get the real life stand utilization.
- Quintiq (Den Bosch, the Netherlands) provides advanced planning and scheduling software that supports airports to optimize resource utilization. Quintiq offers aviation solutions for planning issues; including gate and stand planning. The software takes into account all applicable rules and constraints, such as airport specific rules, arrival patterns, and airline and handler rules and preferences. For assigning arrivals and departures to stands, the planner gets decision support via scores and colors indicating suitability.

- Brussels Airport is using this software for the tactical and operational gate planning. By implementing the software solution Brussels Airport wants to support expected growth and improve the service to its airline customers.
- Inform Groundstar Stand Planning plans a flight schedule rule based. The business rules are defined in the base data of the system. A user interface called Base Data Editor makes it possible to maintain in a comfortable way the set of rules for the allocation.
 - Inform stand planning is used by Dubai International Airport and AAS has purchased this tool to replace the current Gate Management System.

6 Conclusions

The 'sense of urgency' for notifying and managing the imbalances at the aircraft stand area of AAS in an early stage grows due to the higher occupation rate of the stands and the time needed to act on those imbalances. For this matter AAS needs a tool in which what-if analyses can be done which give insight into the dynamics and interdependencies of the system. The system of assigning aircraft to gates has multiple constraints, multiple criteria, multiple objectives and conflicting objectives. Moreover, the complexity increases due to the stakeholders involved in the flight-to-gate assignment and the amount of assignments which have to be planned each day.

At AAS there are many allocation rules that need to be taken into account when planning the aircrafts to a gate, next to the allocation rules known by the gate planner and which are not documented the most important documented allocation rules are recorded in the Regulation Aircraft Stand Allocation Schiphol (RASAS). The level of detail in the allocation rules depends on the scenario which the researcher wants to run with the decision support tool. Therefore, the tool must be flexible in terms of adding, changing or deleting constraints/rules.

Since the gate assignment problem has the characteristic of a NP-hard class of problem there is no known algorithm for finding the optimal solution within a polynomial-bounded amount of time. The multiple criteria and multiple constraints of the problem make it very unlikely that an optimal solution can be found and verified. Several attempts are made to develop and test solution methods for the problem, however often those tests are done with a small set of data. Computational experiments showed the effectiveness of the proposed technique in (Dorndorf, Drexl, Nikulin, & Pesch, Flight gate scheduling: Stateof-the-art and recent developments, 2007), especially in comparison with the results of a modern rule based decision support system. However, currently AAS, Frankfurt Airport, Brussels Airport and Dubai International Airport uses tactical planning tools based on rulebased techniques, and most commercial software tools use the rule-based technique with heuristics scheduling methods to satisfy constraints.

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