RUNWAY CAPACITY PLANNING SUPPORTED BY DYNAMIC PROGRAMMING

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Keywords: *Strategic Airport Planning, Dynamic Programming*

Abstract

Airport planning nowadays is becoming more and more difficult because of the increasing complexity of the airport system and the different and often conflicting objectives of the stakeholders involved in the planning process. TU Delft Airport Development Center (TUD-ADC) is therefore working on decision-support systems that enable decision advisers to conduct an analysis of the entire airport system.

One of those systems is the Airport Business Suite that provides a user with a user interface for analyzing the airport operation and business in order to match future demand and capacity.

Another system that is currently being developed is the Holistic Airport Resource Management and Optimization System (HARMOS), which has more or less the same goal as ABS but is based on another philosophy. HARMOS employs mathematical optimization techniques in order to support the airport planning process more efficiently.

One of the problems that a decision support system for airport planning should be able to address is the runway expansion problem, i.e. where and when to expand the runway system. This paper shows how both ABS and HARMOS could be used for analyzing this problem. Due to the status of HARMOS software development part of the analysis will only be described conceptually [1]*.*

The ABS analysis process of the runway expansion problem makes clear that ABS' flexibility is kind of a disadvantage in this case. A lot of user input is required for setting up the so-called peak day and yearly cases in ABS. Besides that, the user has to interact heavily with the ABS in order to run these cases, evaluate and post-process the results. Only after having done all of that, a user could start making comparisons between different runway expansion plans.

The philosophy of HARMOS enables a user to focus more on the problem at hand and the user's objective, i.e. what would be the best (in terms of costs) investment plan for runway expansion. By turning the runway expansion problem into a dynamic programming problem, the analysis and comparison process can be highly automated which makes identification of the best plan very efficient.

1 Introduction

Airports these days are more and more becoming a business. In order to survive an airport must operate efficiently under a set of boundary conditions imposed by (inter)national authorities. Therefore, an airport must develop strategies in order to stay in business in the near and far future. However, due to the increased complexity of the airport system and its environment, developing strategies is not that easy. Apart from the

[1] At the moment of writing the final results could not yet be produced; therefore these will be presented at the conference itself.

fact that future conditions for the airport are unknown, a multitude of aspects has to be considered. An airport decision maker also has to acquire insight into the business process and objectives of the other airport stakeholders, such as the airlines and air traffic service provider, in order to asses the impact and acceptability of his/her strategic plans.

Current practice when developing strategic plans is to (1) model the current airport operation (needed as a baseline for making comparisons) (2) conduct a study that forecasts future conditions, (3) make an estimation of an airport's future performance (qualitatively and/or quantitatively), (4) identify the bottlenecks in the airport system, (5) define a strategic plan, i.e. which policies are used and what investments need to be planned, that deals with the bottlenecks, and finally (6) evaluate the effectiveness of the strategic plan. After that, the plan has to be discussed with the other airport stakeholders in order to reach consensus about the proposed changes to the airport system, which might result in repeating (part of) the process described above. This process involves a huge amount of work since every part of the job is done by different parties and spans a considerable time. This motivates the need for decision-support systems for airport planning.

TUD-ADC is therefore working on decision-support systems for airport strategic planning. At the moment, TUD-ADC is developing two different types of decision support systems, namely the Airport Business Suite (ABS) which is based on the concept of non-linear navigation and HARMOS which uses mathematical optimization techniques.

The objective of this paper is to describe how both decision support systems are used for analyzing plans for runway investments.

Runway expansion of Amsterdam Airport Schiphol (AAS) will be used as an example, since just recently a limited cost-benefit analysis [1] has been conducted that investigated the social benefits for expanding the airport with a sixth and/or seventh runway. It appeared that, although Amsterdam Airport Schiphol has opened a new runway early 2003, total runway capacity will not be sufficient to match future traffic demand.

The contents of this paper is as following. Section 2 first gives some more information about the cost-benefit analysis just mentioned; after that the problem definition that is used in this study is presented. Section 3 presents the Airport Business Suite and shows how it can be used for analyzing runway expansion plans. In section 4 the philosophy and design of HARMOS is introduced. The other part of this section is used to describe the analysis of the runway expansion problem with HARMOS. The problem analysis itself is presented in section 5. Conclusion and recommendations are presented in section 6.

2 Problem Description

This section gives a detailed description of the problem. First some background information is given, followed by a detailed problem statement and a description of the scenarios that have been used in the analysis.

2.1 Background Information

Because preliminary studies for AAS showed that the new runway system (called 5P) is not capable of handling future traffic demand, the possibilities for expanding the runway system with a sixth or seventh runway are to be investigated. Three variants for runway expansion, depicted in Figure 1, have been investigated in [1] and will also be used here. The first variant, called 6PK, is a runway system with a total of 6 runways with an additional runway parallel to the existing 06-24 runway (Kaagbaan); the second, called 6P, has also 6 runways with an additional runway located in between the 01L-19R (Zwanenburgbaan) and recently added 18-36 runway (Polderbaan); and the third, called 7PK, has a total of 7 runways where both runways from the other two runway systems are present.

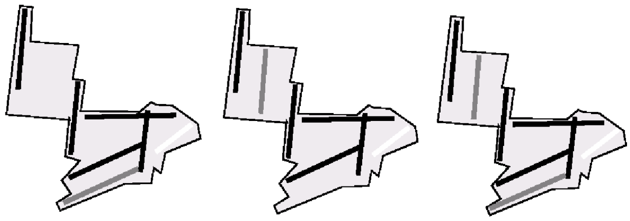

Figure 1: Variants for runway expansion

2.2 Problem Statement

When traffic demand increases, an airport needs to take action to make sure that service levels don't decrease. One such actions is expanding the airside capacity in terms of runways. In order to do this efficiently and economically, two issues have to be dealt with, namely, (1) where to put the new runway and, (2) when should the runway(s) become operational. The first question is related to noise, costs and operational considerations; the second is related to expected economic growth and the associated growth in traffic demand. The airport management needs to deal with both issues such that investments in runway capacity are timely conducted so that future traffic demand is matched with capacity at minimum costs and acceptable noise impact.

So, for the runway capacity planning, a decision-maker has to figure out which runway should be build at what time for a given planning period. Lets's assume that there are three distinct periods in time where such decisions should be made. For the first period (2003-2010), there are three possibilities, namely:

1. Keep the current runway system (5P);
2. Add a runway parallel to the Kaagbaan (6PK);
3. Add a runway in north-south direction (6P).

For the second period (2010-2020), there are a different number of possibilities, depending of course on the decision that was made in the previous period. If the previous decision was (1) then there are four possibilities, namely:

1. Keep the current runway system (5P);
2. Add a runway parallel to the Kaagbaan (6PK);
3. Add a runway in north-south direction (6P);
4. Add both runways simultaneously (7PK).

If decision (2) had been taken in the first period, there are two possibilities, namely:

1. Keep the runway system (6PK);
2. Add a runway in north-south direction (7PK).

If decision (3) had been taken in the first period, the possibilities are:

1. Keep the runway system (6P);
2. Add a runway parallel to the Kaagbaan (7PK).

For the third and final period (2020-2030), the process is similar. A overview of the decision tree just described is given in Figure 2.

As can be seen from Figure 2, there are a lot of possibilities for runway expansion. All these possibilities or investment plans need to be evaluated. After this evaluation, the best plan can be selected for implementation. The next two sections, 3 and 4 will therefore describe how decision support systems could be used for this evaluation process. Before that, first the scenario that will be used as input for the evaluation process will be discussed.

2.3 Scenarios

Uncertain future conditions have been taken into account by using three different scenarios that describe economic growth and technological development at a different pace.

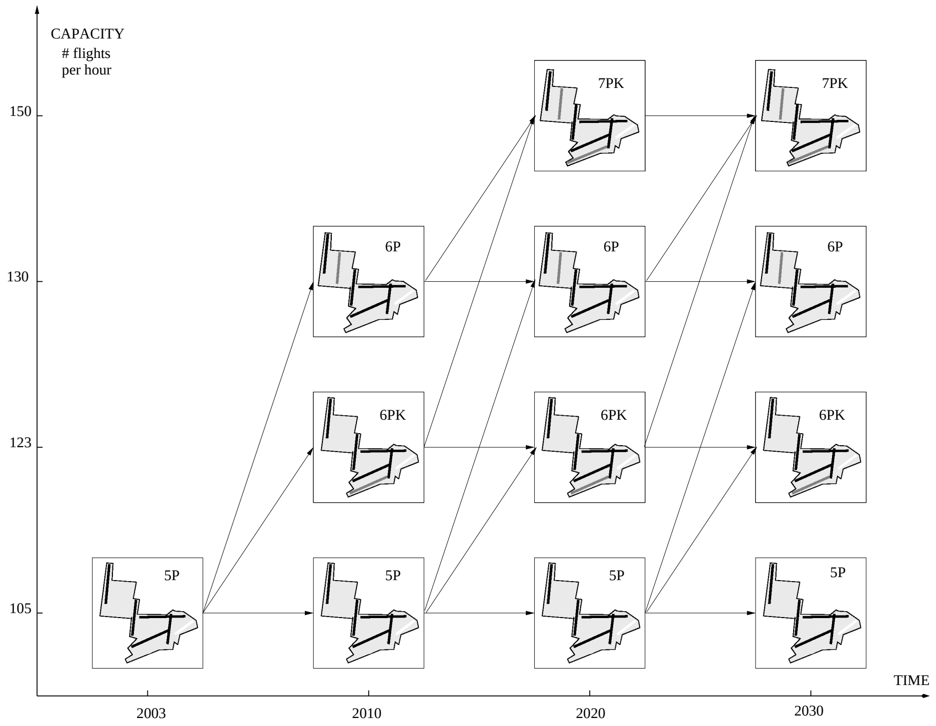

Figure 2: Alternative investment plans for runway capacity expansion

The planning period that is considered spans about thirty years, from 2003 until 2030. During this period three distinct times, i.e. 2003, 2010, and 2020, for making decisions about investments in runway capacity have been set. So, airport performance needs to be evaluated in 2003, 2010, 2020 and 2030. For this performance evaluation, forecasts of economic and technological developments (collectively called a scenario) is needed.

2.3.1 Economic Growth

Future traffic demand depends on developments in economic growth, which are rather unpredictable. Therefore three different economic growth scenarios will be used as input for the planning problem, ranging from limited (2 %) to above average (7 %) growth of traffic demand.

The economic growth percentage is used to extrapolate a flight schedule for the 20th peak day at Schiphol. This flight schedule has been extracted from the time table for the summer of 2003, which was published by Schiphol at their website. The baseline demand distribution for arriving and departing flights is presented graphically in 3.

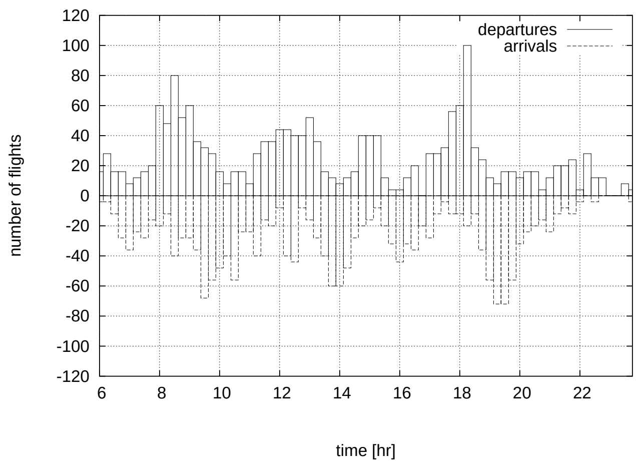

Figure 3: Graphical representation of converted flight schedule

Figure 3 clearly shows the peaks in the demand distribution for the arriving and departing flights. These are the result of the system of flight banks that is used by the hub carrier, Royal Dutch Airlines (KLM). The total number of flights amounts to 1050 for this particular day.

2.3.2 Technological Developments

The next decades, new technology for ATC/ATM ground systems as well as airborne equipment will become available. As a result, airspace and airport capacity will increase. New ground tools will enable an air traffic controller to handle more aircraft in a sector than is possible today. Improved radar technology and navigation equipment will increase tracking accuracy and decrease navigational errors. As a consequence, separation standards can be adjusted. Introduction of new technologies makes it possible to loosen the separation standards while maintaining the same safety level.

For this study it is not exactly required to know what technology will be introduced in the future. It is just assumed that new technology will be introduced that will loosen current separation standards. For each time period in the scenario, a different separation standard matrix will therefore be specified.

3 Airport Business Suite

This section first describes the Airport Business Suite and its philosophy; after that a brief description on using the ABS is given.

3.1 Overview

The Airport Business Suite [5] has been designed as a set of integrated tools that allow the information needed for strategic decision-making to be synthesized in an efficient, effective, and consistent manner.

The only part of the ABS that will be discussed here in some more detail is the model system of ABS. A graphical representation is shown in Figure 4. The set of models to be included in the ABS resulted from a division of the airport business process, which resulted in five sets of models.

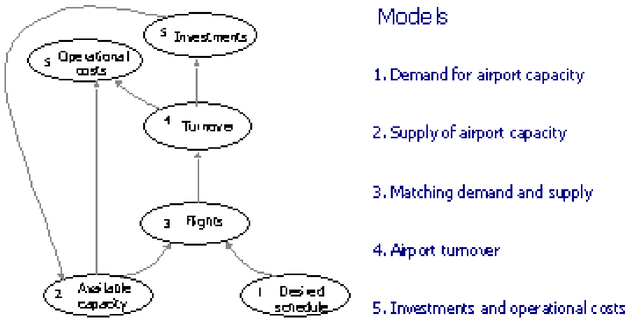

Figure 4: The ABS Model System

3.1.1 Model 1: Demand for airport capacity

The first model generates a flight schedule based on present-day flight schedule data or manual input. A future flight schedule is created by selecting a forecast year and an economic growth percentage.

3.1.2 Model 2: Supply of airport capacity

Capacity and delay are two of the principal measures of performance of an airport system. To assess these important performance characteristics, a comprehensive set of tools, covering all relevant airside and landside elements of the airport system, has been implemented as modules within Model 2 of the ABS.

For capacity calculations the Federal Aviation Administration (FAA) airfield capacity model has been included. A network of queuing modules is implemented for predicting delays due to congestion in the various airport elements.

The ABS Model 2 also incorporates a terminal capacity module but since the focus of this study is on runway capacity, the terminal model won't be discussed any further.

ABS also enables a user to fairly automatically generate input for the Integrated Noise Model (INM), a noise contour calculation program.

3.1.3 Model 3: Matching demand and supply

The output provided by Model 2 is of critical importance for the ABS user. Often the initial output of Model 2 will not show satisfactory performance. For example, capacity or quality limitations may be exceeded, preventing the airport from accommodating the desired demand. However, Model 3 lets the user tune the airport's performance by altering the desired flight schedule, the airport's design, and/or the airport's operations. The function of Model 3 is to provide the tools to enable the user to conduct this tuning process. Through the ABS' flexible Graphical User Interface (GUI), the airport strategic planner can test a wide range of alternative approaches to matching supply with demand.

3.1.4 Model 4: Airport turnover

This sub model (nr. 4) estimates airport revenues and costs, and - being the difference between the two - the profits (or losses). At this moment, this model is reimplemented to make it more generic.

3.1.5 Model 5: Investments and operational costs

In a capital-intensive business like an airport, investments play a central role. Investments are therefore covered by this sub model. Just like the previous model, this model is being reimplemented.

3.2 Using the ABS

An overview of the analysis process with the ABS is presented in this section. The ABS is based on working with two type of cases, a so-called peak day case and a yearly case.

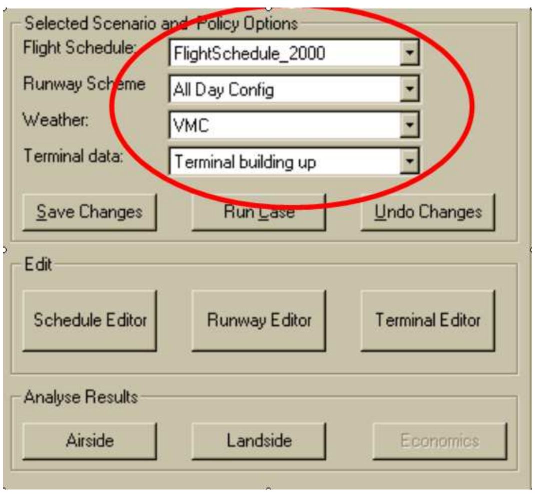

Figure 5: Selecting datasets via the ABS GUI

Peakday case This is a collection of data related to one single day. For this particular day a flight schedule, runway use scheme (i.e. a specification of how the runway configurations are used), and weather type needs to be specified. A user has to prepare this data beforehand by using the one of the editors that the ABS GUI has available. After doing this, the appropriate data can be selected from drop down lists as shown in Figure 5. When everything is set up, a peak day case can be run. By running a peak day case, capacity and delay computations are performed for the entire day. Finally, one can evaluate the output by viewing several graphs.

Yearly case This is a collection of peak day cases and it is used to evaluate the annual airport performance (such as noise impact, capacity coverage). A yearly case therefore describes how each of the runway configurations defined in the peak day case are used throughout the year. For each of the peak day cases (i.e. runway configurations) the usage percentage needs to be specified. The runway configurations and the associated usage percentages are used to generate an input file for the INM so that the noise impact can be evaluated.

4 HARMOS

Here, the HARMOS decision support system will be presented. After that the analysis of the runway expansion problem with HARMOS will be described.

4.1 Overview

The key element of HARMOS is the employment of mathematical optimization techniques for the determination of the most efficient policies for (1) management of the airport operation and (2) allocation of resources (both financial and infrastructural). A primary aim is to make the system truly 'easy-to-use' and 'robust' for the decision-makers actually relying on it in strategic airport planning studies. The easy-to-use requirement also entails that for using the decision-support system no specific knowledge or training with respect to the employed optimization techniques is necessary.

4.1.1 Functional description

The HARMOS system can best be explained by discussing the Use Case Diagram in Figure 6, which displays the functionality of the system at the highest level.

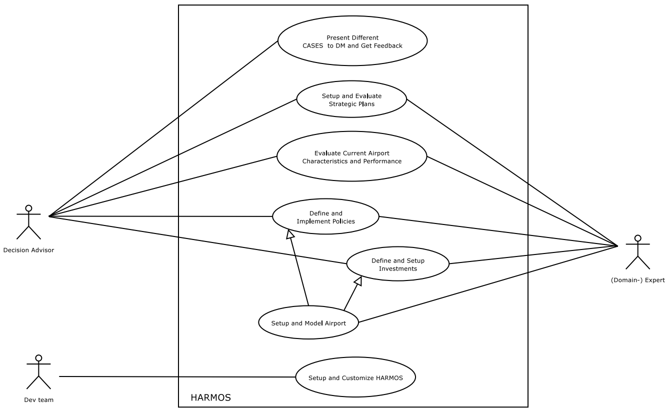

Figure 6: HARMOS: High-level Use Case Diagram

Figure 6 shows the HARMOS system, its users, and the actions that it should be able to perform. Three type of users have been identified, namely:

1. **Development team**: these are the people that are developing the HARMOS software (that's us). HARMOS will consist of a generic part and a customized part. An airport or other stakeholder that decides to use HARMOS for strategic planning will most likely need user-specific functionality. Therefore the system should be build such that functionality for customizing the software is included;

2. **Expert**: this is a person that has specific knowledge of (a part of) the airport system. This user will interact the most heavily with the system since experts are needed for populating the system with data, tuning of models, and validating the various computations done by the system;

3. **Decision adviser**: this is the person that advises the people that make the actual decisions. As advisers they need to be able to test different strategies (defined by their decision makers or themselves) for developing the airport for different futures. They also need to be able to clearly present different strategic plans to the decision makers so that the Decision Maker (DM) can make comparisons.

Seven different actions are to be performed by the HARMOS system, i.e.:

1. **Setup and customize system**: the development team needs to be able to customize HARMOS for a specific user (stakeholder) based on their requirements;

2. **Setup and model airport**: an (domain) expert or a team of experts needs to be able to setup and model the airport. i.e. data collected about the physical layout of the airport and the operations at the airport should be stored in and managed by HARMOS;

3. **Evaluate current airport characteristics and performance**: HARMOS should provide the users with an overview of the airport characteristics and its performance. This action is a quick way of getting an overview of the airport layout, operations and performance. It is used by both the experts and the decision advisers but in different ways. Domain experts will probably only focus on that part of the airport system (detailed look) that is related to their expertise. Decision advisers will need to get a general overview of the system and its performance (bird's view);

4. **Define and implement policies**: strategic planning involves the exploration of different policies and their associated effects on the system. It is therefore essential that HARMOS provides functionality to define various different policies;

5. **Define and Setup Investments**: another aspect of of strategic planning is making the proper investments at the correct time. This use case provides this functionality;

6. **Setup and evaluate (part of) strategic plan**: a strategic plan consist of a set of policies to be implemented for the future together with investments in the airport's infrastructure. Given a certain scenario (economical developments, etc.), the strategic plan will result in a certain future performance. A user of HARMOS should therefore have the functionality to setup and evaluate different strategic plans;

7. **Present different cases to DM and get feedback**: depending on the combination of the scenario and the strategic plan, the future airport will look and perform different. Decision makers need to determine how to go forward with the airport development. Therefore the decision adviser needs to be able to present him or her with a clear overview of the combinations of strategic plans and future scenarios that have been setup and evaluated during action number 6). A decision maker will then be able to select the best way forward based on his/her feeling about a certain future scenario.

4.1.2 Software implementation

HARMOS itself is implemented in Python using wxPython for the GUI. Python is an object oriented language for which a lot of packages for interfacing with other code already exist. Examples are:

- The python COM package which makes it possible to control and run Microsoft COM objects (also known as Active X components);

- Packages for connecting to a Database Management System (DBMS). The package for dealing with the Postgresql DBMS is used by HARMOS, since the Postgresql system is used for storing airport data;

- Packages for running C or Fortran code. These are e.g. used for running *lp_solve* [2], which is linear programming code written in C . The F2Py package will be used for running our NOISSH tool ([6], [4], [3]), which is Fortran code for optimizing noise abatement procedures.

4.2 Using HARMOS

At the moment of writing this paper, development of HARMOS is an ongoing activity. Currently, HARMOS is able to run and control the input parameters of the ABS model 2. This has been accomplished by using the python COM package as interface to the ABS model 2 (ABS has a modular design so all sub models have been implemented as COM objects).

Like already mentioned, the philosophy of HARMOS is to use mathematical optimization to enable a more efficient analysis. How this actually works for the runway capacity expansion problem will now be explained.

4.2.1 Dynamic Programming

The problem of determining the best plan for investments in the runway system can be turned into a dynamic programming problem [2]. Graphically, this is presented in Figure 2, where the various options for expansion are shown on a time line for four discrete times, namely 2003, 2010, 2020 and 2030. The vertical axis denotes the average capacity of the runway system in the number of flights per hour. For each moment in time (stage), a decision has to be made about expanding the runway system or not. If one decides to expand the runway system, the location of the new runway has also to be chosen. For Amsterdam Airport Schiphol, this gives a total of 13 investment plans based on the three options given in Figure 1.

[2] `http://groups.yahoo.com/group/lp_solve/`

An investment plan will be evaluated in terms of total costs, i.e. the sum of the delay costs and capacity costs. The best plan is the one that has the lowest total costs over the entire planning period (2003-2020). So, in order to be able to determine the optimal investment plan, the costs of each the 13 investment plans need to be determined in order to evaluate the first objective of the optimization problem.

4.2.2 Objective evaluation

The airport management would like to plan their investments in the period 2003-2020 such that total costs are minimized. These costs are considered to be the sum of delay costs and capacity costs. Delay costs are directly related to the (mis)match between capacity and demand. If demand exceeds capacity, delay will be incurred. The average annual delay depends on the way the runway system can and will be used throughout the year. Capacity costs are the cost of investment capital and the operational and maintenance cost. HARMOS will include modules for evaluating these costs.

5 Problem analysis

This section describes how ABS and HARMOS are actually used for analyzing the runway expansion problem.

5.1 Using the ABS

In ABS the following steps for providing quantitative data needed for evaluating the runway expansion problem, need to be taken:

1. Setting up projects and peak day cases;
2. Running peak day cases and evaluating its output;
3. Setting up yearly cases;

The following subsections will describe each of these steps in more detail.

5.1.1 Setting up projects and peak day case

Four ABS projects (called 5P, 6P, 6PK and 7PK) have been defined, one project for each runway system. For each of those projects a number of peak day cases respectively yearly cases need to be defined. In order to cover the runway configurations that are used throughout the year, eight peak day cases have been defined. These peak day cases describe how the runways of that particular runway system are used (i.e. the runway configuration).

5.1.2 Running a peak day case

After setting up the case by creating and selecting the appropriate datasets (see also section 3.1), a case can be run. Running a case will start the computation of the capacity and delay for the airside and landside. When it is finished, the results can be evaluated by looking at several graphs. Here, the capacity and demand graphs for the arrivals and departures are the most interesting since these provide information about the average delay. One of those (many!) graphs is presented in Figure 7.

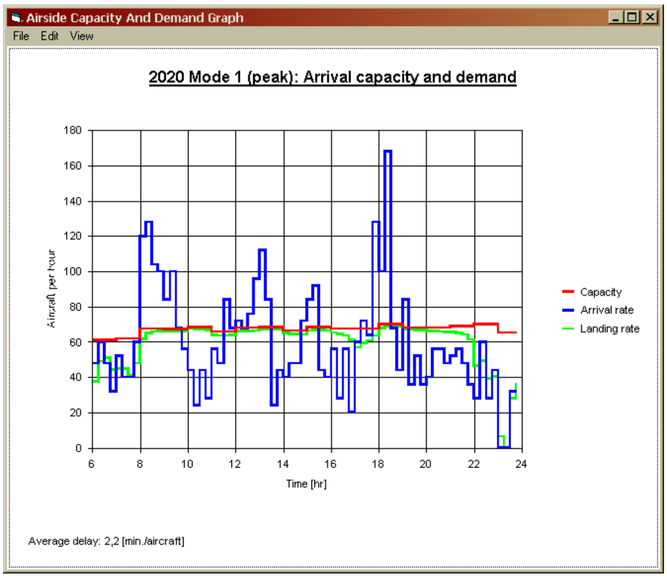

Figure 7: Example of peak day case output

The graph shows the demand for either arrivals or departures in the form of bars per 15 minutes. The runway capacity is plotted with a red line. The average delay is indicated as text in the lower left corner of the graph. Note, that for every case, the average delay for the departures and arrivals needs to be collected for post-processing.

5.1.3 Setting up yearly cases

The next step is using the previously setup and processed peak day cases, to build a number of yearly cases since here the interest is in annual performance characteristics, like the annual average delay and noise impact. The yearly cases specify how those runway configurations are used throughout the year. For the 5P project four yearly cases are needed, since the 5P system needs to be evaluated for the year 2003, 2010, 2020 and 2030. For the 6P and 6PK project three yearly cases are needed, since the 6P and 6PK system needs to be evaluated for the years 2010, 2020 and 2030. For the 7PK project, two yearly cases are needed since the 7PK system needs to be evaluated for the years 2020 and 2030.

For each of those yearly cases, the usage percentages for each of the runway configurations (defined in the peak day case) need to be assigned.

5.1.4 Conclusion

The previous sections described how an ABS project is setup, populated with peak day cases and yearly cases. Here, the baseline project (5P) has been used as an example. Figure 8 shows a screen shot of ABS with this project opened. The left side of this figure shows the project tree for this project, containing 24 peak day cases (8 peak day cases per yearly case) and four yearly cases (2003, 2010, 2020, 2030). Each of these cases needs to be run and after that the output needs to be evaluated and collected for post-processing and comparison.

In order to account for technological developments, the correct input data for the capacity model also needs to be specified before running a case. In the current version of the ABS, this needs to be done manually by editing a text file that specifies the separation standards to be used.

Since there are three variants for runway expansion, three additional ABS projects (6P, 6PK, 7PK) have been setup in order to be able to analyze these expansion options. Although tools for capacity, delay, and noise impact are integrated in the ABS, the activity of setting up the projects, analyzing and comparing all the results is an elaborate task. Note that comparing the different runway investment plans (delay costs versus capacity costs) did not even start yet.

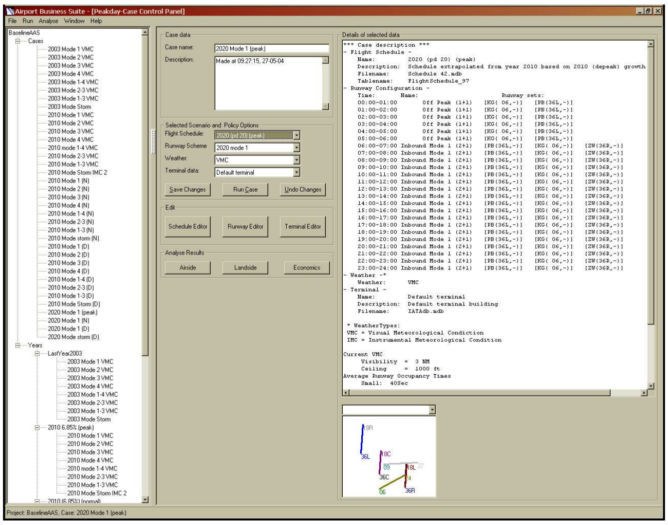

Figure 8: Screen shot of Airport Business Suite

The creation of yearly cases in each project requires a user to interact heavily with the GUI. Another thing that adds to user workload is the fact that for each yearly case, peak day cases with the appropriate data need to be created. Therefore, it might be beneficial to try to automate some of the above mentioned tasks. That is exactly what has been done in HARMOS, which will be discussed in the next section.

5.2 Analysis with HARMOS

The actual analysis with HARMOS could not be conducted yet, since the GUI is still being implemented. At the moment HARMOS is however able to import data from ABS projects. After doing that the peak day cases defined in the ABS project are available for processing within HARMOS, which will be explained in some more detail in the next sections.

5.2.1 Setting up yearly cases

A HARMOS user can define its own yearly case by selecting peak day cases (i.e. runway configurations) and assigning runway usage percentages. Because HARMOS uses the python COM package for controlling the ABS model 2, only one yearly case per runway system (5P, 6P, 6PK, 7PK) needs to be setup. When this is done, the yearly cases can be processed for all years of interest (2003, 2010, 2020, 2030) by passing the appropriate flight schedule as an argument to the ABS model 2 COM object. This is already a enormous time-saver because only four yearly cases have to be setup instead of 12 yearly cases when working with ABS.

Besides that, setting the correct input data for accounting for technological developments has also been automated in HARMOS by rewriting the text file with separation standards automatically.

5.2.2 Running the cases and processing its output

After setting up a yearly case, by selecting a number of peak day cases and assigning usage percentages, HARMOS will allow a user to run the ABS model 2 for all peak day cases subsequently. Because HARMOS is controlling ABS model 2 through its runtime arguments, there is no need to run peak day cases one at a time like in ABS. After each individual run, the output data for that peak day case is processed immediately so that when the calculation session ends all annual information (here: average delay) is available.

5.2.3 Optimal Planning

A dynamic programming algorithm is currently being implemented as a HARMOS module. Such a module enables a user to determine the best investment plan based on his/her objectives. The objective is to minimize the overall costs. The overall costs are the sum of delay costs and capacity costs. Delay costs are directly related to the (mis)match between capacity and demand. Capacity costs are the cost of investment capital and the operational and maintenance cost.

Each decision, i.e. stick with the current runway system or invest in a new runway, has costs associated with it. The first decision leads to increasing delay cost which may or may not be acceptable. The second decision results in additional capacity becoming available which will decrease delay cost but - next to the cost of the actual investment - increases operational and maintenance cost. By turning this decision problem into a dynamic programming problem it will be very easy to determine the best investment plan.

5.2.4 Conclusion

Like mentioned before, HARMOS incorporates mathematical optimization techniques for conducting airport performance analysis and planning. With respect to runway capacity planning it turns out such an approach makes this task much more efficient too because the analysis tasks to be performed (done manually with ABS) can be highly automated.

Performing the analysis with another scenario is therefore very easy and does not require a user selecting new datasets everywhere (as it is the case in ABS).

6 Conclusions and recommendations

This paper presented two kind of decision-support systems for strategic airport planning. The ABS, which is based on the philosophy of non-linear navigation and HARMOS which is based on the philosophy of mathematical optimization. For both decision-support systems the support for analyzing the runway expansion problem has been investigated. Based on this preliminary investigation, the following can be concluded:

- ABS' flexibility turns out to be a disadvantage in this case. Because of heavy data requirements, a lot of user input and interaction is needed with the system even before one can actually start making comparisons between different runway expansion plans. More automation in ABS is needed before a user can efficiently analyze this problem;

- A strong point with respect to ABS is its modular design. The modular design made it possible to use the capacity and delay model of the ABS in HARMOS;
- The optimization approach that is used in HARMOS (i.e. turning the runway expansion problem into a dynamic programming problem) is expected to make determination of the best investment plan much more efficient. Implementation efforts are still ongoing but it already became clear that this approach enables a highly automated analysis process. With HARMOS the focus can be more on the problem itself instead of on the analysis process that is needed for the problem.

An interesting addition to the problem definition is to include a second objective. Besides minimal cost, the chosen investment plan could also be required to have minimal noise impact during the planning period. Such a problem will be explored, in terms of requirements for the HARMOS system and the optimization techniques, during future research.

7 Literature

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