Henk Hesselink, Joyce Nibourg, Ludovic d'Estampes, Pascal Lezaud

Airport Capacity Forecast

Short-term Forecasting of Runway Capacity

H.H. Hesselink and J.M. Nibourg
Air Transport Division
National Aerospace Laboratory (NLR)
Amsterdam, Netherlands
Email: {henk.hesselink, joyce.nibourg}@nlr.nl

L. d'Estampes and P. Lezaud
MAIAA Laboratory
Ecole Nationale de l'Aviation Civile (ENAC)
Toulouse, France
Email: {estampes, lezaud}@recherche.enac.fr

Abstract— **Airports expect major benefits from increasing predictability of the operation. This paper will investigate the use of forecast information to determine forecast airport capacity, which will allow airport stakeholders to optimize the use of their resources. The focus will be on *forecasting runway capacity*, at most airports the major factor for the overall airport capacity. The possibility to model forecast runway capacity, based on probabilistic inputs, will be investigated with a lead time up to two days. Inputs from meteorological services (wind speed, wind direction and visibility) are the major factors for determining which runways to use. Other inputs are runway availability, operational procedures and demand. The runway configuration of Amsterdam Airport Schiphol, with a complex layout of six runways, has been chosen for the evaluation. A large dataset, covering runway use of 2012 and half 2013, was used to evaluate the model, which forecasts runway configurations first and then calculates capacity forecasts. The paper will show that a high quality runway capacity forecast is feasible.**

Keywords-component; airport; capacity; foreasting; runway management

I. INTRODUCTION

For preparing operations at airports, plans are made by each stakeholder to ensure that operations are running smoothly. These plans concern the allocation of personnel and the use of infrastructure and other resources to cater for expected demand. In case of disrupted operations, caused by e.g. bad weather or strikes, it is important to have precise information on the available capacity so that actions can be taken in advance to ensure that aircraft and passengers experience as little as possible from the disruption and that the infrastructure and resources that are still available, will be used in an optimum way.

This paper will focus on forecasting runway availability, hence forecasting runway capacity, through an automated method, based on the weather forecast and other relevant parameters. The paper will discuss the runway and capacity forecasting method and present results from an implementation of the method.

The capacity of the runway configuration depends on the lay out and visibility conditions as separation increases with lower visibility. The first step in determining runway capacity is the determination of the runway configuration that will be used. Tailwind and crosswind constraints limit the use of runways, while the configuration of parallel, dependent and crossing runways also has significant influence on capacity of the complete system. Furthermore, the expected demand of arrival and departure traffic is a factor in deciding to use a specific configuration of runways. The second step is the runway capacity forecasting, as presented in this paper, which has been set up and evaluated taking Amsterdam Airport Schiphol as example. The work presented in this paper builds on earlier research toward runway configuration forecast, as described in [1] and [2].

To evaluate the accuracy of the models, we have used the MAPE (Mean Absolute Percent Error) criterion and examined the distribution of the errors through the use of histograms. The forecasted runway configuration and capacity has been compared with the actual runway use (configuration and capacity) at Schiphol over the period from January 2012 to June 2013.

The research question we are addressing is to find out whether it is possible to use the probabilistic weather forecast to provide a probabilistic forecast of runway capacity, with a certainty that will allow stakeholders to make well informed decisions.

II. RUNWAY CONFIGURATION CHANGE MANAGEMENT

For efficient operations at airports, it is necessary that the runway configuration does not change too often. Runway changes are costly operations; moreover ATC developments in Continuous Descent Operations (CDO), Collaborative Pre-Departure Sequencing (CPDS) and Airport Collaborative Decision Making (A-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 early knowledge on the runway in use at the time of arrival. Depending on the runway that will be used, the aircraft may take up to ten minutes more; an unacceptable uncertainty in terms of planning of CDOs. Just as well, taxi times differ significantly from one runway to another, which has a serious impact on the planning systems in A-CDM.

The work in this paper is based on work carried out in the project *Airport Capacity Forecast (ACF)*, carried out by NLR, ENAC and GESAC.

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 local communities on noise limits. Several airports operate a preferential runway system: 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.

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

A. Runway configuration forecast

To forecast the runway capacity, it is necessary to first make a forecast of the runway configuration that will be used. In [1] and [2], a method for determining an optimum runway configuration has been described. Based on the direction of available runways and the wind direction, all available runways, where cross- and tailwind are not above limits, can be determined, see Figure 2. Next, an overlay with the preferential runway system and information on runway availability determines which runway configuration will be best to use. ATC will eventually take a decision based on this but also considers factors like changing wind over time and whether the calculated runway configuration is well within limits for cross- and tailwind or just at the boundaries of safety.

For *forecasting* runway configurations, another factor plays a role: uncertainty. The most uncertain factor is the weather. We can use the weather forecast to make a forecast of the runway configuration, just as described above, but the uncertainty in the weather will have its reflection in the configuration forecast. Other uncertain factors include the start time of maintenance (depending on e.g. weather) and information on demand (leading to expected time of runway configuration changes).

For the study presented here, we will use the example of the runway system and the mode of operation of Amsterdam Airport Schiphol. The airport operates at most times several runways simultaneously. The airport's lay out is presented in Figure 1. Schiphol's preference is to use runways in segregated mode as the use of separate runways does not require special measures for separating traffic at the runways. 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 indicated: 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.

Figure 1. Schiphol Runway Lay Out

Based on traffic demand, five different peak periods can be distinguished: the arrival peak period with two arrival and one departure runways (2+1), the departure period with one arrival and two departure runways (1+2), the off-peak period (1+1), the night (1+1) and the inter-peak period (2+2). The latter may only be used in limited periods of the day to cater for handling extra demand during the switch from one peak to another and cannot be used for planning purposes. The opposite occurs as well: if during an arrival or departure peak, demand is not too high, ATC may decide to temporarily close one of the arrival or departure runways.

We have developed a model to determine a probabilistic forecast of the runway configuration that will be used. The model uses forecasted wind direction and wind speed with a given variance and forecasted visibility conditions with a given uncertainty in percentages. TABLE I shows the different possible runway configurations in the rows, together with their forecasted scores of use in the columns. The columns indicate the lead time of the forecasts. The scores in the cells indicate per runway configuration the possibility of being able to use within the given variance of the wind and visibility limits. Colours are a value indication: from yellow to indicate a high score to red to indicate a low score. For example, the score of the runway configuration 18R/18L 18C is equal to 77 %, which indicates there is a 77 % possibility to use this runway without having to change runway configuration in the next hour.

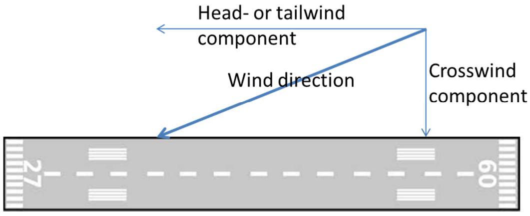

Figure 2. Runway crosswind and tailwind

TABLE I. RUNWAY CONFIGURATION SCORES (FOR DEPARTURE PEAK, ONLY)

OUTBOUND PEAK				15	16	17	18	19	20	21
06	-	36L	36C	0	0	0	0	0	0	0
18R	-	24	18L	52	49	60	**67**	65	**80**	**94**
36R	-	36L	36C	0	0	0	0	0	0	0
18R	-	18L	18C	**77**	**53**	**63**	67	**67**	81	97
06	-	36L	09	0	0	0	0	0	0	0
27	-	36L	24	0	0	0	0	0	0	0
27	-	24	18L	3	21	30	23	38	55	44

TABLE II. PART OF CAPACITY OF CONFIGURATIONS AVAILABLE AT AMSTERDAM AIRPORT SCHIPHOL[1]. AN EMPTY CELL MEANS THAT THE CONFIGURATION IS NOT AVAILABLE UNDER THE SPECIFIED CONDITIONS.

Runway configuration			**Arrival**						**Departure**					
			Good Visibility		***Marginal Visibility***	***Low Visibility Procedures***			***Good Visibility***		***Marginal Visibility***	***Low Visibility Procedures***		
Peak period	***Arrival***	***Departure***	***UDP***	***NUPD***		***Phase A***	***Phase B***	***Phase C/D***	***UDP***	***NUDP***		***Phase A***	***Phase B***	***Phase C/D***
Arrival peak	06+36R	36L	68	65					40	40				
	18R+18C	24	68	65	65	55	45	35	37	30	30	25	25	20
	36R+36C	36L	65	60	65	55	45		40	40	35	25	25	
	18R+18C	18L	68	68	68	55			40	40	35	25		
	...													
Departure peak	06	36L+36C	38	38					70	70				
	18R	24+18L	38	38	38	25			74	74	70	50		
	36R	36L+36C	38	38					70	70				
	18R	18L+18C	38	38					70	70				
	...													

In order to make a forecast of the runway configuration that will most probably be used, a method has been designed, based on the scores in the table, together with the knowledge that some configurations are preferred over others because of noise considerations. The method incorporates non-availability of runways because of planned maintenance and availability of equipment, such as ILS. The method for determining the runway configuration has been described in [1]. In the example in TABLE I, at 15:00, the highest score is 77, and we can predict that runway configuration 18R/18L 18C will be used; while at 21:00, the airport will have changed to 18R/24 18L (a score of 94 is sufficiently high to select this combination, even though a higher score exists). Somewhere in between 15:00 and 21:00, the airport will change configuration.

B. Runway capacity forecast

TABLE II provides the capacity of runway configurations for different peak periods (inbound peak, outbound peak, off peak and night) and for different visibility conditions (Good Visibility, Marginal Visibility, Low Visibility Procedures phases A, B, C/D, and (N)UDP for (Non) Uniform Daylight Period) [7]. The visibility conditions as used by Schiphol are given in TABLE IV.

TABLE IV. VISIBILITY CONDITIONS USED BY SCHIPHOL

Classification	**Visibility (VIS/RVR)**		**Ceiling**
Good	>5 km VIS	and	> 1000 ft
Marginal	1.5 – 5 km VIS	or	300 – 1000 ft
LVP phase A	550 – 1500 m RVR	or	200 – 300 ft
LVP phase B	350 – 550 RVR	or	< 200 ft
LVP phase C	200 – 350 RVR		
LVP phase D	< 200 RVR		

[1] Because of commercial sensitivity of these figures, the ones presented in this table are not the real values, however the order of magnitude is comparable to the actual ones. The actual table has been used in the study.

The method described below applies for all peak periods. We selected January, 2012 to June, 2013 as evaluation period. The weather forecast gives us the percentage for each visibility category (good, marginal, A, B, C/D). TABLE III shows this information for the considered period. As can be seen, the total of the columns of visibility is equal to 100 %.

All figures indicate the *declared capacity*, which is the capacity per hour used to specify the number of slots available for schedule coordination purposes, taking into account airport infrastructure, typical operating conditions, accepted delay and political issues [5][6]. Declared capacity can vary throughout the day accounting for inbound or outbound peak periods, off-peak periods or night time. Actual runway performance will slightly differ from this value, as the traffic realisation depends on the traffic mix: different aircraft types on one runway will require larger inter-aircraft separation, leading to lower performance. Besides, demand can be below capacity, leading to actual performance lower than capacity.

TABLE III. PERCENTAGES OF VISIBILITY FORECASTS

Date	**Hour**	**Visibility**				
		Good	***Marginal***	***LVP A***	***LVP B***	***LVP C/D***
10/01/2012	5:00	70	15	15	0	0
10/01/2012	6:00	65	15	15	5	0
10/01/2012	7:00	65	30	5	0	0
⋮	⋮	⋮	⋮	⋮	⋮	⋮
18/07/2012	22:00	70	30	0	0	0
18/07/2012	23:00	70	30	0	0	0
19/07/2012	0:00	60	40	0	0	0
⋮		⋮	⋮	⋮	⋮	⋮
30/06/2013	11:00	100	0	0	0	0
30/06/2013	12:00	100	0	0	0	0
30/06/2013	13:00	100	0	0	0	0

TABLE V. ARRIVAL AND DEPARTURE CAPACITY

Date	Hour	Arrival							Departure						
		Good Visibility		*Marginal Visibility*	*Low Visibility*			*Total*	*Good Visibility*		*Marginal Visibility*	*Low Visibility*			*Total*
		UDP	*NUDP*		*Phase A*	*Phase B*	*Phase C*		*UDP*	*NUDP*		*Phase A*	*Phase B*	*Phase C*	
10/01/2012	5:00	0	16,8	3,6	3,6	0	0	**24**	0	17,5	3,8	3	0	0	**24,3**
10/01/2012	6:00	0	43,6	10,1	8,4	2,2	0	**64,2**	0	20,8	4,8	3,6	1,3	0	**30,5**
10/01/2012	7:00	0	43,6	20,1	2,8	0	0	**66,5**	0	20,8	9,6	1,2	0	0	**31,6**
⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	**⋮**	⋮	⋮	⋮	⋮	⋮	⋮	**⋮**
18/07/2012	22:00	16,8	0	7,2	0	0	0	**24**	17,5	0	7,5	0	0	0	**25**
18/07/2012	23:00	0	16,8	7,2	0	0	0	**24**	0	17,5	7,5	0	0	0	**25**
19/07/2012	0:00	0	14,4	9,6	0	0	0	**24**	0	15	10	0	0	0	**25**
⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	**⋮**	⋮	⋮	⋮	⋮	⋮	⋮	**⋮**
30/06/2013	11:00	68	0	0	0	0	0	**68**	37	0	0	0	0	0	**37**
30/06/2013	12:00	38	0	0	0	0	0	**38**	74	0	0	0	0	0	**74**
30/06/2013	13:00	68	0	0	0	0	0	**68**	37	0	0	0	0	0	**37**

Using the following equation, we are able to compute the arrival and departure capacity figures for the considered period. A forecast per hour will be used here.

$$C_{rwy}(X,Y) = \mathrm{P(G)} \times C_{\mathrm{G}}(X,Y) + \mathrm{P(M)} \times C_{\mathrm{M}}(X,Y) + \mathrm{P(A)} \times C_{\mathrm{A}}(X,Y) + \mathrm{P(B)} \times C_{\mathrm{B}}(X,Y) + \mathrm{P(C/D)} \times C_{\mathrm{C/D}}(X,Y)$$

where X is the estimated configuration, Y is the estimated peak period and for each couple of (X,Y), C_{G} is the capacity of the runway configuration with good visibility, C_{M} is the capacity of the runway configuration with marginal visibility, C_{A} is the capacity of the runway configuration with low visibility procedures, phase A, C_{B} is the capacity of the runway configuration with low visibility procedures, phase B and $C_{\mathrm{C/D}}$ is the capacity of the runway configuration with low visibility procedures, phase C/D.

TABLE V presents this computation. For each column of visibility (good, marginal,…), we compute a capacity, which is the product of the percentage of visibility (from TABLE III) and the capacity of the runway in this condition of visibility (from TABLE II). The column, named "Total", is the sum of these columns and represents the weighted forecasted capacity for arrivals and for departures. Because of the weighted values (percentage = numbers between 0 and 1), the weighted forecasted capacity is not necessary an integer value. The value the will eventually be presented on the display and used by the decision maker will need further study.

III. EVALUATION

In this section, accuracy of the forecast of the runway configuration and accuracy of the forecast of runway capacity are evaluated using statistical methods.

TABLE VI. FORECASTED AND ACTUAL CONFIGURATION

Date	Hour	Forecasted configuration	Actual configuration
10/01/2012	5:00	18R/24	18R/24
10/01/2012	6:00	18R 18C/24	18R/24
10/01/2012	7:00	18R 18C/24	18R 18C/24
⋮	⋮		
18/07/2012	18:00	27/24 18L	18R/24
18/07/2012	19:00	18R/24 18L	18R/24 18L
18/07/2012	20:00	18R/18L	18R/24
⋮	⋮		
30/06/2013	11:00	18R 18C/24	18R 18C/24
30/06/2013	12:00	18R/24 18L	18R/24
30/06/2013	13:00	18R 18C/24	18R 18C/24

A. *Evaluation of runway configuration forecast*

In [3], the algorithm to forecast the configuration (column "Forecasted configuration" in TABLE VI) is described. The actual configuration is the configuration chosen by the controller (column "Actual configuration" in TABLE VI).

In TABLE VII, the number 1 for "Actual configuration" (or for "Forecasted configuration") represents the most preferred configuration for each peak period. For example, "Configuration 1" is 06 36R/36L for the departure peak, 06/36L 36C for the arrival peak, 06/36L for the off-peak and 06/36L for the night period. The table therefore contains the union of these four possible runway configurations.

TABLE VII shows the differences between the forecasted and the actual configuration in a contingency table, which it displays the frequency distribution of two qualitative variables. In the table, the non-diagonal numbers (every number except the grey-marked numbers) are non-matching forecasts and the "Actual configuration" is the one that is observed in the operation from January 2012 to June 2013. For example, the number 2741 is the number of good forecasts for the first configuration (actual configuration = forecasted configuration = 1); the number 134 indicates the number where the first configuration was forecasted, while the second configuration was actually used (forecasted configuration=1; actual configuration=2).

We can see in the TABLE VII that for the forecasted configuration or for the actual configuration, the first two preference configurations (1 and 2) represent a large majority (7914 for the forecasted and 6941 for the actual). ATC is able to use the first and second preference from the preferential system almost 70% of the time.

TABLE VII. CONTINGENCY TABLE OF FORECASTED/ACTUAL CONFIGURATION

		Actual configuration								
		1	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*...*
Forecasted configuration	*1*	2741	134	149	59	135	64	10	27	
	2	110	3328	34	276	165	43	101	9	
	3	107	6	183	2	10	81	10	25	
	4	10	223	31	293	13	4	19	1	
	5	4	36	0	0	98	2	5	0	
	6	18	3	1	4	4	59	0	0	
	7	1	189	8	1	0	1	205	9	
	8	1	30	2	0	0	25	9	2	
	...									

TABLE VIII. ERRORS OF POOR FORECASTS

Actual configuration	Error
1	1 – 2741 / 2992 = 0.08
2	1 – 3328 / 3949 = 0.16
3	1 – 183 / 408 = 0.55
4	1 – 293 / 635 = 0.54
5	1 – 98 / 425 = 0.77
6	1 – 59 / 279 = 0.79
7	1 – 205 / 359 = 0.43
8	1 – 2 / 73 = 0.97
...	

We can compute for qualitative variables an equivalent to the Mean Square Error (MSE) to monitor the accuracy. For example, we can compute the score = number of good forecasts divide by total number of observations (the number of good forecasts is equal to the sum of figures in the diagonal of the Table VII, the grey cells).

$$\text{Score} = 6909/9120 = 0.758. \tag{1}$$

This score seems acceptable, since it means that three times out of four, the configuration is forecasted correctly.

We can compute the different errors in the forecasts, as illustrated in TABLE VIII and we can observe that the higher preferences have smaller errors. The reason for the smaller error in the 7th runway configuration is an operational one. In the 7th configuration, in some of the periods, a western configuration is specified, which can be forecasted relatively easily with western wind. Higher other configurations are north or south.

B. *Forecasted capacity vs actual capacity*

To evaluate the capacity forecast, we need the actual capacity, which is computed from the observed configuration and the observed visibility condition (good, marginal…). This information is available, as we are monitoring the situation over 2012 and the first half of 2013. From the weather observation and the information from the airport on the actual runway configurations over this period, we can use TABLE IX as an indication of the realised capacity over the one and a half year.

With the values of TABLE IX, we can draw for arrival and departure the histograms of the errors: 'actual capacity' – 'forecasted capacity' (for each hour and each date), see Figure 3. We can make some remarks:

- The peak in the histogram at value 0 indicates that the forecast can be made with high quality.

TABLE IX. PREDICTED AND ACTUAL CAPACITY

		Arrival		Departure	
Date	Hour	Forecasted capacity	Actual capacity	Forecasted capacity	Actual capacity
10/01/2012	5:00	24	24	24,3	25
10/01/2012	6:00	64,2	38	30,5	40
10/01/2012	7:00	66,5	68	31,6	37
⋮	⋮				
18/07/2012	18:00	32	38	71,8	40
18/07/2012	19:00	38	38	73,8	74
18/07/2012	20:00	38	38	38,5	40
⋮	⋮				
30/06/2013	11:00	68	68	37	37
30/06/2013	12:00	38	38	74	40
30/06/2013	13:00	68	68	37	37

- The cumulative distribution function does not appear to be a Gaussian distribution, because of the second, smaller peak at around minus 30. This bimodality, where the forecasted capacity is larger than the actual capacity, could be explained by the choice of the controller to use two runways instead of three, during an arrival or departure peak period.

To examine the accuracy of the forecast, different criteria exist. The Mean Square Error is the most commonly used but it is not well-adapted to our study. In fact, a runway capacity with an error of 5 aircraft compared to the realised capacity of 10 aircraft per hour has more impact than an error of 5 aircraft with a capacity of 70 aircraft per hour. That is why we decide

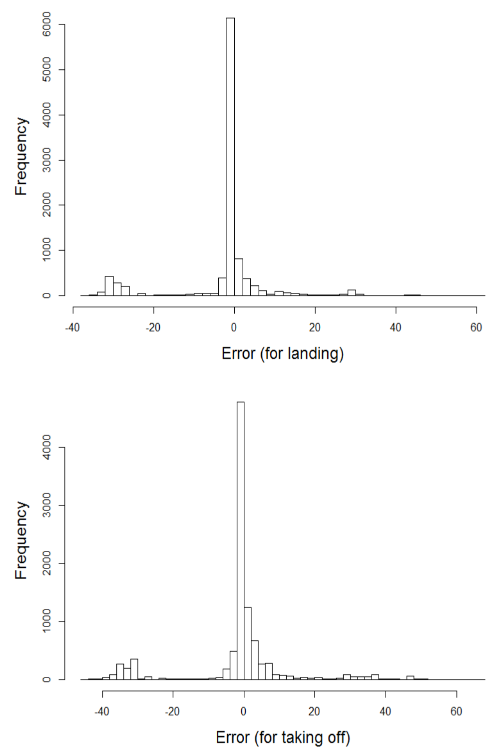

Figure 3. Histograms of errors for arrival capacity (top) and for departure capacity (bottom)

to divide the error by the actual capacity to give more emphasis to the error of 5 out of 10. For this reason, we will compute the Mean Absolute Percent Error (MAPE), which is the mean of these values (|actual-forecasted| / actual).

We have the following values:

MAPE (arrival) = 12.88 %

MAPE (departure) = 15.32 %

C. Discussion

This section will discuss the results of the runway configuration forecast and the capacity forecast.

Score of the forecast for runway configuration is 0.758, while the MAPE for the forecast for runway capacity is 12.88% for the arrival and 15.32% for the departure capacity. These figures are considered sufficiently accurate to use in operation.

Surprisingly, capacity scores are higher than those for the runway configuration, while the capacity forecast is based on the configuration figures. This seems contradictory. The reason is that some different runway configurations provide (almost) the same capacity, so that a small error in the determination of the runway configuration may have no effect on the capacity figure.

Just as well, we can note that an erroneous forecast of the runway configuration does not mean that all runways in the configuration have been forecasted wrongly. Some runway configurations have overlapping runways, e.g. the inbound configuration 18R 18C / 18L uses two landing runways: 18R and 18C and one runway for take-off: 18L. A similar configuration is 18R 18C / 24, with the same arrival configuration but another departure runway; in the situation where one of the configurations has been forecasted, but the other was actually used, we have considered the runway configuration to be forecasted wrongly, even though two of the three runways have been forecasted correctly and all inbound runways have been forecasted correctly. The resulting capacity for both runway configurations shows indeed the same inbound capacity (68 movements per hour) and almost similar outbound capacity (40 for the three parallel runways and 35 when using runway 24, because of the slight dependency between the runways).

This motivates why the runway configuration forecast can be off, while capacity forecast can be correct, after all.

Several reasons for erroneous runway configuration forecasts have been examined:

- Weather forecast accuracy.
- Methodological issue.
- ATC makes another decision.

Weather forecast: From [7], it can be seen that specifically visibility is difficult to forecast and about 10% of visibility forecast does not classify the forecast in the correct category. Through use of our probabilistic approach, the margin in error reduces but still exists. Analysis has shown that the impact of weather forecast is in the magnitude of 5%.

Methodology: The method used can be improved and the analysis given above will help to further understand where changes to the method can be made. It must be noted again here that in many cases the arrival configuration has been forecasted correctly, while the departure is not, in which case the runway configuration has been considered to be forecasted incorrectly. Analysis has shown that some wind directions show better results, specifically a northern or southern wind will demonstrate a highly accurate runway configuration forecast, while a north-eastern or south-western wind performs significantly worse. The night period at Schiphol is more restrictive, leading to very accurate forecasts.

ATC: The air traffic control supervisor eventually will decide on what runway configuration to use. He will consider more aspects than is possible in our forecast, like local phenomena in the weather (rain or thunderstorms) and incidents on runways or taxiways. Just as well, when reconfiguring the airport from northern to southern runway use, sometimes some intermediate configurations are used for a brief period of time. These cannot be forecasted.

Further work towards runway capacity forecast will focus on the elements described above to improve quality of the forecasts.

One element already mentioned to be further studied, is the presentation of the information. Operators will either have to get acquainted to the probabilistic presentation of forecast data or will have to be presented with figures they can apply directly. In the latter case, the figures will have to be rounded off to the nearest integer value that represents one possible runway configuration with a corresponding capacity figure. Obviously, information will get lost but this will better fit to the operation.

The presentation will largely depend on the environment in which the forecasting will be integrated. In a larger operating environment, such as Total Airport Management (TAM), the forecasting element will become part of the cooperation and planning systems. Methods and presentation will have to connect to that of TAM.

In a larger context, the runway capacity forecast may become part of a larger airport capacity forecast system. Although at most airports, the runway system mostly represents the capacity of the airport as a whole as well, other elements may become bottlenecks in specific situations. For example, at some airports, the taxiway system becomes the capacity bottleneck in low visibility operations. Other major factors in airport capacity are de-icing operations and snow removal. At landside, the passenger's security passage is a capacity issue that will benefit from good forecast information. In fact, de-icing and security passage are already under investigation by the consortium.

IV. RELATED WORK

Most work on runway capacity is concerned with more efficient use of existing infrastructure, while enhancing capacity. Examples of studies concern those for Arrival Management, Departure Management, and A-CDM. When *forecasted* runway capacity is studied, this is mostly for airport expansions or for periods in which maintenance is scheduled. Examples of studies concern those with fast time simulation studies. As the scope of these studies is different from the capacity forecast that we present in this project, their relevance to the work described is considered limited.

The “other side” of capacity forecasting is considered by us to be demand forecasting. This type of forecasting takes the current situation as basis and will extend the situation through prediction or simulation towards a moment in the future, either long term (months or years) or short term (minutes to hours). Contrary to capacity forecasting, demand forecasting does not consider resource availability to be the basis. When both are put together, Airport Capacity and Demand Balancing, is considered a powerful mechanism, where future capacity is matched with future demand in an optimum manner. Cooperation on planning systems is one of the topics in Total Airport Management and preparation of planning, e.g. through capacity forecast will be one element in the complete chain of processes [4].

Runway configuration advice is given to controllers amongst others at Amsterdam Airport Schiphol, Basle Euro Airport and Brussels Zaventem airport [2][3], through systems that present the air traffic control supervisor the most appropriate runway configuration to use or show what runways cannot be used, because of exceeding wind limits.

Runway configuration forecasting is performed at Frankfurt airport, where the environment is informed on expected eastern or western runway use for the following days [8].

V. CONCLUSION

We have presented a runway configuration forecasting model, based on meteorological information, and evaluated the model with recorded data over 2012 and 2013. Based on the forecasted runway configuration, a capacity forecast has been made and evaluated as well. Runway capacity is at most airport the main factor in airport capacity.

The runway configuration forecast has been proven to be possible with high accuracy, whereas the capacity forecast can be modelled with even higher accuracy. Although capacity is based on the runway configuration, the fact that different configurations allow the same capacity causes this to have higher accuracy. Just as well, some runway configurations consist of partly the same runways and where the configurations could be forecasted wrongly, the capacity of the runways will yield a reasonably correct figure.

The work described here will be beneficial to airports and airspace users, who will be able to better plan their resources. It will bring automation of airport operations to a higher level and enable further automated planning of the operations, where stakeholders will get a role to oversee the operations at a higher level than is currently the case. A higher predictability of the operations can be expected as the adherence levels to target times will lead to increased predictability for runway planning functions in AMAN, CPDS, A-DCB and A-CDM.

Further work is ongoing to improve quality of the runway configuration forecasting and to apply the methodology of capacity forecasting to other airport planning processes, such as planning for de-icing and in-terminal planning of passenger processes. The human machine interface will need to be designed and integrated in a larger set of related functions such as for A-DCB and A-CDM.

ACKNOWLEDGMENT

This work is co-financed by EUROCONTROL acting on behalf of the SESAR Joint Undertaking (the SJU) and the EUROPEAN UNION as part of Work Package E in the SESAR Programme. Opinions expressed in this work reflect the authors' views only and EUROCONTROL and/or the SJU shall not be considered liable for them or for any use that may be made of the information contained herein.

We would like to thank the people at GESAC for their support to the modelling for Airport Capacity Forecast. We also thank Stéphane Catteau for his help and advice.

REFERENCES

[1] H.H. Hesselink and J.M. Nibourg, *Probabilistic 2-Day Forecast of Runway Use*, Ninth USA/Europe Air Traffic Management Research and Development Seminar (ATM2011), Berlin, 14-17 June 2011, NLR-TP-2011-287

[2] H.H. Hesselink, J.M. Nibourg, and Y.A.J.R. van de Vijver,; *Environment-Aware Runway Allocation Advise System*; ICAS in Anchorage, Alaska, USA; Sep-2008; CEAS in Manchester, UK; Oct-2009; NLR-TP-2008-506

[3] Belgocontrol AIP, eAIS Package, Belgium and G.D. of Luxembourg , Publication date 4 September 2014

[4] Günter, Y. et.al; *Total Airport Management – Operational Concept And Logical Architecture*; Jun 2006

[5] IATA. (2004). *Airport Development Reference Manual* (9th ed.). (IATA, Ed.)

[6] IATA. (2014). *Airport Development Reference Manual*. (10th). (IATA, Ed.)

[7] KDC - LVP Project team, *Improved Low visibility and Ceiling Forecasts at Schiphol Airport*, Final report, part 1, July 2008.

[8] http://www.forum-flughafen-region.de/monitoring/fluglaerm-monitoring/betriebsrichtungsprognose