Flight to Gate Assignment: Solution Methods and Complexities at Planning Horizons

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 NP-hard 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.

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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 basis [1]. 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-heuristics [2], simulation), and purpose (i.e. planning or real-time dispatching) (Murty, Wan, Yu, Dann, & Lee, 2008). First the multiple objectives of the airport,

Gates at Amsterdam Airport Schiphol. Photo by Hubert Croes 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.

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 schedules [3] 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 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.

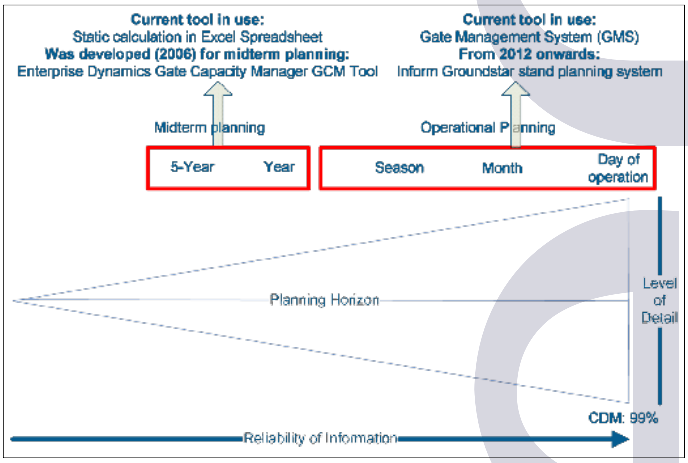

Figure 1: *Planning Horizon and Reliability of Information. To improve this static capacity analysis it is suggested to develop a flight-to-gate planning tool for tactical purposes which takes into account the dynamics of the constraints and will be flexible to run 'what-if' analyses.*

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 problem [4] 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).

Intercontinental Flights at Amsterdam Airport Schiphol. Photo by Hubert Croes.

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):

	one gate can process one aircraft at the same time;
	service requirements;
	space restrictions with respect to adjacent gates must be fulfilled;
	minimum ground time of the aircraft;
	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).

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.

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-objective [5] 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.*

Leisure Flights at Amsterdam Airport Schiphol. Photo by Hubert Croes

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 <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.

Commercial Tools and Practical Usability

In the previous section literature on development for solution methods on the flight-to-gate 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 sys-

tem. 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.

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: State-of-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 rule-based techniques, and most commercial software tools use the rule-based technique with heuristics scheduling methods to satisfy constraints.

About the Author

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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

References

Babic, O., Teodorovic, D., & Tosic, V. (1984). Aircraft stand assignment to minimize walking. . Journal of Transportation Engineering , 55–66.

Bihr, R. (1990). A conceptual solution to the aircraft gate assignment problem using 0,1 linear programming. . Computers and Industrial Engineering , 280–284.

Cheng, Y. (1997). A knowledge based airport gate assignment system integrated with mathematical programming. Computers and Engineering , 837-852.

Diepen, G., van de Akker, J., Hoogeveen, J., & Smeltink, J. (2007). Using column generation for gate planning at AAS. Utrecht: Technical Report Utrecht University.

Ding, H., Lim, A., Rodriques, B., & Zhu, Y. (2005). The over-constrained airport gate assignment problem. Computers & Operations Research , 1867-1880.

Doganis, R. (2010). Flying off Course 4th edition. Oxon: Routledge.

Dorndorf, U., Drexl, A., Nikulin, Y., & Pesch, E. (2007). Flight gate scheduling: State-of-the-art and recent developments. The international journal of management science , 326-334.

Drexl, A., & Nikulin, Y. (2008). Multicriteria airport gate assignment and Pareto simulated annealing. IEE Transactions -Operations Engeneering , 385-397.

EUROCONTROL, P. R. (2005). Punctuality drivers at major European Airports. Brussels: EUROCONTROL.

Flyvbjerg, B., Bruzelius, N., & Rothengatter, W. (2003). Megaproject and Risk: an Anatomy of Ambition. Cambridge: Cambridge University Press.

Hassounah, M., & Steuart, G. (1993). Demand for aircraft gates. . Transportation Research Record , 26–33.

Hu, X., & Di Paolo, E. (2007). An efficient genetic algorithm with uniform crossover for the multi-objective airport gate assignment problem. IEEE Congress of Evolutionary Computation. Singapore.

Mangoubi, R., & Mathaisel, D. (1985). Optimizing gate assignment at airport terminals. . Transportation Science , 173–188.

Murty, K., Wan, Y., Yu, V., Dann, J., & Lee, R. (2008). Developing a DSS for allocating gates to flights at an international airport. University of Michigan.

Obata, T. (1979). The quadratic assignment problem: evaluation of exact and heuristic algorithms. New York: Rensselaer Polytechnic Institute.

Onwubolu, G., & Babu, B. (2004). New optimization techniques in Engineering. Berlin: Springer-Verlag Berlin Heidelberg.

Sage, A., & Armstrong Jr., J. (2000). Introduction to Systems Engineering. John Wiley & Sons, Inc. .

Sasikumar, M., & Ramani, S. (2007). A practical introduction to rule based expert systems. New Delhi: Narosa Publishing House.

Wipro Technologies. (2009). Gate Assignment Solution (GAM) Using Hybrid Heuristics Algorithm. DRAFT TECHNICAL WHITE PAPER ON GATE ASSIGNMENT SOLUTION . Team Airline Innovation Centre of Excellence, Wipro Technologies.

Yan, S., & Chang, C. (1998). A network model for gate assignment. Journal of Advanced Transportation , 176–189.

Yan, S., & Huo, C. (2001). Optimization of multiple objective gate assignments. Transportation Research A 35 , 413–433.

Yan, S., & Tang, S. (2007). A heuristic approach for airport gate assignments for stochastic flight delays. European Journal of Operational Research , 547-567.

Yan, S., Tang, C., & Hou, Y. (2010). Airport gate reassignments considering determinstic and stochastic flight departure/arrival times. Journal of advanced transportation , published online in Wiley InterScience DOI: 10.1002/atr. 141.

Zografos, K., & Madas, M. (2006). Development and demonstration of an integrated decision support system for airport performance analysis. Transportation Research Part C (14), 1-17.

Endnotes

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

[2] 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.

[3] Details such as destination, arrival and departure day/time, number of passengers, type of aircraft, visit time, etcetera.

[4] 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).

[5] 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.