Ninth USA/Europe Air Traffic Management Research and Development Seminar (ATM2011)

Probabilistic 2-Day Forecast of Runway Use

Efficient and safe runway allocation based on weather forecast

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Abstract – In this paper, we present a method to predict runway use at airports for the period of one hour to two days in the future. Based on actual, nowcast, and forecast meteo data, probabilistic runway use can be an aid to air traffic controllers in choosing runway combinations for a period of time as long as possible.

A stable runway system is necessary; first as runway changes are costly operations, moreover, ATC developments in Collaborative Decision Making (CDM) and Continuous Descent Operations (CDO) require an efficient traffic flow and predictable runway allocation for aircraft in order to create lasting plans.

The proposed system has been evaluated at Amsterdam Airport Schiphol, with its complex noise preferential runway system, and unstable weather conditions, where we demonstrate a quality of 60 to 70% in predicting runway use on a meteo and traffic sample for the year 2009. The work has been performed by the National Aerospace Laboratory NLR in cooperation with the Royal Netherlands Meteorological Institute (KNMI).

The system we propose will assist air traffic controllers to anticipate upcoming weather changes and will enable more lasting runway use. Other benefits from our system are that airlines will be given the opportunity to look further ahead, based on the runways that will be in use for the following 3 to 10 hours, to improve operational planning. Inhabitants of the local communities around the airport will get insight into the traffic that will fly over their houses. Being informed is the first step in understanding and will reduce the number of noise complaints.

Keywords: ***runway allocation, weather forecast, planning systems, airport noise, noise preferential runway system, air traffic control, decision support***

I. INTRODUCTION

The tower and approach supervisor air traffic controllers together are responsible for selecting runways. In close co-operation with Air Traffic Control The Netherlands (LVNL), the National Aerospace Laboratory NLR has developed RAAS, a decision support system for allocating runways to inbound and outbound traffic at Amsterdam Airport Schiphol. The system became operational at Approach and Tower ATC in 1998 [1] and has been in operation at Basel Euro Airport since 2008 [2].

A stable runway system is necessary. Runway changes are costly operations, moreover ATC developments in Continuous Descent Operations (CDO) and Collaborative Decision Making (CDM) require an efficient traffic flow and predictable runway allocation. An aircraft on route to an airport will be able to better plan its landing time from knowledge on which runway it will land. Based on the runway that will be used, the aircraft may take up to ten minutes more, an unacceptable difference in planning of CDOs. As the lead time of CDO plans becomes longer (up to 90 minutes) it will be more important to anticipate the runway use of the airport. Also taxi times may differ significantly from one runway to another, which has a serious impact on the planning systems in airport CDM systems.

Air traffic control bases the decision for using runways on traffic demand (one or more runways necessary), meteorological conditions (wind direction, wind speed, gust, and visibility), and the availability of runways and ILS systems. An evenly important factor is the agreement with politics (legislation) and local communities on noise limits.

From these factors, meteo is the most uncertain parameter as it changes continuously over time; large changes may occur in the weather in brief time periods. The air traffic controller will therefore not only look at current weather conditions, but will also take into account the weather forecast for the next hours in his decision on which runways to use.

We have investigated a method through which ATC supervisors can anticipate upcoming weather changes up to 30 hours ahead, enabling them to choose more lasting runway use. As meteo forecasts are probabilistic by nature, possible runway combinations will be given in terms of probabilities as well.

The method has been evaluated by comparing the predicted runway use with actual runway use. This was done for the year 2009, based on historical data. Results are promising: 60% to 70% of the runway use can be predicted well, where the remainder of the cases must be explained by other factors (e.g. non-availability of runways, rain showers, altitude winds). The exact score differs per situation. During the night period, predictions have a higher quality than those for the day time period.

Other possible users for the proposed system are airlines who can anticipate runway use and thus make better predictions for aircraft arrival times. Furthermore airport surrounding communities will benefit as they can be informed about predicted aircraft noise (information is the first step in understanding). As seen before, CDOs and CDM will improve predictability of their operations if the runway information is known on forehand.

This paper is organized as follows. Chapter 2 describes the factors that play a role in runway allocation. In chapter 3, the most important factor, the meteorological information, is analyzed and the probabilistic nature of the information discussed. Chapters 4 and 5 form the theoretical core of the paper and describe the use of probabilistic meteo information to determine runway allocation. Chapter 6 gives the results of an evaluation of runway use at Amsterdam Airport Schiphol over a one year period. Finally, chapters 7, 8, and 9 give an outlook on related work and future possibilities with our proposed method.

II. DECISION FACTORS ON A RUNWAY SELECTION

Air traffic controllers make a choice for use of a runway based on different factors [2][8]. The wind and visibility are the most important factors as these are concerned with safety of operations. Other factors are requested capacity, runway and ILS availability, and social factors such as noise restrictions, originating from the environment and politics. As we have evaluated our system at Amsterdam Airport Schiphol, the situation at this airport will be used for illustration.

Runways combinations are sets of one or more runways. Depending on their relative configuration, different runway combinations have a different capacity. When operating more than one runway, controllers prefer the use of independent runways as this gives a high capacity and does not require special measures for separating traffic. Runways can be used in mixed mode or segregated mode. Mixed mode gives a higher capacity, but also dependencies. Amsterdam Airport Schiphol operates its runway system in segregated mode as much as possible. For indicating runway combinations, in the examples used below, we will use standard runway numbers, where first arrival runway numbers will be given and then departure runway numbers. Arrivals and departures will be delimited by a slash. For example 06 36R/36L means that three runways are in use: runways 06 and 36R are for arrivals and runway 36L for departures. When two departure runways are in use, this will be indicated as for example 06/36L 36C.

A. Meteo

Most important meteo parameters for deciding which runways to use are wind (direction and speed) and visibility. Wind has two elements: direction and velocity, which are used for determining the crosswind and tailwind components for each runway. A maximum cross- and tailwind will be applied and when exceeded, the runway will not be used in any of the possible combinations. Usually, in good conditions, a cross wind limit of 20 knots and a tail wind limit of 7 knots are allowed (including gusts). Furthermore, if both the crosswind and tailwind are at their limit, the runway will not be used.

Depending on the surface condition of the runway, which can be either dry or wet, the cross- and tail wind limits differ, i.e. in wet weather conditions tailwind is not allowed and the cross wind limit will be reduced. More accuracy can be achieved by actually measuring the runway friction coefficient.

Visibility conditions are important decision parameters in allocation of landing and take-off runways. Visibility consists of two parameters: horizontal visibility and cloud base.

At the moment that visibility or cloud base is at or below the level of LVC (Low Visibility Conditions), the system will indicate this and supervisor controllers will use local rules for runway assignment.

Visibility conditions are also related to ILS. Below certain visibility values landing runways can only be used if they are equipped with ILS.

B. Demand

Depending on traffic demand, one or more runways can be used at any time. Traffic demand can distinguish arrival or departure peaks, off-peak, or night period. Typically, at Schiphol, the segregated runway use policy leads to using two arrival runways and one departure runway during an arrival peak and vice versa during a departure peak. During off-peak and in the night one arrival and one departure runway are used.

Sometimes four runways are used during transitions between peaks, be it that this use is limited due to government regulations.

C. Runway and ILS availability

Runways may be unavailable for short periods (runway check, friction test, snow sweep, etc.) or for a longer time, e.g. for maintenance.

Status of the ILS is important for advising a runway to be used for arrival. The ILS status consists of a category, glide path indicator, and localizer.

Depending on ILS category, a runway can be used for landing within restricted visibility conditions. Per landing runway, the ILS category can vary, so that the runways can be used under different visibility conditions.

D. Social factors

To be able to meet noise restrictions, airports can bring a noise preferential runway system into use. When more than one runway combination satisfies all weather criteria, the one that is most preferred with respect to noise load management will be used. This preference is laid down in a predetermined ordered set of runway combinations: the preference list [3].

Preference lists are used at several airports with a more complex layout of runways. Amsterdam Airport Schiphol has evolved into a complex airport with runways in different directions that would have an uneven impact on communities in its vicinity if not for the use of a preferential runway system, see Figure 1. Airports with similar complex layouts, such as Logan International Airport in Boston and John F. Kennedy International Airport in New York, also make use of preference

lists to control noise load in its surroundings. At the US airports, noise load balancing is carried out on a voluntary basis. The Netherlands is unique in the fact that noise restrictions are enforced by law, making noise load the main steering parameter [4].

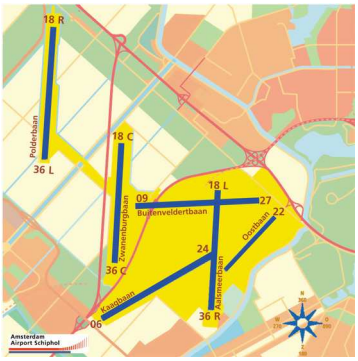

Figure 1. Schiphol Runway Lay Out

III. Probabilistic Meteo Forecast

More attention needs to be paid to the meteo forecast. Weather forecasts are usually given in terms of values with uncertainty figures or standard deviations. Relevant parameters for the runway allocation problem are wind direction, wind speed, gust, visibility, and cloud base. For our research, we will assume that the values are given with their standard deviation, a method commonly used by meteorological institutes. Furthermore, we will assume a normal distribution of the uncertainty, which is for most meteo forecasts a valid assumption.

Short term weather forecasts provide a weather forecast every hour for the next six hours. Long term forecasts provide an update every three hours for the next two days. When deemed necessary by the meteorologist, an intermediate update of the forecast can be provided at any time. Uncertainty will be higher with an increased look ahead time.

Weather and weather forecast are available through several services. All large airports have a dedicated meteorological service and the necessary equipment, which provide accurate local information on the local weather conditions. Visibility values are provided for the airport; when necessary Runway Visual Range (RVR) is given per runway or per part of the runways. In general, meteo service providers and equipment provide information on wind and visibility; necessary information for deciding runway use.

Wind information contains:

- Wind direction in degrees
- Wind speed in knots
- Gusts in knots
- Standard deviation on wind direction
- Standard deviation on wind speed

Visibility information is given as chances to the following parameters:

- Chance of visibility per category, given in horizontal visibility, Runway Visual Range (RVR), and cloudbase values, given in percentage

An example of meteo forecast information is given below, from the weather forecast of Amsterdam Airport Schiphol as provided by the Royal Netherlands Meteorological Institute KNMI. Significant events that may have their influence on runway allocation are for our purpose marked yellow, orange, or red (depending on severity), see Figure 2.

Time (hour)	20	21	22	23	00	01	02	03	06
Visibility < 5 km and/or ceiling < 1000 ft (%)	10	10	10	10	10	10	10	40	90
RVR < 1500 m and/or ceiling < 300 ft (%)	0	0	0	0	0	0	5	10	20
RVR < 550 m and/or ceiling< 200 ft (%)	0	0	0	0	0	0	0	5	10
RVR < 350 m (%)	0	0	0	0	0	0	0	0	0
Wind direction (deg)	350	340	330	330	330	330	340	340	350
Wind speed (kt)	8	7	6	5	5	5	5	6	7
Gusts (kt)	12	12	11						
Standard deviation wind direction (deg)	20	15	25	30	40	30	30	30	30
Standard deviation wind speed (kt)	2	2	2	2	2	2	2	2	3

Figure 2. Example Meteo Forecast with Gust and Standard Deviation

Notice that no gust is given as of 23:00. This indicates that gust will be below 5 knots (compared to the wind speed), hence not significant.

IV. Determining a Runway Use Prediction

Weather forecasts are, by nature, uncertain. As seen above, the uncertainty is given in terms of variation or standard deviation over the predictions of wind direction, wind speed, and visibility conditions. This uncertainty will be reflected in the expectation of runway use. We can see this in the following example.

An airport with two crossing runways, one north-south and one east-west will have difficulty deciding which runway to use with a southwestern wind, because of cross wind limits. A forecast of south-southwestern wind will give preference to the north-south runway; however, because of the uncertainty in the

prediction of wind direction, a small chance exists that eventually the wind will have a stronger western component than expected, so that the east-west runway will need to be used for operations.

The probabilistic meteo inputs need to be translated to a deterministic output, since the list of runway combinations has a limited number of possibilities. In our study, we will present the output of the forecast runway allocation system as possible runway configurations, together with their probability for use.

A. *Method*

We regard the input of the weather forecast in two probabilistic directions: wind direction and wind speed. This leads to a two dimensional array of possible inputs to our system, each associated with a probability value, see Figure 3.

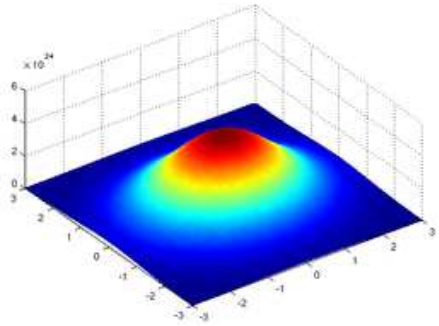

Figure 3. Two Dimensional Gaussian Distribution

This landscape represents the variation in wind direction and wind speed, where the value represents the probability. To cover 99.6% of the surface, we need to consider three times standard deviation.

In our method, we represent the wind direction and speed by a limited number of values, with a step size of 5 degrees for the wind direction and a step size of 1 knot for the wind speed. This leads to a grid of wind vectors (combination of direction and speed). For each point on the grid the best runway combination will be determined. In Figure 4. different combinations are found. For example, the white area represents all runway combinations 06/36L, and the green area represents all combinations 18R/24.

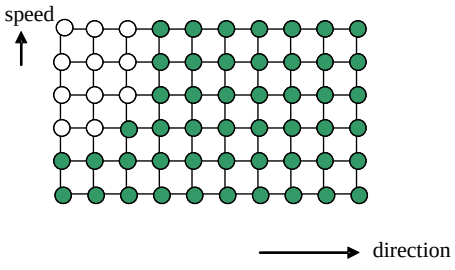

Figure 4. Grid with Runway Combinations

The probability for each combination can now be determined by the size of the weighted surface of the Gaussian function. This is a two dimensional problem.

Suppose we have one change of runway combination when varying smoothly along the set of n wind vectors $V_{t(1)},...,V_{t(n)}$, each provided with a specific probability value $P_{t(1)},...,$resp. $P_{t(n)}$, and the change takes place when passing vector k ($1<k<n$). Then the probability of each combination can be determined by integrating the Gauss distribution function between standard deviation bound and $t(k)$.

Finally, the result for each combination is multiplied with the probability for the visibility condition. This gives the probability for each runway combination. So now the probabilistic meteo forecast has been translated into a list of runway combinations, each with its own probability. The grid from the figure gives for example the following distribution:

Runway combination	probability
06/36L	13%
18R/24	87%

We used a modified version of the Runway Allocation Advise System (RAAS) to calculate the different runway combinations in the grid. RAAS is in use at Schiphol Airport and is a decision support tool for the tower and approach supervisors to assess runway use given current meteo conditions [1][2]. A mean grid has a size of around 150 nodes, so that we must invoke RAAS around 150 times. Running time for processing one grid is in between one and two minutes.

B. *Runway combination selection*

The next step is that we need to assess the list of runway combinations that is generated. For this, we can distinguish two situations. The first is the list as is, which can be interpreted as the possibilities that either one of the mentioned runway combinations will be used. In the example above, we can thus narrow the list of possibilities down to two possible combinations. Chance is 87% that for the given time frame runway combination 18R/24 will be used. We can also suggest the combination 06/36L for 13%.

The second situation is that at any certain moment, the air traffic controller will have to make a choice concerning the runways that will be used. Should the aforementioned situation occur at the moment the controller needs to choose, then he will almost definitively select the northern runway use, i.e. 18R/24. In this case, we can ‘translate’ the given probabilities of 13% and 87% to a near 100% certainty that the northern runway use will be selected.

V. EVALUATION METHOD

In order to validate our method and to investigate the situation where a choice needs to be made, we compared the predicted runway use with actual runway use.

When comparing predicted runway use with actual runway use, an algorithm to select the “most probable” runway combination needs to be determined. For this, we use for every

runway combination its weight (expected probability), *w*. The distance between two predicted runway combinations with weight w_1, resp. w_2, is defined as $|w_1-w_2|$. The actually used runway combination will get weight *1*, where *1-w* is now the distance between the chosen runway combination and the predicted runway combination. This distance is an indication for the quality *q* of the prediction.

A. Discussion

The example given in the previous section gives a reasonably clear situation for selecting the combination 18R/24. If we now notice that the actual runway combination that was used during the given period of the prediction is the same, we have a hit. However, in many cases, the situation is not that clear. Below, we give a few examples where it is more difficult to determine what the actual runway combination will be.

First, the situation in the given picture shows a distinct white and a distinct green area but in practice, the areas show overlap. We determine the probability of use for each runway combination within safety and operational restrictions. This will lead to a situation as given in the example below:

Runway combination	probability
06/36L	75%
18R/24	85%

We can observe the most preferred combination (because of noise considerations) on top of the list has a slightly lower probability of use than a less preferred combination. The controller can choose the highest combination in the list as this will be noise preferred, but this also has the highest possibility of exceeding wind limits in the course of the period, so that he runs the risk of having to change runways during his shift. If he chooses the second combination in the list, he will have to provide his motives for the choice of a less noise preferred runway combination.

This situation will be easier to judge when the first and second combination are both given a very high probability, let's say 97% for the first and 99% for the second. In this case, the controller will certainly choose the first combination as the risk of exceeding wind limits is very limited. In practice, we have noticed that controllers tend to choose the highest possible runway combination when the possibility figure is above 80%.

Another situation occurs when the possibilities to use runway combinations all are below this 80% threshold. An example is given below:

Runway combination	probability
06/36L	55%
18R/24	5%
18R/18L	7%
36R/36L	52%
18R/09	1%
06/09	69%

The controller now can choose for 06/09 with the highest probability, but this is a combination that excludes the preferred north-south runways of Schiphol. Instead of selecting the runway combination with the highest probability (06/09), in this case, we have observed controllers tend to use a combination that includes one of Schiphol's north-south runways. In both cases, chance of having to change runways during a given period is quite high, so in this situation it will be better to use the noise preferred combination for as long as possible. According to our analysis, controllers tend to use the first and second preferred combinations in the list more often than the others.

B. Algorithm for Selection from the List of Possibilities

We need to find an algorithm to determine the "best fit" runway combination from the list of possibilities, given the above mentioned considerations. We examined several algorithms for this.

Algorithm 1. In this algorithm, we assume a list of possible preferred runway combinations as explained in the previous section. To select the runway combination to use, we first select the most preferential runway combination from the list and determining its probability score. The remainder of the list of combinations will then be evaluated compared to the previous ones.

The choice for a runway combination is now the first one which scores above a threshold, e.g. 80% or if there is none, the combination with the highest probability will be selected.

```
LOOP (all combinations)
WHILE NOT found
    IF combination_i (score) > threshold
      THEN FOUND (combination_i)
    ELSE next-combination

IF NOT FOUND THEN
    LOOP (all combinations)
    IF combination_x-1 (score) < combination_x (score)
      THEN FOUND (combination_x)
```

Algorithm 2. In this algorithm, again we determine for each runway combination its probability, independent of its ranking on the noise preferential list. This will lead to a probability value for each runway combination.

However, the choice for a runway combination is now more difficult. We will select the runway combination that is above a certain threshold (e.g. 80%), but only if there is no combination that is higher in the list which only differs a limited percentage (e.g. 20%). For example:

Runway combination	probability
06/36L	65%
18R/24	70%

The choice will be 06/36L as this indeed has the lowest probability, but it differs less then the 20% threshold from the

highest probability, so that the controller will probably choose the noise preferential combination.

LOOP (all combinations)
IF combination$_{x-1}$ (score) < combination$_x$ (score)
THEN FOUND (combination$_x$)

LOOP (all-higher-combinations)
WHILE NOT FOUND
IF combination$_x$ (score) – combination$_i$ (score)
< threshold
THEN FOUND (combination$_i$)
ELSE next-combination

Algorithm 3. As in algorithm 2, but with a different selection criterion. We have observed (as indicated above) that there is a tendency to use the first or second (depending on wind direction) noise preferential combination, so we first decide whether one of these combinations can be used and only if not, we investigate the possibilities for the others.

IF combination$_1$ > threshold
THEN FOUND (combination$_1$)
ELSE IF combination$_2$ > threshold
THEN FOUND (combination$_2$)
ELSE LOOP (combination-3-to-final)
etc…

VI. Results of the Evaluation

The evaluation has been made for the year 2009 on the predictions and on historical runway use. The evaluation has been carried out for different periods: the arrival peak, departure peak, off peak, and the night period.

Furthermore, the evaluation has been carried out for several time horizons of predictions.

The aim of the evaluation is to validate the algorithms as described in section V. The evaluation has been carried out by comparison of provided runway configuration predictions of a specific period with actual runway use during that period. Deviations are analyzed to gain insight into the way a controller performs runway allocation. The results are fed back to improve the algorithm.

A. *Steps*

Step 1 is the input processing from the file that contains meteorological predictions for a large number of periods. There will be overlap between different prediction periods. In this step, one period is selected and processed.

Step 2 is the invocation of RAAS for each meteo prediction, which covers a period of 1-6 (short term) or 6-30 hours (long term) ahead. For each hour possible runway combinations are determined and probabilities are calculated accordingly. This is done for the different periods: night, off-peak, arrival or departure peak. In Figure 5. , the blue area indicates the night period, yellow is an off-peak, green an arrival peak, and red the departure peak.

t=7 : 03:00 - 06:00	06	-	36L	-	22.92%
	18R	-	24	-	75.72%
	18R	-	18C	-	0.05%
	27	-	24	-	0.17%
	36C	-	36L	-	0.61%
t=7 : 03:00 - 06:00	06	-	36L	-	22.92%
	18R	-	24	-	75.72%
	18R	-	18L	-	0.05%
	27	-	24	-	0.17%
	36R	-	36L	-	0.61%
t=7 : 03:00 - 06:00	06	36R	36L	-	22.92%
	18R	18C	24	-	75.72%
	18R	18C	18L	-	0.05%
	27	18R	24	-	0.11%
	27	-	24	-	0.06%
	36R	36C	36L	-	0.61%
t=8 : 06:00 - 09:00	06	36R	36L	-	11.93%
	18R	18C	24	-	85.08%
	18R	18C	18L	-	0.03%
	27	18R	24	-	0.66%
	27	-	24	-	0.30%
	36R	36C	36L	-	1.44%
t=8 : 06:00 - 09:00	06	-	36L	36C	11.93%
	18R	-	24	18L	85.08%
	18R	-	18L	18C	0.03%
	27	-	24	18L	0.66%
	27	-	24	27	0.30%
	36R	-	36L	36C	1.44%

Figure 5. Snapshot of all possible Runway Combinations with Chance > 0

Step 3 is the determination of the quality *q* of the prediction. The result of this process will determine the success of the project.

Step 4 concerns the analysis of "unsuccessful" predictions. This has to be done manually, where trends can be signaled for implementation in updates of the algorithm.

Figure 6. shows the analysis for one day, June 26th. We can observe that 83% of the time, the runway allocation has been predicted correctly. In 10% of the time, the second highest value from the prediction was used, and in 7% of the cases, some runway combination was used that was not predicted as first or second.

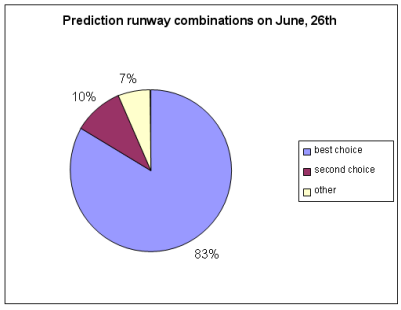

Figure 6. First, Second, and Other Choices

B. *Results*

We evaluated algorithm 1 with one year of traffic (2009) and different values for the threshold. Total score percentages for algorithm 1 sum up as given in Table 1 per peak period.

Table 1. Results of Algorithm 1

Peak	**>80%**	**>70%**	**>60%**	**>50%**
Landing	50%	52%	52%	50%
Night	68%	67%	65%	64%
Off-Peak	58%	59%	58%	57%
Departure	54%	54%	54%	53%
Total	59%	60%	58%	57%

In the rows, the different values for the periods are given: the night and off-peak periods are best predicted.

The results are rather disappointing. First, it can also be observed that the figures in the different columns do not differ significantly from each other. Apparently, the air traffic controller chooses the combination with the highest probability in around 59% of the cases, independent of the quality (or score) of the combination. This indicates that the algorithm is too simple and needs extension to refine the choice further.

Algorithm 2 improves the selection of a runway combination by making the choice dependent on the scores of other combinations. Algorithm 2 can be applied with different parameters for

- threshold 1 = minimum difference between highest score and the alternative, and
- threshold 2 = minimum score necessary to be selected,

given as threshold1/threshold2 in Table 2.

Table 2. Results of Algorithm 2

Peak	10/50	20/50	30/50	40/50	20/60	20/70	30/70
Landing	49%	52%	53%	52%	52%	52%	53%
Night	68%	69%	67%	64%	69%	68%	67%
Off-Peak	58%	60%	60%	58%	60%	60%	60%
Departure	54%	56%	55%	54%	56%	55%	54%
Total	59%	61%	60%	58%	61%	60%	60%

The table shows the hit-score for several values of both thresholds. Here, it can be observed that the additional threshold that was introduced actually makes a difference, see for example the increased score in columns 1 and 2. We can read here that the overall quality of the algorithm increases when we search for combinations, higher in the preference list, but with a lower probability, provided that the difference between the two probabilities is no more than 20% (20% difference in column 2 as compared to the 10% of column 1).

From the table we can see that with a threshold 1 of 20% is still realistic to expect that the runway combination that is higher in the list will be selected.

A further refinement was made in algorithm 3, where we first assume the top two combinations to be selected and only below a threshold, we will decide on the others. The result of this is given in Table 3.

Table 3. Results of Algorithm 3

Threshold 90%	Total nr.	%
Landing	4637	66
Night	9958	80
Off-Peak	7986	72
Departure	3658	69
Threshold 80%	Total nr.	%
Landing	4976	70
Night	10598	86
Off-Peak	8638	77
Departure	3909	73

It can be observed that the accuracy increases to in between 70% and 85% with a threshold of 80%. Again, the off-peak and night have the highest score q.

The next step in evaluating this algorithm is to define the choice between the first and second runway combination.

C. *Factors that influence the results*

When using a historical dataset, it is impossible to reconstruct a situation exactly as it was at that time. Many factors, which are not recorded, have their influence on the decision of the air traffic controller.

The most important factor is runway closures for scheduled and unscheduled maintenance. Maintenance takes a few hours to several days. Scheduled maintenance is, as the word implies, known beforehand, but an external factor can change the plan. Bad weather or unexpected events at some other runway can seriously disturb maintenance plans. Brief maintenance can not be foreseen.

Also the weather prediction may differ from the actual observed weather or local weather phenomena occur. Local showers, snow, altitude winds, and fog have their influence on the decision whether to use a runway or not. Usually, these effects are temporary. Again, not everything can be foreseen, like local showers or decisions on which runway to clear snow from first.

Several other factors play a role. These can be accidents and incidents on runways and taxiways, maintenance on taxiways, runway inspections, bird scare, etc.

Finally, air traffic controllers are reluctant to change runways, especially during peak periods. They will use a runway as long as this is safe. When traffic demand is low, they will choose to operate two instead of three runways during a peak period.

VII. RELATED WORK

Many airports in the world operate a noise preferential runway system, where the operational runway use is determined by agreements with surrounding communities for as far as safety permits. Almost all airports have agreements on preferential runway use, although not all will call it so. Details of preferential runway systems can be found at airport AIP entries and at the web site of Boeing [5].

A system for runway allocation was set up in [6]. Here, for enabling fast time calculations on noise at Sydney airport, a system called TNIP Runway Allocator was developed to build data sets for use in aircraft noise prediction for a longer period of time, which lead to expected airport noise contours. This model is not based on probabilistic meteo input. The same system has been evaluated for Brisbane Airport.

A preferential runway advisory system (PRAS) and enhanced PRAS (ENPRAS) [7] have been developed for Boston Logan International Airport. The system assists air traffic controllers with recommended runway configurations which satisfy weather and wind requirements, recognize

runway maintenance needs, and accommodate anticipated demand levels. The operational system emerges from research performed by MIT.

In [8], a study for Helsinki Vantaa Airport shows the impact of weather on runway allocation. The study has a focus on improving weather prediction and providing information to the control tower on anticipated weather changes that might influence runway use. In the study an analysis was made of the effect of runway changes in terms of delay.

VIII. OTHER USE OF THE SYSTEM

The system described in this paper is meant as an information system to the air traffic controller, who has a means to better decide on runway allocation to avoid unnecessary runway changes.

The system can be used by airlines to improve their fleet management process and by surrounding communities to get insight in current and expected noise. Just as well, the system can be integrated in the Collaborative Decision Making (CDM) programs and in an arrival management function, to improve overall planning.

A. Airlines

Airlines will benefit from the use of a runway prediction system as they have to schedule operations at the airport. Airlines will benefit from predicted runway use for several hours ahead.

B. Communities

Inhabitants from communities around airports benefit from a runway prediction system in that they will get insight into noise over their houses. Insight is always the first step in understanding why aircraft have to fly certain routes. The user interface for an application must be provided through a web interface, so that everyone can have access to the information.

C. Embedding in other systems

An arrival management function will benefit from prediction of runway allocation. Current work on Continuous Descent Operations (CDO) assume that aircraft will initiate their approach in a neighbouring sector to the airport's sector. When making an arrival schedule this far ahead, it is important to know what runways will be in operation at what time.

IX. CONCLUSIONS

We have presented a system for determining runway allocations based on weather forecast information. The system uses probabilistic meteo forecasts to conclude the most probable runway combination that will be used for the following 1 to 30 hours. The system has been evaluated on one year of historical data for Schiphol airport.

We have observed, and did not expect either, that a 100% score to predict runway use is not feasible; depending on the method chosen, a hit-score of in between 60% and 70% is shown. However, none of the methods outperforms fully all other methods. One option is to present the end user with different results from different methods and let him make a choice himself, based on his expert judgement.

The system is mostly interesting for airports with a noise preferential runway system, where runway allocation is performed based on meteo conditions for safety and on agreements with the local communities on noise levels.

The results are promising and suggest that a system for runway prediction can be developed further. A runway allocation system will be a necessity for new developments in CDO and CDM, as we see that the time horizon of these planning systems gets larger. Also, it will enable further optimisation of airport operations of ATC and for airlines. The system can also be used for communication with local communities.

Further work needs to be directed towards achieving a still higher percentage of hits. This can be done through fine-tuning our method and incorporation of more factors that determine runway use, like altitude winds and local weather phenomena such as rain showers and snow.

ACKNOWLEDGMENT

The work described in this paper has been carried out in close cooperation with the Royal Netherlands Meteorological Institute KNMI.

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