A PRACTICAL APPROACH TO MULTI-OBJECTIVE CAPACITY ANALYSIS OF AN ENVIRONMENT-AWARE AIRPORT

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Abstract

The expected increase in air traffic puts a high pressure on airports. Continuous changes in the air transport market, in environmental constraints, and in public tolerance require a delicate balance between airport capacity and environmental capacity, and thus, a new level of decision support for analysing trade-offs between multiple objectives. Consequently, there is a need to enhance decision-support capabilities performing trade-offs with optimisation methods for efficient airport solutions. This paper presents the results of a study of airport capacity versus environmental capacity. It is a starting point for new modules using optimisation to enhance airport decision-support systems with multi-objective analysis capabilities.

1 Introduction

In the last decades people have become more and more aware of impacts of air transport on the environment and of the subsequent need for sustainable air transport. Since air transport is still expected to increase (with an annual rate of approximately 3%; cf. [1]), measures are needed to reduce the nuisance of air transport on the environment. One approach to lower the environmental load is optimising airport operations with respect to noise, local air quality, emissions and third-party risk, while accommodating the increase in traffic, and providing decision support to airports and their stakeholders for making trade-offs in offered solutions. Typical airport decision-making questions that could be answered through this approach are:

- How much and what type of air traffic can be accommodated by the airport?
- What is the impact on the environment?
- How can this traffic be accommodated most efficiently and with minimum environmental impact?
- How can the airport be an efficient link in the (air) transport chain?

Obviously optimisation and answering the aforementioned questions can be complicated for airports with a large number of runways, varying meteorological conditions, and high traffic peaks. To deal with such cases innovative solutions are needed.

The present study focuses on a practical multi-objective optimisation problem regarding airport capacity and noise impact in the vicinity of the airport. The aim will be to maximise airport capacity in terms of the number of aircraft movements, while simultaneously minimising the noise impact in terms of the number of houses or inhabitants within a pre-defined noise-level contour.

The study is a first step to enhance airport decision-support systems with multi-objective analysis capabilities. In this step the capabilities of NLR's multi-objective optimisation tools are demonstrated for simultaneously optimising airport capacity and environmental capacity. To this end two case studies are performed using representative air traffic data of Amsterdam Airport Schiphol. These cases also show how noise load due to air traffic can be reduced by using different flight procedures and how air traffic growth can go together with a reduction in environmental impact.

The organisation of the paper is as follows. In Section 2 the scope of the multi-objective

optimisation problem is addressed. Benefits gained from such optimisation are discussed in Section 3. Section 4 provides a description of the optimisation problem, and Section 5 sketches the calculation methods and outlines the tools used to solve this problem. In Section 6 the case studies are presented and analysed. Section 7 gives some concluding remarks and suggestions for future work.

2 Scope

In airport operation design problems the aim is to optimise the capacity for air traffic and the efficiency of handling this traffic. Such problems constitute a complex field of airport interactions. In this paper the airport design problem is restricted to objectives directly related to the airside and environmental capacity. Trade-offs between traffic growth and environmental indicators such as noise load, emissions and third-party risk are then major points of interest for decision making in airport operation. Other key performance indicators such as economics, delays, landside capacity are considered as effects of a resulting solution, not part of the problem definition itself. Decision variables are the ways aircraft movements are handled in terms of runway usage, routing and flight procedures.

Still this scope comprises a wide variety of study subjects. To organise the type of problems the following operation levels can be distinguished:

- Single flight level: designing flight arrivals and departures at the airport. An example is trajectory optimisation for minimum fuel use and minimum noise and emissions (cf. [2]). This research aims to find new route designs to be applied to operational flight procedures.
- Airport scenario level: designing scenarios of handling traffic. An example is airside flight planning and sequencing (cf. [3]). This work identifies runway usage schemes from minimising delay, third-party risk, and noise.
- Measure level: designing management of scenarios. An example is the

optimisation of operation modes on runway preferential order, minimising mode transitions and risk of exceeding noise limits (cf. [4]). This optimisation supports the airport operations management in high capacity utilisation within noise limits.

The case studies in this paper focus on the optimisation of the flight procedure mix at scenario level. A realistic airport scenario is selected as starting point describing aircraft movements at the airport within a certain time frame. The flight procedure of the arriving or departing aircraft is considered to be a decision variable. Variation of the departure procedure, e.g., an ICAO-A or ICAO-B procedure, will either keep noise load closer to the airport or move it further away from the airport. A suitable mix of flight procedures may avoid high noise levels in densely populated areas. The aim is to find the best flight procedure distributions by minimising noise load and, additionally, maximising airport capacity.

3 Application benefits

As mentioned before this paper focuses on demonstrating the capabilities of NLR's multi-objective optimisation tools for simultaneously optimising airport capacity and environmental capacity. In view of the increasing complexity of air transport and the need for integrated analysis, such tools can play an important role to improve the know-how in airport analysis:

- More efficient analysis by replacing iterative what-if analysis with automated best solution search;
- Extended level of system support for multi-objective efficiency analysis.

The added value in analysis efficiency and enhanced system support will be explained for a typical application area where optimisation methods can be a substantial improvement to integrated analysis.

Nowadays the need for integrated analysis is delivering systems capable of composing scenarios for treating multiple performance indicators and applying widely used validated tools as simulators/calculators, each most often handling a single performance indicator (cf. [5]

and [6]). NLR participates in European and national projects to develop this kind of systems. An example is the European project SPADE, Supporting Platform for Airport Decision-Making and Efficiency Analysis, which connects such tools into user-centric scenarios [5].

The main achievement for decision support (from this system development) is to perform what-if analysis on multiple performance indicators driven by a common scenario, hiding underlying detailed modelling, resulting into mutually consistent and comparable results. This basic capability is a pre-requisite to evaluate performance indicators, compare results, and perform trade-offs. Automated trade-offs are not available or just very limited, mostly because current developments mainly concentrate on deploying new system technology, designing methods for common scenario definition, constructing airport data models, and connecting existing analysis tools.

Since manual trade-offs will be insufficient, an extended level of automated methods for multi-objective analysis is necessary. For example, the SPADE platform hosts a number of applications, also called SPADE use cases. NLR is developing one that analyses impacts of changes in flight schedules for a wide range of performance indicators, including capacity and noise. The selected study in this paper perfectly fits this application, because capacity and noise load are optimised. New software modules implementing optimisation methods would be a welcome extension to the offered capabilities.

4 Problem description

As mentioned in Section 2 the paper focuses on the optimisation of the flight procedure mix at scenario level. The optimisation problem specifies two design objectives: airport capacity in terms of number of aircraft movements and noise load in terms of the number of houses or inhabitants within a noise-level contour. The aim is to simultaneously optimise the noise load and the airport capacity. Decision variables of traffic handling are shifts in the applied flight procedures and traffic growth without affecting

the aircraft-type mix per runway and the ratio of the number of aircraft movements between pairs of runways.

Design constraints arise from limits in capacity of airport operation and infrastructure, such as runway capacity, and noise limits originating from reduction targets or legal noise regulations. Some constraints are part of how the decision variables are applied to change the pattern of aircraft movements, such as rules or limits for shifting flight procedures. Other constraints are accounted for in optimisation, such as the maximum noise levels at predefined points, often indicated as noise enforcement points.

More specifically, the following multi-objective problem is addressed, where, for ease of notation, it is assumed that only shifts in flight procedures for arrivals are allowed:

- Airport scenario, including:
    - R: number of runways at the airport;
    - $\tilde{N}_r$: initial number of arrivals at and departures from runway r;
    - $\tilde{N}_{rAB}$: initial number of arrivals at runway r that can fly both procedure A and procedure B;
    - $\tilde{N}_{rA}$ ($\tilde{N}_{rB}$) initial number of arrivals at runway r flying procedure A (procedure B), but that can also fly the alternative flight procedure B (procedure A); so
        $$\tilde{N}_{rAB} = \tilde{N}_{rA} + \tilde{N}_{rB};$$
    - P: set of enforcement points.
- Decision variables:
    - f: growth factor of number of flights (growth factor is the same for all runways, aircraft types, and number of arrivals and departures);
    - N_{rA}: number of flights arriving at runway r that can fly both procedure A and procedure B, but to which flight procedure A is assigned;
    Note that the number of flights arriving at runway r that can fly both procedure A and procedure B, but to which flight procedure B is assigned (denoted by N_{rB}) can be expressed as:
        $$N_{rB} = f \cdot \tilde{N}_{rAB} - N_{rA},$$
    since the growth factor f is the same for all runways r.

- Constraints:
    - $f > 0$;
    - $N_{rA} \geq 0$ for $r = 1, \ldots, R$;
    - $N_{rB} \geq 0$ for $r = 1, \ldots, R$;
    - $L_p(f, N_{1A}, \ldots, N_{RA}) \leq L_{p,max}$ for $p \in P$, where L_p is the noise level in enforcement point p, and $L_{p,max}$ the maximum noise level in enforcement point p.
- Objective:
  The objective is to simultaneously minimise the noise load H within a specific noise contour and to maximise the airport capacity C:

$$\min (H(f, N_{1A}, \ldots, N_{RA}), -C(f)),$$

  where

  $H(f, N_{1A}, \ldots, N_{RA})$ represents the number of houses or inhabitants within a specified noise-level contour,

  and

  $C(f) = f \cdot \sum_{r=1,\ldots,R} \tilde{N}_r$ represents the total number of aircraft movements.

5 Algorithm

A pre-requisite to perform optimisation is a system capable of evaluating the design objectives H (i.e., the number of houses or inhabitants within a specified noise-level contour) and C (i.e., airport capacity in terms of the number of aircraft movements), and the constraints (in particular the non-linear constraints $L_p(f, N_{1A}, \ldots, N_{RA}) \leq L_{p,max}$) as function of the decision variables. The optimisation problem does not allow for an analytical solution, and is therefore solved by means of an iterative (search) algorithm. Such an algorithm normally requires many objectives and constraints evaluations in the search for the optimum. The methods for evaluation, optimisation and their interaction are described in the next sections, as well as the composed evaluator and optimiser modules implementing these methods.

5.1 Evaluator

The evaluator performs scaling or rearranging aircraft movements and noise impact calculations. In the context of the optimisation problem it takes as input the decision variables traffic growth factor and flight procedure shift factors, and calculates the number of aircraft movements in total and per runway, the area of the specified contour, the number of houses/population within this contour, and the noise levels in the enforcement points.

The evaluator operates on an airport scenario describing the initial traffic, the airport and its surrounding area. These are static input data sets, not varied in the data processing.

An evaluation executes the following sequence of steps calculating:
- New set of aircraft movements as result of the scale or shift factors on the initial set of aircraft movements within the airport scenario;
- Noise levels resulting from the new set of aircraft movements in a grid structure covering the area of interest;
- Noise levels in enforcement points;
- Contour for a specified noise level;
- Properties of the contour such as area, affected houses and population inside.

The evaluator tool typically incorporates a number of basic modules: a traffic generator, a noise calculation model, contour calculator and geographical analyser (cf. Fig. 1).

All basic modules are selected from the proprietary NLR environmental tool set. In particular, the Dutch noise calculation model is used (cf. [7]) as the case study applies an Amsterdam Airport Schiphol (AAS) scenario. A software implementation (NRM) of this model, developed at NLR, has been selected mainly because of its model compliance, existing model data sets for AAS scenarios and experience in accommodating the data sets. The latter is especially required for this study when using additional or new flight procedure schemes.

In the following paragraphs the calculation methods within the selected tools are identified and those of particular interest are discussed in more detail.
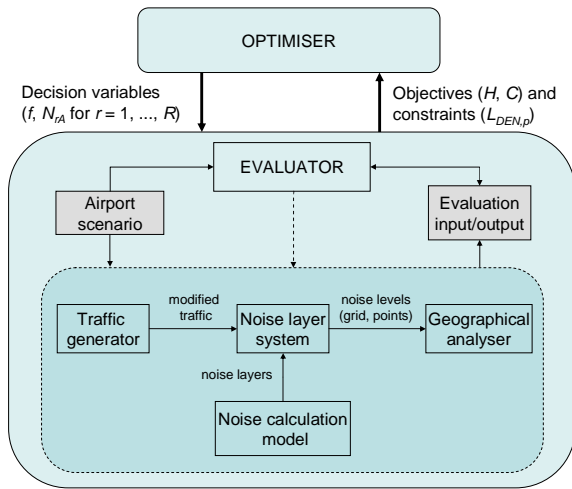
Fig. 1. Data flow in the evaluator module

5.1.1 Traffic generator
The traffic generator provides the capability for scaling traffic and shifting flight procedures. The starting point is the initial traffic in the airport scenario, already converted to NRM flight parameters. At this stage, the traffic is a set of traffic lines, each representing a number of movements of a traffic event type characterised by the parameters aircraft category, route, runway, and flight procedure.

Traffic volume scaling simply multiplies the number of movements with a factor equally for each traffic line. Alternatively, non-uniform factoring can be applied discriminating groups of aircraft movements, e.g., different factors for "runway - flight procedure" combinations. The traffic generator provides a table-oriented mechanism for specifying this type of functions as a set of factoring rules. This enables a flexible way to create a new mix of the same aircraft movements.

In general factoring rules create an increase or decrease in the total number of aircraft movements when the set of rules do not balance the effects of factors. In cases where the total number of movements needs to be preserved, a compensation mechanism is necessary. Mapping rules specify how to compensate an increase of a group. For instance, a rule stating that any change in a traffic event with procedure A should introduce the same change in the corresponding event with procedure B. When the number of movements of the corresponding

event is not sufficient to absorb the factor, the compensation method applies a maximum partial application of the requested factor. Related to the example above the total number of A and B does not change on factoring with compensation.

5.1.2 Noise calculation model
The NRM tool is capable of calculating grid-based equivalent continuous sound levels (L_{eq}) for modelled flights in terms of aircraft category, runway, route, and flight procedure. It also provides a function for scattered points calculation and contour calculation. The iso-contour is calculated from the grid containing L_{eq} noise values. The average level for day-evening-night L_{DEN} is used in this study as L_{eq} dose measure.

5.1.3 Geographical analyser
Standard methods for contour area calculation and counting houses and population are used to quantify the noise load in populated area. The calculations account for possible inner holes within the outer enclosing contour line. Counting houses is based on public demographic data, containing location-bound number of houses and population figures. The counting method is a summation combined with a point-in-polygon algorithm.

5.1.4 Noise layer calculation
The noise calculation for traffic events is the most demanding calculation task, time-consuming and requiring significant computing resources. A typical run calculating grid noise levels takes about an hour or more for an annual AAS traffic on an average desktop computer. A way to speed up the noise level calculation is to use a system of noise layer summation. This shortens the calculation time to less than a minute, when a priori noise layers have been calculated, simplifying calculations to summation of noise layers.

Since fast evaluation is important to advanced analysis and optimisation, a noise layer generation system is applied in combination with NRM. This front-end system builds a database of noise layers for airport scenarios. For one scenario, the database can contain as much noise layers as there can be

different traffic events. A noise layer is a grid (or point) result for one traffic event, in which each value is expressed in the exponential form of the sound exposure level (cf. [7]). A single noise evaluation of traffic then simplifies to a linear combination of noise layers, the pre-calculated results of included traffic events. The L_{DEN} value in dB(A) is the logarithmic value calculated from this total sum.

5.2 Optimiser

The multi-objective optimisation analysis aims to minimise the noise load and to maximise airport capacity simultaneously, subject to a number of linear and non-linear constraints, including maximum noise levels in enforcement points. There is, however, not a generally acceepted judgement to directly relate noise load to capacity. Hence, it would be rather arbitrary and subjective to reduce the problem in Section 4 to a single-objective optimisation problem by, for instance, applying a weighting scheme that reflects the relative importance of these two objectives and summation of the weighted objectives.

A multi-objective optimisation problem is not likely to have a single solution that simultaneously optimises each objective. A common and useful concept for such a problem is Pareto optimality [8]: a solution is called Pareto optimal if an improvement in one objective can only occur by worsening one or more of the other objectives. Hence, the solution of a multi-objective optimisation problem will result in a set of Pareto-optimal solutions.

To determine the set of Pareto-optimal solutions for the multi-objective optimisation problem formulated in Section 4, a genetic algorithm is used. This is an in-house developed Matlab implementation based on the well-known algorithm NSGA-II in [9] and the variant of this algorithm as proposed in [10].

Genetic algorithms typically require many evaluations of the objective function. Thus, it does not allow for computationally time-consuming evaluations. In spite of the noise layer generation system, a typical evaluation is still too time-consuming for optimisation

purposes. Therefore, an efficient approximation of the objective function H will be used.

A vast number of methods, such as polynomial regression and neural networks, exist for creating approximations or fits, together with various statistical verification and cross-validation methods to assess and select the most suitable of these methods. In this study the NLR fitting tool MultiFit is used, which supports highly efficient and user-friendly creation, assessment and comparison of fits with a wide range of multi-dimensional interpolation and approximation methods (cf. [11]). This tool is also implemented in Matlab.

The approximation of the objective function, found by using the MultiFit tool, is connected as evaluation function to the genetic algorithm. This approach actually decouples the actual evaluator module and the optimiser module, by just transferring a data set as input for the optimiser. The data set contains a number of evaluations and per evaluation the values of the decision variables, the objectives and the constraints. Fig. 2 displays the interactions between the various modules for optimisation.
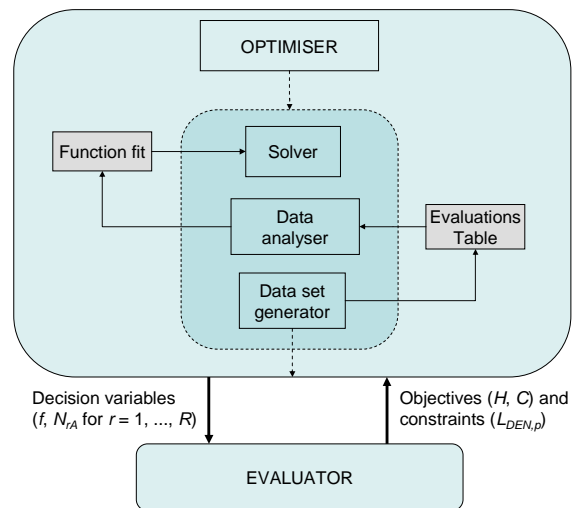

Fig. 2. Data flow in the optimiser module

6 Case studies

In this section the results of two case studies are discussed, demonstrating the applicability of NLR's tools for multi-objective optimisation and

illustrating the potential of these tools for "multi-variable" airport efficiency studies.

These case studies are based on a baseline scenario for Amsterdam Airport Schiphol (AAS). AAS facilitates traffic at six runways. In this scenario the traffic defines the annual number of flights, the aircraft types and weight categories, the runways used, the routes flown and the procedures used. Both the routes and the procedures are modelled, and thus not based on actual flight data. In the baseline scenario all aircraft fly ICAO-A procedures. In order to be able to find an optimal mix of ICAO-A and ICAO-B procedures, ICAO-B profile data are added to the noise calculation model. The ICAO-B procedures are calculated in such a way that they are comparable to the existing ICAO-A procedures. The noise limits in the enforcement points used in this scenario are not used in reality. They were altered to match with the new profile data and to become active constraints in optimisation.

Before addressing optimisation in the case studies; two sub-problems are studied first.
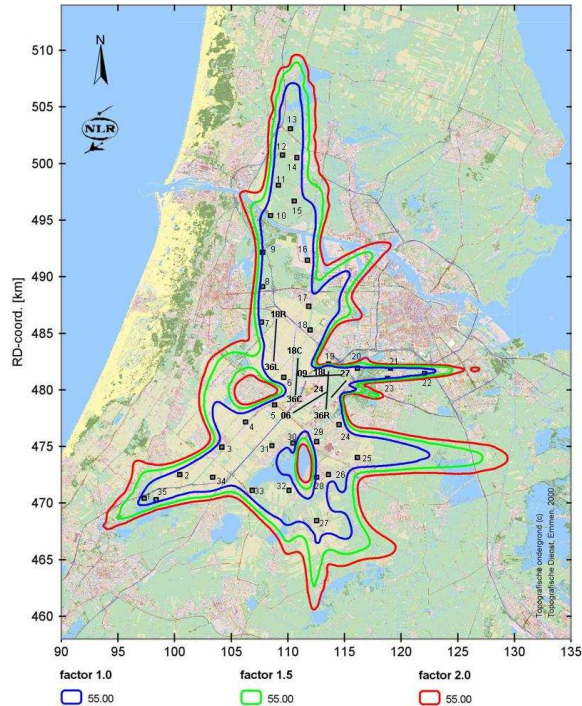

Fig. 3. Effect of a uniform increase in traffic

The first sub-problem assesses the effect of an increase in traffic, without changing the procedure mix per runway, by multiplying the number of flights in a baseline scenario by a factor f. Increasing this factor evidently leads to a higher noise load. This effect is illustrated in Fig. 3 for several values of f. This figure shows contours that enclose the area with a noise level of at least 55 dB(A) L_{DEN}. As expected, the area of this contour increases when the factor becomes higher. Uniform scaling raises the noise levels similarly and extends the contour areas gradually including more populated areas.

In the second sub-problem the flight procedures are varied in order to reduce the total noise load and the amount of people affected by the noise) is assessed. In the baseline scenario, all aircraft types fly an ICAO-A procedure. In order to reduce the noise load, several aircraft types are allowed to fly an ICAO-B procedure instead. The differences between the two procedures can be seen from their altitude, speed and thrust profiles. Fig. 4 displays the difference in height profile of the ICAO-A and ICAO-B procedures.
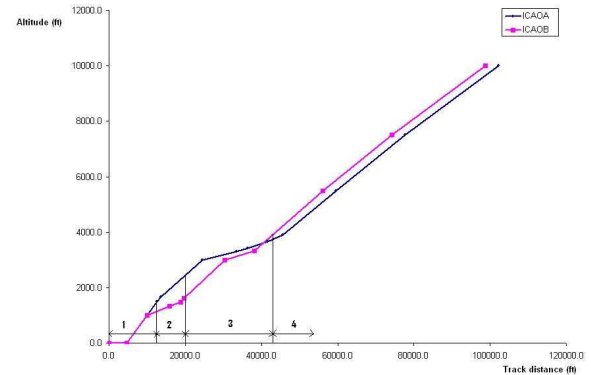

Fig. 4. Altitude profile of ICAO-A and ICAO-B procedures, respectively

The main difference between the two procedures is that the ICAO-A has a larger altitude gradient during the first part of the climb phase, while the speed of the ICAO-B procedure increases more rapidly during the initial climb phase. Shifting to more ICAO-B procedures will result into higher noise levels closer to the airport. The contour shows a tendency to nearby broadening and distant narrowing. Shifting noise levels along the runway direction may provide a control to avoid populated areas.

6.1 Case study I: Single-runway optimisation

The first case study addresses the optimisation of an ICAO procedure mix in combination with traffic growth on a single runway. A runway with substantial traffic is selected from the baseline AAS scenario: the North-South directed runway 36L-18R (see Fig. 3). A subset from the baseline traffic is selected to study the flight procedure mix, i.e., the aircraft flying an ICAO-A procedure and that are enabled to fly an ICAO-B procedure. Considering only this subset (containing 33% of the total number of movements) does not compromise the results of optimisation because growth independently applies to all aircraft movements.

A 5x5 full factorial design is generated for the two decision variables: traffic growth factor f and number of aircraft N_{1A} flying an ICAO-A procedure. The latter is represented as a shift factor at this runway (f_{1A}) on the initial number ($N_{1A} = f_{1A}.\tilde{N}_{1A}$). Running the evaluator on this design creates a data set containing the objective (H and C) and constraint values ($L_{p,max}$) for each pair of decision variable values. The evaluator calculates H in terms of contour area and number of houses within, and C as effective number of aircraft movements (including noise penalty multipliers on day, evening or night). On this data set different fit-functions are applied, and the most accurate fit is determined by a p-fold cross-validation assessment with the MultiFit tool. The Kriging-qC fit method [11] is found to provide the best fits for the 3 objectives and the constraint functions. To give an impression of the dependencies, the data set and the fits are shown in Fig. 5.

Analysing the data set, the capacity figures are straightforward, i.e., the effective number of aircraft movements is proportional to the traffic growth and independent of the procedure mix on the runway. Increasing the traffic growth for a fixed procedure mix shows a fairly proportional increase in area. Also the number of houses shows a similar behaviour, but not that strict, especially high growth results in contours that enclose more densely populated areas. A shift from ICAO-A ($f_{1A} = 1$) to ICAO-B procedures ($f_{1A} = 0$) at a fixed growth shows a decrease in area, and also in the number of

houses, although more irregular. In this situation, at fixed growth, both the 55-L_{DEN} contour area and the number of houses are minimal when using exclusively ICAO-B on this runway.
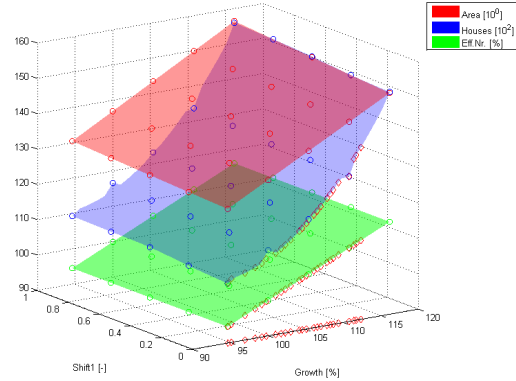

Fig. 5. The 3 objective functions in the domain (surfaces: fits; circles: data points; red diamonds: Pareto points)

Including simultaneous variation in traffic growth may produce different results, looking for an in-between favourable mix. A structural way to investigate this is to apply multi-objective optimisation on noise H and capacity C. In the decision space, the feasible Pareto points are found for $f_{1A} = 0$ (100% ICAO-B) and upper-bounded f-values (Fig. 5). The upper-bound is set when the first noise constraint in an enforcement point is violated. In the considered range of growth there is no in-between favourable mix. This seems reasonable when looking more closely to the data set. The number of houses as function of shifts for fixed growth is always decreasing, with varying gradients but does not show any local minimum.

6.2 Case study II: Multi-runway optimisation

In the second case study both the traffic growth and the procedure mix on the five main runways will be optimised. The traffic is the same as used for the first case study. Similar to case study I, the capacity will be scaled with a growth factor and the procedure mix on each of the runways will be modelled as shift factor on ICAO-A procedure. However, in this case an optimal mix of procedures will be determined for each runway. This means that the dataset for this case will be generated for a total of six

decision variables, i.e., f and f_{rA} for $r = 1...5$. A random space-filling method is applied for sampling the decision space, effectively limiting the number of evaluator runs required to generate the data set.

Analysing the data set, again (like in the previous case) the growth factor dominates largely the objective values. The shifts per runway have less effect, but their contributions do vary substantially among runways, depending on the traffic volume per runway and the runway situation in the surrounding populated areas.

The fact that the procedure mix on more than one runway will be optimised means that there will be interaction between the effects of the procedure shifts on the different runways. This can be seen in the noise levels in the different noise enforcement points (see Fig. 6). Since these noise levels can be affected by traffic from more than one runway, this means that the optimiser has to find optimal procedure mixes on both runways so that the noise constraints are not violated.

Also for this data set the most accurate fit is determined by a p-fold cross-validation assessment with the MultiFit tool, now yielding the Kriging-lE fit method [11] as the best fits for the 3 objectives and the constraint functions.
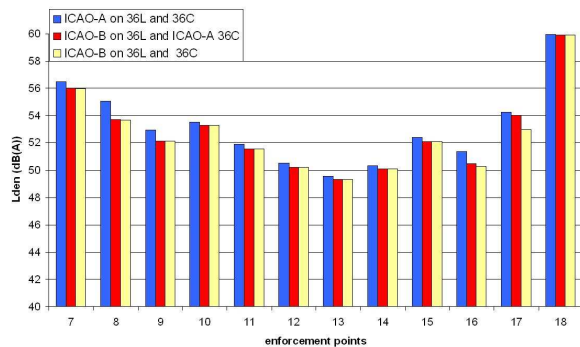

Fig. 6. Effect on noise levels in some enforcement points for procedure shifts on one or two runways

With these fits, the multi-objective optimisation algorithm again determines the Pareto front as illustrated in Fig. 7. Most of the feasible Pareto points are found for shifts equal to 0 (100% ICAO-B). It can be concluded that interaction between runways does not lead to new insights in best procedure mixes. Similar to

case study I, the optimisation resulted into minimum noise load and maximum capacity when all flights on all runways follow an ICAO-B procedure and the maximum growth factor is limited by the noise level constraints.
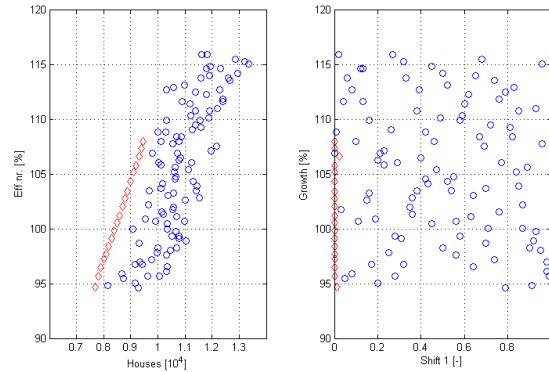

Fig. 7. Feasible Pareto points for min(Houses) and max(Eff.nr.) (red diamonds: ensga algorithm; blue: data points)

7 Concluding remarks and future work

This paper demonstrated the use of NLR's multi-objective optimisation tools for simultaneously optimising airport capacity and noise load, and presented some first optimisation results. It is a first step in the quest for innovative solutions to enhance airport decision-support systems with multi-objective analysis capabilities. The application of the tools, with some additional dedicated improvements, seems promising for further research in this area. Below a few improvements are addressed.

The two case studies showed that minimum noise load and maximum capacity are obtained when all arriving flights follow an ICAO-B procedure and traffic growth complies with the noise level constraints. However, these case studies considered only a part of all flights to change flight procedures and applied a uniform increase in traffic. An improvement to refine this research is to allow for more variation and differentiation in flight profiles, e.g., using noise-optimised flight procedures, and reduced flaps and reduced thrust procedures.

The current research provided a first, but limited, insight on the overall effect of noise

load due to traffic growth and changes in the procedure mixes at the different runways. To obtain more profound insights two options are proposed. The first option is to investigate various noise contours simultaneously (instead of focusing on only one). Another option is to analyse the noise levels and population density on grid cells and minimize the impact on the whole grid. This means that no contours will be used for the optimisation.

Another improvement of the current research is to look for decision variables that would enhance the control on the location or realism of noise load. This of course introduces more operational complexity, such as using new trajectories or using actual flight data.

To increase the multi-objective optimisation capabilities of the tools used, these tools could be extended to other and even additional performance indicators. Think for instance of third-party risk and local air quality. This would enable the optimisation of air traffic with respect to other environmental quantities.

The software product demonstrated in the case studies comprises a dedicated assembly of tools in both the evaluator module and the optimiser module. In view of the extended scope, such as other objectives, other problem definitions and possibly also alternative optimisation methods, this product requires a highly adaptable architecture. Various tools may be needed to support the evaluator and the optimiser modules, and need to cooperate on a common scenario and optimisation schema. Future work needs to focus on delivering such a product as extended analysis level in decision support systems. A next step, for example, could be to build and integrate such a product into the integrated analysis system SPADE. Finally, a challenging task will be to introduce the use of multi-objective analysis capabilities by airports and their stakeholders.

Acknowledgements

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