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Flexible Runway Scheduling for Complex Runway Systems: Using a Multi-Objective Optimization

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Runway usage at complex airports is currently prescribed by a preference list focusing on minimizing noise and providing a manageable flow for ATC. However, fuel burn and the demand of flight is not considered. This study proposes a flexible runway scheduling model and is an improvement of the current flexible runway allocation model. The model is able to assign continuous delay to the scheduled flights and by changing the decision variables a new separation constraint is proposed to accurately model complex runway dependencies. A multi-objective optimization is performed for fuel burn and noise disturbance using Mixed-Integer Linear Programming (MILP). The model is tested on Amsterdam Airport Schiphol (AAS) for different scenarios. A fuel reduction of up to 7% is possible depending on the operational peak and O/D data. At the same time, noise violations are limited in the vicinity of the airport. This provides the opportunity to expand operations while complying with local noise regulations. Furthermore, the model can be used to explore operating strategies for different objectives for every runway configuration.

I. Introduction

In 2020 the aviation sector was brought to a standstill due to the Corona virus. However, the growth as seen in the previous years is expected to recover [1]. Data provided by the International Air Transport Association (IATA) [11] states that in 2018 over 8.3 trillion Revenue Passenger-Kilometers (RPK) were flown and estimates provided by the International Civil Aviation Organization (ICAO) expect a growth of 4.3 per cent per year for the period 2015-2035 in terms of RPK [12].

The growth of the aviation sector has a direct influence on the operations of airports. As the demand for flying increases, the number of operations performed at an airport increases with it. To cope with the increasing operations, several factors and expansion possibilities can be considered while ensuring capacity, safety and regulations.

As physical growth of the airport is often not possible due to local restrictions, airports turn to other possibilities to optimize their operations given the current infrastructure. One of the biggest contributors to airport capacity is the runway capacity which is defined by Neufville as: "the expected number of movements in a time period on a runway system without violating Air Traffic Management (ATM) rules, assuming continuous demand" [18]. To improve runway capacity, several studies in different research areas have been performed. The RECAT-EU scheme is one of those results and is a revised separation scheme described by Rooseleer and Treve [20] and validated by Hu et al. [10].

Noise disturbance has become a topic of discussion in the expansion of airport operations [4]. Airports operating under noise restrictions often follow a preferred runway list according to regulations and agreements with (local) governments. These preferred sequences together with ICAO noise abatement procedures ensure noise disturbance is limited but not negligible [2][13].

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II. Modelling

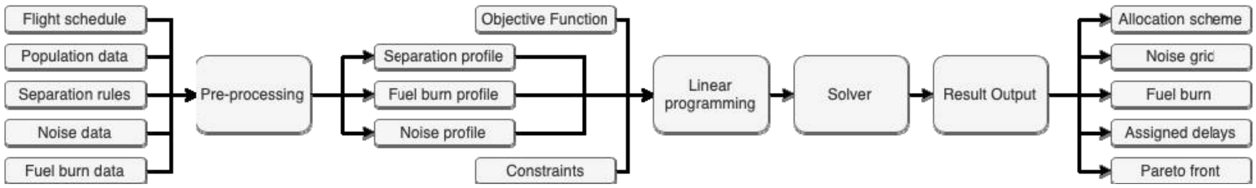


Figure 1: Flow diagram

A. Separation modelling

The most dominant factor influencing runway capacity is the minimum separation requirement between operations [3]. The minimum separation time is dependent on several parameters such as i) operation type, ii) weight class and iii) runway use. The model builds further upon the pair-wise separation method as proposed by Van Der Meijden [26].

B. Fuel Burn Modeling

As the model will make a trade-off between fuel burn and noise disturbance, accurate modeling of both is important. In this research a method is proposed for the fuel burn calculation which is based on previous research performed by Delsen [5] and parameters obtained from the Base of Aircraft Data (BADA) [6].
To calculate the fuel burn of a flight the flight path is divided into several stages for which the individual fuel burn is calculated. The total fuel burn calculation is expressed in kilograms of kerosene. The fuel burn per segment is then calculated:

$$TFB = \sum_{s \epsilon S} TFB_s$$

$$TFB_s = \frac{D \cdot \dot{m}_f}{V_{TAS}}$$

The distance per segment (D) can be obtained from Aeronautical Information Packages [15] which are provided per airport. The fuel flow ($\dot{m}_f$) in [kg/s] is obtained from AEDT. This database provides coefficients of all types of aircraft which are currently in use. The fuel flow is thrust dependent and can be obtained assuming a thrust specific fuel consumption:

$$\dot{m}_f = C_T \cdot T_{hr}$$

In this research the segments for arriving aircraft are divided into three parts: i) the segment from the Initial Approach Fix (IAF) to the Final Approach Fix (FAF), ii) the segment from the FAF to the runway and iii) the segment from the runway to the pier. For departing aircraft the segments are divided in two parts: i) the segment from the pier to the runway and ii) from the runway to the first waypoint on the Standard Instrument Departure (SID).

The model is able to assign delays to aircraft if necessary. This delay comes at the cost of additional fuel consumption and has to be incorporated in the model as well. For arriving aircraft it is assumed that the delay takes place at the IAF. The fuel flow at that stage is taken as the cost per second of delay for arriving aircraft. For departing aircraft it is assumed that the fuel burn during the taxi phase is extended. In the model, taxi thrust is assumed to be 7% of total thrust [14] from which the fuel flow can be calculated with previous equations.

C. Noise Modeling

The second objective for which the model will optimize is noise disturbance. As fly-over noise is a nonstationary signal, the duration of the sound has to be taken into account. For this, the Sound Exposure Level (SEL or LAE) can be used. The overall A-weighted sound pressure level is indicated by L_A. The integration time is removed and replaced with a constant of T_1 = 1s.

To use the equation in a linear optimization problem, the logarithmic parts of the equation have to be adjusted.

For this, the Acoustic Energy Level can be used.

$$AEL = \frac{E_n}{E_0} = 10^{\frac{SEL_n}{10}}$$

$$L_{DEN} = 10\log\left[\sum_{n=1}^{n_{flights}} w_n \frac{E_n}{E_0}\right] - 10\log\left[\frac{T_{ref}}{T_0}\right]$$

To calculate the SEL for an aircraft operation a noise modeling program is used. In this research use is made of the Aviation Environmental Design Tool (AEDT) designed by the FAA [24]. By defining the group of aircraft of interest, a set of measurements can be obtained for every combination of runway, aircraft and STAR/SID for each individual gridpoint. In this research it is assumed that the assigned delay does not imply extra noise disturbance. Delay is assigned at the IAFs or at the ground, not adding noise to the defined noise grid.

III. Linear programming formulation

The model is formulated as a Mixed Integer Linear Program (MILP) where variables can be integer or binary.

A. Variables

The decision variables (DV) and auxiliary decision variables (ADV) are summarized in Table 1. The condition for which a binary variable is one is given as description, otherwise the variable is zero. An auxiliary decision variable is not directly in the objective function, but a combination of them can be used in the optimization process to enhance the performance.

Table 1: Decision and Auxiliary Decision Variables:

Variable	Description
x_f^r	1 if flight **f** is assigned to runway **r**
g_{xy}	1 if noise limit is exceeded at point **xy**
D_f	Delay for flight **f** in [sec]
T_f	Operation time for flight **f** in [sec]
$x_{i,j}$	1 if flight **i** is before flight **j**

B. Objective

$$\min \quad Z = \alpha \cdot n_f \sum_{f \epsilon F}\left[\left(\sum_{r \epsilon R} c_f^r x_f^r\right) + c_d D_f\right] + \beta \cdot n_n \sum_{xy \epsilon P} c_{xy} g_{xy} + c_{opt}\left(OR + D_{max} + T_{max}\right)$$

The objective function consist of three parts:, fuel consumption, noise limit exceedance and overall efficiency.

The objective for fuel consumption is a minimization of the combination of the fuel cost of assigning flight f to runway r indicated by the cost variable c^r_f and the assigned delay in seconds with a cost indicated by c_d in [kg/s].

If the noise limit is violated at a gridpoint, indicated by g_{xy}, than the cost of that disturbance is given by the number of people, c_{xy}, living at that location.

For overall efficiency, the model has the option to switch the order of scheduled flights if this favors the overall objective, but endless order changes (OR) are not desired. Furthermore, the model has a penalty for the maximum delay, D_{max}, as this prevents delaying one aircraft endlessly in favor of others. The final parameter, T_{max}, ensures that the flights are handled as quickly as possible.

C. Constraints

$$\sum_{r=1}^{R} x_f^r = 1, \forall f \in F$$

Each flight has to be assigned to one runway and one runway only.

$$x_{i,j} + x_{j,i} = 1 \quad ,\forall j \neq i \cap | TS_i - TS_j | \leq SW$$
$$x_{i,j} = 1 \quad ,\forall j > i \cap | TS_i - TS_j | > SW$$
$$T_j - T_i \geq 0, \forall j \neq i \cap TS_j - TS_i > SW, \forall i \in F$$

Flights are allowed to switch order if they are within a specified window (SW) of each other. To ensure that order changes outside this window are prohibited two extra constraints are necessary.
The first constraint determines the value of the auxiliary decision variable, $x_{i,j}$, which can be used for separation. Notice that if j is smaller than i and not within the SW, this variable must always be zero.
The second constraint determines the time between the operation and ensures that outside the SW a First-Come, First-Serve principle is used.

$$-Mx_{i,j} - Mx_i^r - Mx_j^q + T_j - T_i \geq -3M + T_{i,j}^{r,q}, \forall i \in F, \quad \forall j \in | TS_i - TS_j | \leq 2SW, \forall r, q \in R$$

With the order of flights determined, the separation constraint can be implemented using a big-M method. This makes it possible to only activate constraints when all decision variables are active, otherwise the constraint is inactive. The separation time, $T^{r,q}_{i,j}$, is dependent on the operation of the flights, the aircraft type of both flights including their weight classes and the runways on which they operate. To enhance model performance it is chosen to only consider separation requirements for flights within 2 SW as this would ensure sufficient coverage for all combinations as long as the SW is not smaller than the largest separation requirement.

$$g_{xy} = 1 \rightarrow \sum_{f=1}^{F} \sum_{r=1}^{R} c_{xy}^{f,r} x_f^r > L_{limit} \quad \forall xy \in P$$
$$g_{xy} = 0 \rightarrow \sum_{f=1}^{F} \sum_{r=1}^{R} c_{xy}^{f,r} x_f^r \leq L_{limit} \quad \forall xy \in P$$

For noise disturbance an indicator constraint is used. This switches the decision variable to 1 if the noise limit is exceeded and remains 0 otherwise. Note that in (35) the cost coefficient $c^{f,r}_{xy}$ is the AEL value that occurs at a grid point when flight f is assigned to runway r.

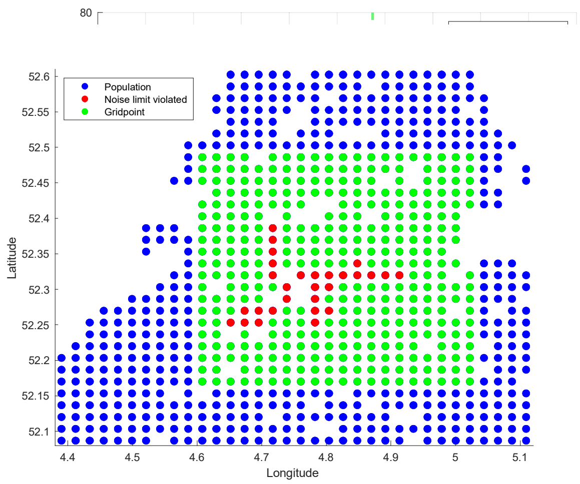
IV.Results

For the analysis of the Flexible Runway Scheduling Model (FRSM) a day of operations at Amsterdam Airport Schiphol (AAS) is analyzed. AAS has a complex runway system with 6 runways oriented in different directions. The Oostbaan(R04/R22) is used only for small general aviation and is therefore omitted from this analysis. Because AAS is located in a densely populated area, noise disturbance is an important issue and therefore AAS operates with a preference list. AAS is one of the largest hubs in Europe and is subjected to inbound and outbound waves. During those peaks runways are used in a 2+1 configuration. If the waves overlap AAS can switch to a 2+2 configuration as well [21].

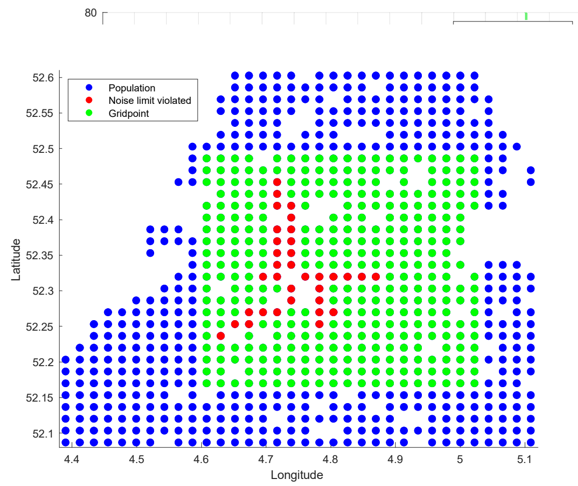
Three peaks at a busy day in August 2019 are evaluated. The FRSM is able to quickly analyze periods of 1-2 hours, but longer periods become increasingly difficult in terms of computing power. As the inbound and outbound waves are the busiest time periods, only those hours are analyzed. The details can be found in Table III. To evaluate the effect of the FRSM, reference scenarios are considered as well. The runways in the reference scenario are shown for arriving (A) and departing (D) aircraft.

Table 2: Scenarios for AMS

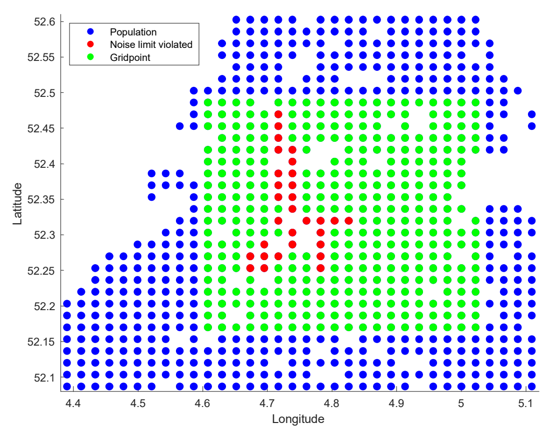
Scenario	Peak	Flights	Reference
1	Outbound	102	A: *R18R* D: *R18L*, *R24*
2	Inbound	159	A: *R18R*, *R18C* D: *R24*
3	2 + 2	123	A: *R18R*, *R18C* D: *R18L*, *R24*



(a) Scenario 1: α = 0.4 and β = 0.6



(b) Scenario 2: α = 0.2 and β = 0.8

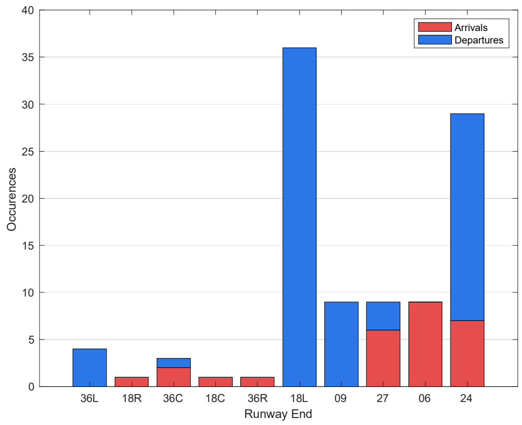


(c) Scenario 3: α = 0.65 and β = 0.35

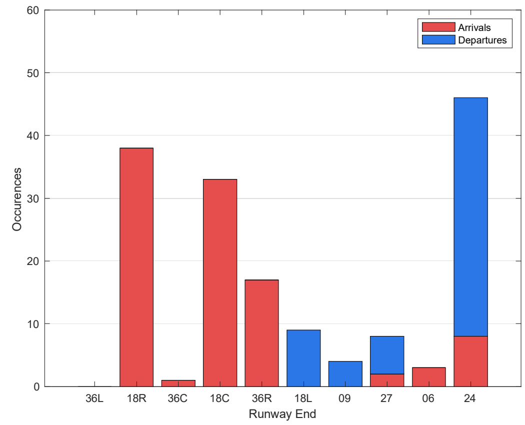
Figure 3: Noise Grids for multiple scenarios

To visualize the effect of varying the weight factors, a Pareto front is plotted for all scenarios as can be seen in Figure 2. As this problem is a multi-objective optimization there is not one optimal solution and a Decision Maker (DM) is to decide which solution is deemed the best. In the Pareto fronts the values for the reference scenarios are plotted as well. A fuel reference is determined in the reference scenario. An optimization is performed with emphasis placed on fuel only (α = 1). For a noise reference a report is used which measures the LDEN violations in a year [17].

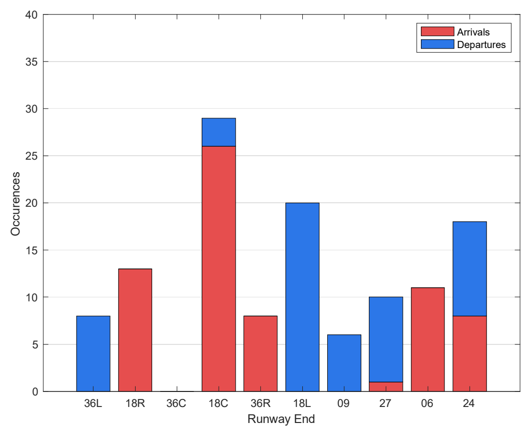
It can be noticed that scenario 2 and 3 exhibit a more flattening behavior than the first scenario. This is mostly due to the presence of arriving flights in the scenarios. Arriving flights generally have a lower noise impact further away from the runway as descent is performed with engines idle. Therefore, most noise violations happen at the common approach path which cannot be avoided altogether. This has as a consequence that smaller differences are obtained when changing weights, resulting in more flattened curves. For further analysis a combination of weight parameters is chosen which is located close the left bottom of the Pareto curve to have reductions in both fuel burn and noise disturbance.



(a) Scenario 1: α = 0.4 and β = 0.6



(b) Scenario 2: α = 0.2 and β = 0.8



(c) Scenario 3: α = 0.65 and β = 0.35

In Figure 3 and Figure 4 the noise grid and runway allocation are shown for a combination of weight parameters for each scenario. In the outbound peak, shown in Figure 3(a) and Figure 4(a), the runways R18L and R24 are heavily favored for departing operations. These runways are used in the reference scenario as well. It can be seen that the arrivals in this scenario are spread over all runways and that R18R is used less with respect to the reference scenario. This can be explained for two reasons. The first reason has to do with the fact that operations on R18R require a longer taxi time to the pier and runways located closer are more favorable. The second reason is found when analysing the use of R24. The multitude of departing operations on this runway violate the noise limit at the departure trajectory and scheduling extra arrivals on the opposite runway end does not come with extra noise cost. It can be noted that the FRSM in this scenario has a preference of scheduling flights close to the pier to minimize taxi operations. R18R/R36L and arrival operations are only allowed on R18R and R18C, while the FRSM schedules arriving flights on the other runways as well. From the noise grid it can clearly be seen that the operations at R18R and R18C violate the noise limit. The operations on R18L/R36R are noteworthy as the operating runway end is switched multiple times during this period to accommodate for both arriving and departing flights. The fact that R09/27 is barely used for operation results in a lower number of violations on gridpoints east of AAS. For the arriving wave the number of people exposed by the noise limit is small. The number of gridpoint violations is in the same order of magnitude as the other scenarios. However, the absence of cities below the final approach fixes of R18R and R18C, together with the fact that other violations are only located close to the airport, has as a consequence that the number of people affected by these operations is limited.

The final scenario is shown in Figure 3(c) and Figure 4(c) where the set of flights consist of an equal division between arrivals and departures. With respect to the reference scenario it can be noted that R24 is used for both operations. Although R18C and R18R are still the predominant runways for arrivals, it can be noted that some arrivals are also spread to other runways. This gives the possibility to have departing flights on R36L as well. The noise grid for scenario 3 has the most violations with respect to the other scenarios. The fact that this scenario spreads the flights relatively even over all runways has as a consequence that the departing and arriving routes for all runways are used, resulting in more violations of the noise limit. When comparing the FRSM to reference scenarios it can be concluded that the FRSM spreads the flights over all runways and that this does not lead to an increase in noise violations with respect to the reference scenario. Noise contours as displayed in [17] show matching profiles with the noise grids, indicating that the FRSM does not violate more gridpoints at new locations.

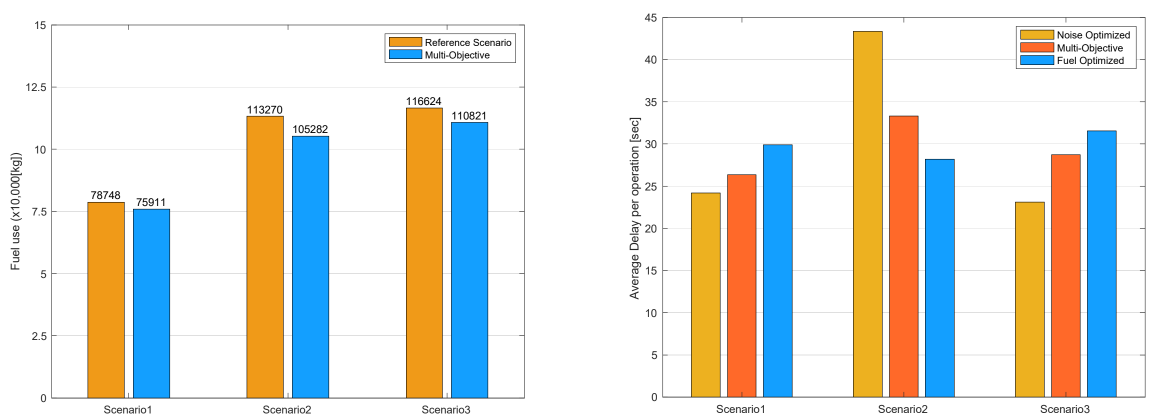


Figure 5: Fuel usage (left) and delay distribution (right)

To analyse the effect of the new scheduling method on the total fuel burn, a comparison can be made with the reference scenario. In Figure 5 left the fuel saving is shown for the different scenarios with respect to the reference scenario. The fuel saving can vary from 3.6% for the outbound scenario to 7.1% for the inbound scenario. The mixed operation scenario has a fuel saving of 5.0%. As AAS has, on average, 5 daily inbound and 6 outbound peaks a significant fuel saving can be obtained for a full day of operation. The difference between fuel saving for the outbound and inbound scenario can be explained when analyzing Figure 4(a) and Figure 4(b) and investigating the origin and destination of the flights. The destinations for the departing flights are mostly located south, heavily favoring R18L and R24. These runways are also used in the reference scenario. This means that most departing flights already operate on their fuel-optimal runway. This reduces the potential for fuel saving. The origin of the arrival flights is spread more evenly and therefore higher fuel saving can be obtained when the flights are spread over the entire runway system.

The FRSM has the possibility to delay certain flights for separation requirements or when this favors the overall optimization. Further analysis is done by comparing three optimizations for each scenario. These optimizations consist of a run where emphasis is placed on noise optimization ($\beta = 1$), fuel optimization ($\alpha = 1$) and the multi-objective scenario as obtained from the Pareto front. The total delay is calculated first and then divided by the flights in that scenario to obtain an average delay.

In the first scenario it can be seen that the delay increases as more emphasis is placed on fuel optimization. While this seems counterintuitive at first, it indicates that it can be favorable to delay some aircraft to wait for a vacant preferred runway. In the second scenario it can be seen that delay decreases when more emphasis is placed on fuel saving. For a noise optimized scenario the model assigns more delay to limit the number of runways used, thereby decreasing the number of gridpoints with a noise limit violation.

The difference in the delay trend can be explained on the basis of the operations performed. In general, the cost of delaying a taxiing aircraft is lower than for an aircraft in the air. As the first scenario consist of mostly departing flights, the cost of waiting for a preferred runway is less than the difference for the second optimal runway. For the arriving scenario, flights are preferred to be on the ground as quickly as possible as this is deemed more efficient than waiting in the air for a preferred runway.

Further analysis also proved the effectiveness of assigning a penalty to the maximum delay as it is not favored to delay one aircraft endlessly in favor of others. It showed that the maximum assigned delay in the scenarios is about 6-7 minutes, which is deemed acceptable.

V.Discussion

A. Fuel and noise

Airports operating in a densely populated area use a preference list for the runway use which is only considering noise disturbances and the current wind conditions. At a time where fuel consumption and specifically fuel saving is becoming a topic of interest, the development of the flexible runway scheduling model (FRSM) proves to be a solution for both. By considering fuel burn and noise disturbance it is shown for Amsterdam Airport Schiphol (AAS) that reductions in both objectives are possible.

For fuel reductions it is found that savings are possible ranging from 3 - 7%. Further analysis of these scenarios showed that the type of operation and the origin or destination of the flights have an impact on the potential fuel reduction with respect to the reference scenarios. For AAS the runways operated in an outbound peak are directed south. In scenario 1 the number of flights having a destination south is more than 50% and so their optimal runway is already operated in the reference scenario. For the inbound reference scenario only runways are used which are oriented north, while the incoming flights arrive from all directions equally. If flights are scheduled according to the FRSM more optimal flight-runway combinations arise and therefore more fuel reduction is possible. Another source of higher fuel reduction has to do with the taxi times from and to R18R/R36L. In the reference scenario, arrival flights are assigned to R18R and have to taxi from there to the terminal. Analysis of the airfield shows that the taxi distance from this runway to the terminal can be 2-3 times greater than other runway-terminal combinations. Taxi operations also have a significant impact on fuel burn and therefore reductions are possible by scheduling aircraft closer to the terminal, thereby reducing taxi times.

For noise disturbance the FRSM is compared to the actual noise data from 2016. Based on this data [17] 48,300 people endured noise disturbances above the LDEN limit. The FRSM is able to schedule flights while ensuring this limit is not violated. Further investigation in the number of people that are affected by a noise violation reveals the fact that certain municipalities are located directly under the approach or departure routes of certain runways. The fact that they are located relatively close to a certain runway comes with the consequence that the noise limit is almost always violated if that particular runway is used. When comparing the noise grids for scenario 1 and 2 it can be seen that for the inbound peak more gridpoints are violated, but that actually less people are affected by this violation. This is mainly due to the fact that the population located north of R18C and R18R is sparse. When evaluating scenario 3 it is found that during that operational profile most people are affected by the noise. This is mainly due to the extra noise violation to the left of AAS where also a village is located.

For noise regulations in general a remark should be made. Noise regulations and limits are in agreement with government and are determined on a yearly basis. This means that it is allowed for operational hours to exceed the noise limit as long as this does not affect the yearly average. The scenarios analyzed in this research demonstrate that noise limits are indeed violated for a period of time, but it should be taken in mind that this has to be compensated for during operational hours when the demand is lower.

B. Trends & Possibilities

The results for AAS are further analysed in detail to examine trends and key decisions the model makes. These key decisions could already be used in current day operations without the implementation of the flexible runway scheduling method. First, an analysis is performed for the allocation of weight classes at runways. In scenario 1 a shift can be observed for the allocation of Heavy aircraft ('UH' and 'LH'). When the emphasis of optimization is shifted from noise to fuel, more flights are scheduled on R18L, opposed to flights located on R36L and R09. A similar shift can be observed in scenario 2. For a noise favored optimization ($\beta > 0.5$) most Heavy aircraft are scheduled on R18C or R18R, while a fuel favored optimization shifts the aircraft allocation towards R27.

For every flight there is one runway which amounts to the lowest fuel burn. For every weight class it is examined how many aircraft are assigned to this preferred runway. Overall it is found that with an increasing emphasis on fuel optimization, more flights are placed on their preferred runway. However, some extra trends can be observed. In the first scenario a very high percentage (>65%) of Medium aircraft is assigned to their preferred runway independent of the optimization. In the second scenario the number of Heavy aircraft allocated to their preferred runway increases significantly (3 to 4 times) when the optimization emphasis is placed on fuel ($\alpha > 0.5$).

Besides analysis for weight classes research is also performed for the aircraft types in each scenario. Two general trends can be observed. Some aircraft types are always assigned their preferred runway independent of the optimization. The second trend is that some other aircraft types are always assigned to their preferred runway if fuel optimization becomes dominant. This first trend applies for instance to the A21N, B789 and B763, independent of the scenario. The second trend can be observed for multiple flights, mainly heavy aircraft such as the B744, B77L and B788.

A final trend is observed between runways and waypoints. This is already somewhat discussed in the previous section, but general trends are stated here. In an outbound wave more than 90% of the flights with a destination towards waypoint IDRID or LEKKO are scheduled on R24 or R18L, respectively, independent of the optimization. For an inbound scenario the same trend is still observed for waypoint IDRID. Arriving flights with an origin via waypoint ARTIP are placed mostly (>60%) on R18C independent of the optimization preference. For a mixed peak, flights with waypoint IVLUT are placed almost exclusively on R18L independent of the optimization. In this same scenario flights with waypoint LEKKO are placed on R18L as well as the emphasis is shifted towards fuel.

It is shown that for AAS both fuel and noise can be reduced by changing to a flexible scheduling method. This can have several opportunities in the future. As AAS operates under strict noise regulations, further growth in terms of operations is not allowed in the coming future. Local government and airport management have agreements on the number of operations based on these noise limits and changing to a flexible method could open the conversation for an increase in operations. The flexible scheduling method also has advantages for airlines. Fuel has an important role in the airline cost structure and a reduction can lead to an economic advantage. The third party which benefits from this method are residents in the area. Not only can the flexible scheduling lead to less noise violations, the fact that less fuel is used has a positive effect on the emissions in the vicinity of the airport. Fuel savings have a direct effect on the exhaust emissions produced by aircraft.

For airports operating under less strict noise regulations the flexible scheduling method also provides opportunities. By optimizing more in favor of fuel reduction possibilities could be explored in different operating profiles. Another use could be for airports which operate very close to or over their runway capacity. For different objectives it could be explored which aircraft to delay in favor of others to maximize the runway capacity.

VI.Conclusions

In this paper an improvement is described for the flexible runway scheduling model to fill an existing gap in the current state of the art. Based on the original model constructed by Delsen [5] and the improvements made by Van Der Meijden [26] the new model is extended with the incorporation of accurate separation strategies for complex runway systems as described by Van Der Klugt [25].

The model is adjusted to a scheduling model instead of an allocation model. By changing the decision variables to no longer incorporate the delay but to assign a continuous variable the model assigns continuous delays to the scheduled flights resulting in more accurate operating times and a more compact flight schedule.
It also ensures that an optimization cannot be infeasible as delays are not limited to a maximum. With a new separation constraint is the user able to accurately model complex runway dependencies between runways. With the option to adhere to the First-Come, First-Serve principle the model remains close to the current operating strategies.

The model is tested for a set of operations at Amsterdam Airport Schiphol as this airport is highly congested, is subject to noise regulations and has a complex runway system. It is found that reductions in both objectives are possible. By creating a Pareto front for different scenarios, a combination of weights can be selected by the user. For the selected outbound peak fuel savings are possible of 3.5% and for the inbound peak this can be up to 7%. For noise disturbance it is found that reductions are possible, but that the location of some households can never be mitigated by the model. It is further shown that it can be beneficial to assign more delay in favor of fuel reduction. Key trends are discovered and analyzed which can be implemented in current day operations without many disruptions. These trends relate to the allocation of weight classes on certain runways and combinations between runways and waypoints, which are independent of the optimization emphasis.

The new model should be validated with ATM regulations and the influence of an increased workload for ATC. The new model could be improved by incorporating a taxi scheduling model to explore constraints that arise from flexible runway scheduling. Furthermore, to improve performance research could be directed to solving methods.

With the proposed model, research can be performed to explore the effects of changing the operating strategy to incorporate both fuel burn and noise disturbance and is applicable to any airport configuration.

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