

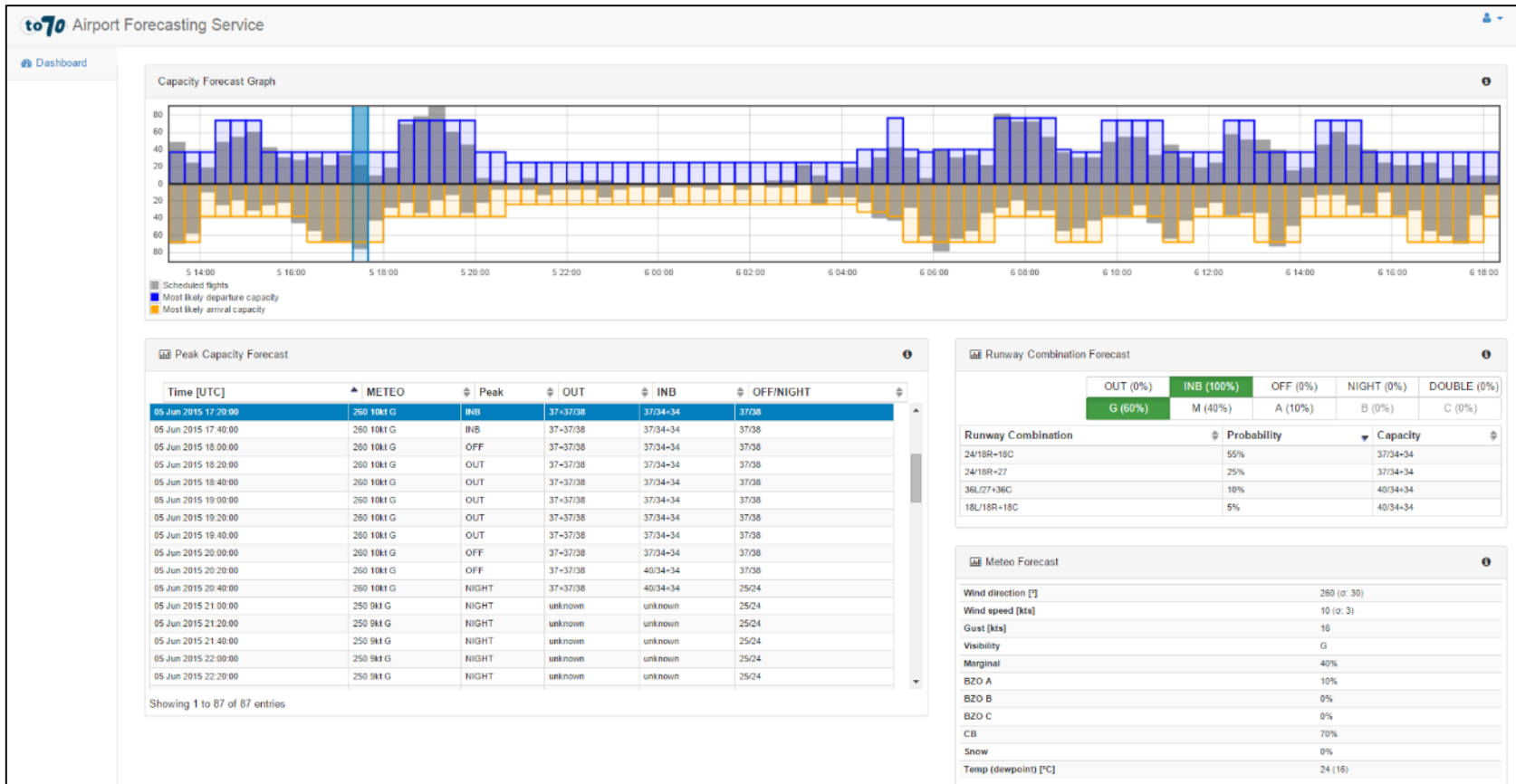
Probabilistic Runway and Capacity Forecasting using Machine Learning to Support Decision Making

SESAR Innovation Days 2016 – November 9, Delft

Arjen de Leege, To70
Ceriël Janssen, KLM



Decision Support System



- Probability forecast of runway use and runway capacity
- Prototype in use at KLM's Operations Control Centre (OCC) at Schiphol Airport

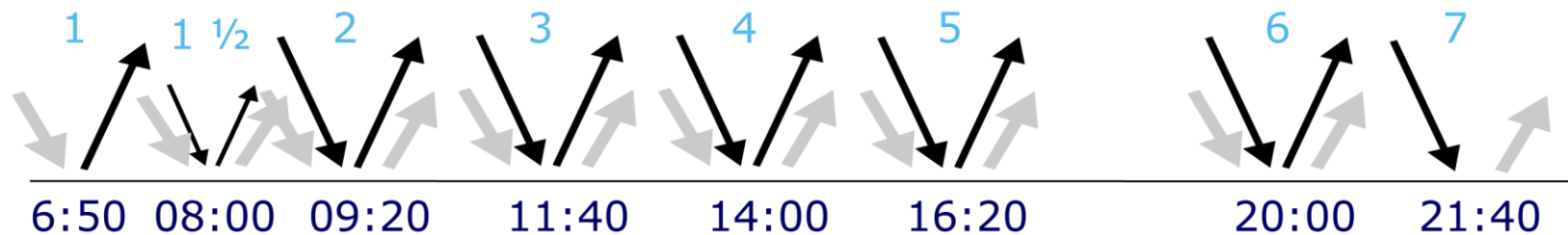
Schiphol Situation

Runway Use at Schiphol

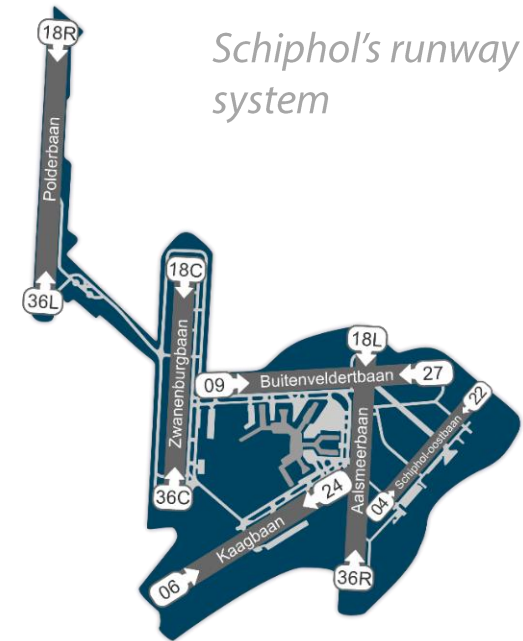
- 6 runways
- Used in 80+ different runway combinations
- Alternates between departure and arrival peaks
- Configuration changes at least 14x per day

Runway selection

- Weather conditions
- Demand
- Noise preferential system
- Runway availability



Schiphol's runway system



Schiphol alternates between departure and arrival peaks

Motivation

Factors affecting airline performance

- Runway Capacity
 - On-time performance
 - Airborne holding
- Runway Use
 - On-time performance
 - Taxi-time

Timely actions required when performance at risk

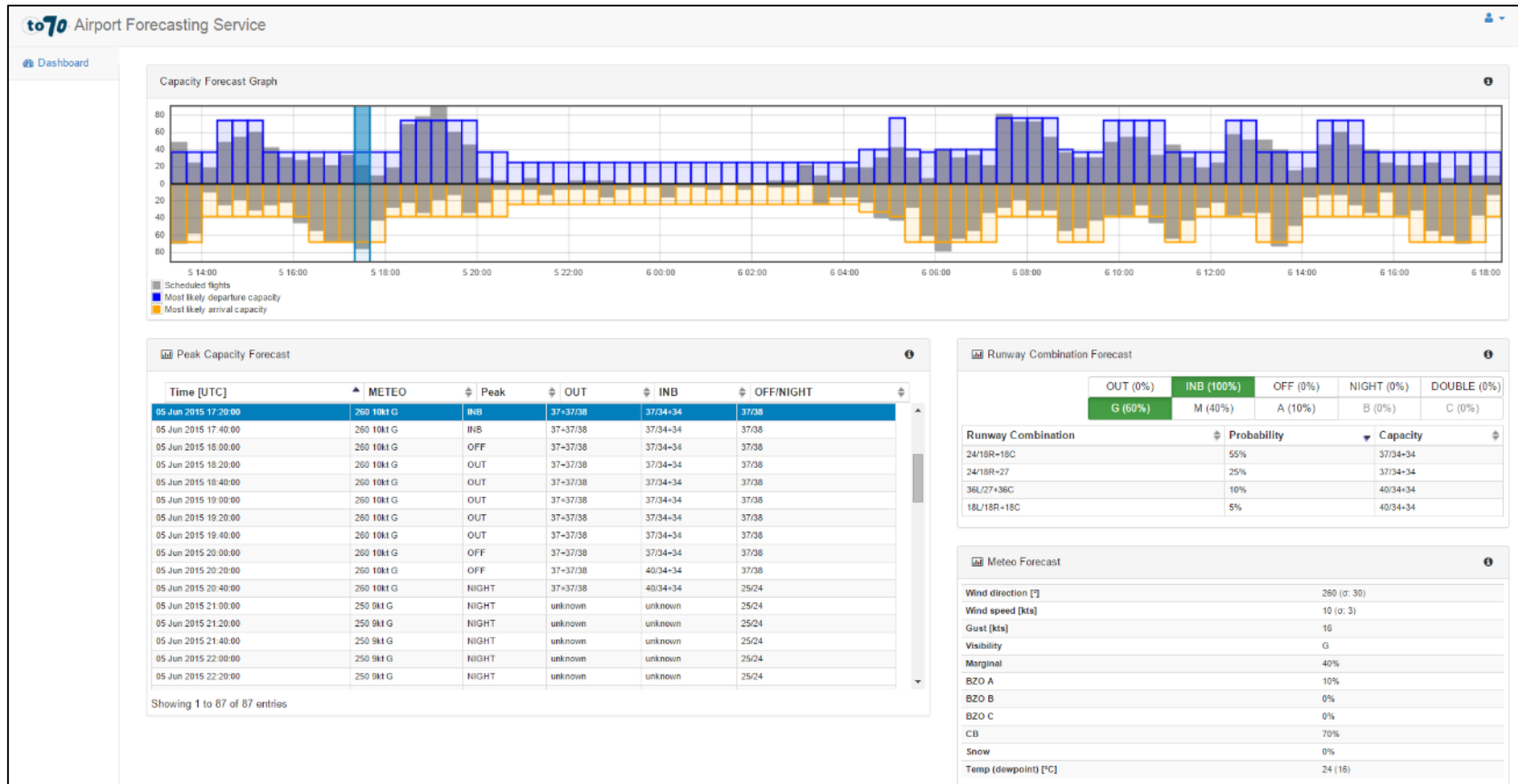
- Possible actions include:
 - Re-route passengers
 - Take extra fuel on board
- Flight preparation starts up to 20-24 hrs in advance
- Decisions based on forecasts

Probabilistic Forecast

- Uncertainty of meteorological forecast
- Runway selection under influence of factors that cannot easily be captured or modelled

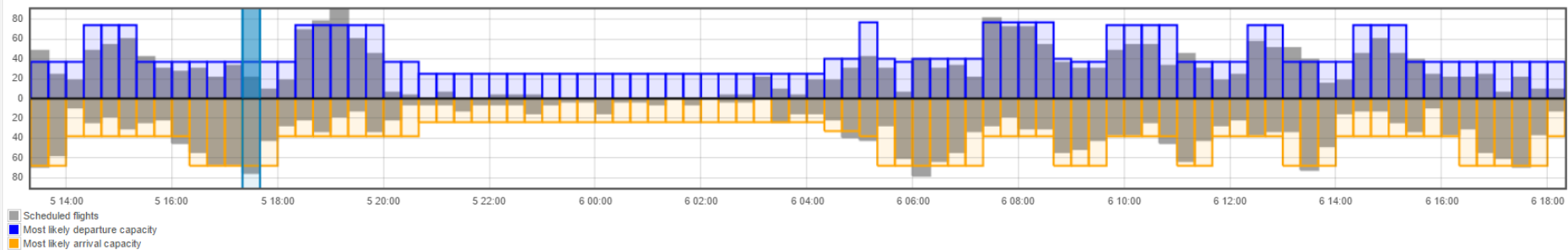


Decision Support System



- Developed together with KLM OCC
- 30 hour probabilistic forecast

Capacity Forecast Graph



Peak Capacity Forecast

Time [UTC]	METEO	Peak	OUT	INB	OFF/NIGHT
05 Jun 2015 17:20:00	260 10kt G	INB	37+37/38	37/34+34	37/38
05 Jun 2015 17:40:00	260 10kt G	INB	37+37/38	37/34+34	37/38
05 Jun 2015 18:00:00	260 10kt G	OFF	37+37/38	37/34+34	37/38
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Showing 1 to 87 of 87 entries

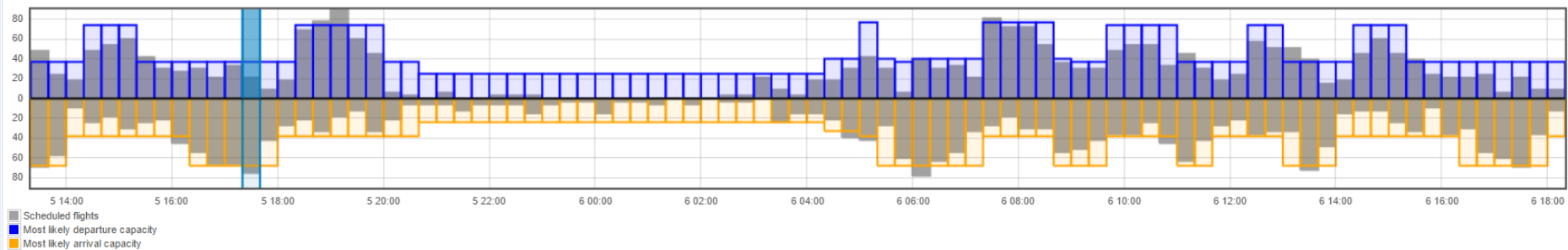
Runway Combination Forecast

OUT (0%)	INB (100%)	OFF (0%)	NIGHT (0%)	DOUBLE (0%)
G (60%)	M (40%)	A (10%)	B (0%)	C (0%)
Runway Combination		Probability	Capacity	
24/18R+18C		55%	37/34+34	
24/18R+27		25%	37/34+34	
36L/27+36C		10%	40/34+34	
18L/18R+18C		5%	40/34+34	

Meteo Forecast

Wind direction [°]	260 (σ: 30)
Wind speed [kts]	10 (σ: 3)
Gust [kts]	16
Visibility	G
Marginal	40%
BZO A	10%
BZO B	0%
BZO C	0%
CB	70%
Snow	0%
Temp (dewpoint) [°C]	24 (16)

Capacity Forecast Graph



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Time [UTC]	METEO	Peak	OUT	INB	OFF/NIGHT
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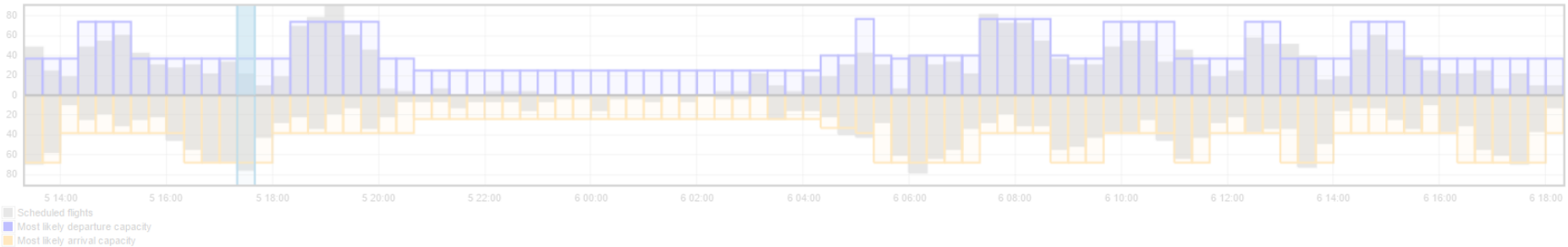
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Snow	0%
Temp (dewpoint) [°C]	24 (16)

- Overview of the next 30 hours
- Capacity vs. Demand per 20 minute period
- Capacity available with a probability of 50% or more
- 20 minute period clickable to get more detailed information

Capacity Forecast Graph



Peak Capacity Forecast

Time [UTC]

05 Jun 2015 17:30

05 Jun 2015 17:45

05 Jun 2015 18:00

05 Jun 2015 18:15

05 Jun 2015 18:30

05 Jun 2015 18:45

05 Jun 2015 19:00

05 Jun 2015 19:15

05 Jun 2015 19:30

05 Jun 2015 19:45

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05 Jun 2015 24:15

05 Jun 2015 24:30

05 Jun 2015 24:45

05 Jun 2015 25:00

05 Jun 2015 25:15

05 Jun 2015 25:30

05 Jun 2015 25:45

05 Jun 2015 26:00

05 Jun 2015 26:15

05 Jun 2015 26:30

05 Jun 2015 26:45

05 Jun 2015 27:00

Runway Combination Forecast

OUT (0%)

INB (100%)

OFF (0%)

NIGHT (0%)

DOUBLE (0%)

G (60%)

M (40%)

A (10%)

B (0%)

C (0%)

Runway Combination

Probability

Capacity

24/18R+18C

55%

37/34+34

24/18R+27

25%

37/34+34

36L/27+36C

10%

40/34+34

18L/18R+18C

5%

40/34+34

Runway Combination Forecast

OFF (0%)

NIGHT (0%)

DOUBLE (0%)

A (10%)

B (0%)

C (0%)

Capacity

Capacity

37/34+34

37/34+34

40/34+34

40/34+34

Temp (dewpoint) [°C]

260 (σ: 30)

10 (σ: 3)

16

G

40%

10%

0%

0%

70%

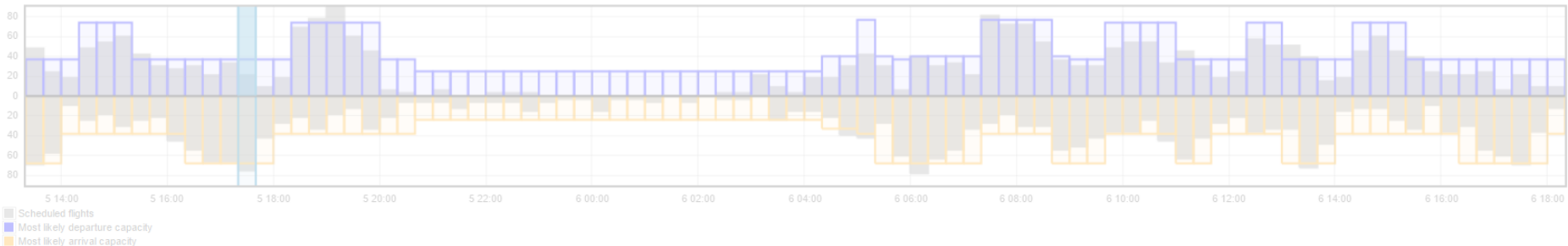
0%

24 (16)

For the selected 20 minute period

- Runway combinations, probabilities, capacity
- What-if scenarios
 - Different runway mode (e.g. outbound peak instead of inbound peak)
 - Visibility conditions (e.g., marginal instead of good)

Capacity Forecast Graph



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Snow	0%
Temp (dewpoint) [°C]	24 (16)

Capacity table

- Same information as graph
- Summary of meteo

Meteo for 20 minute period

- Most likely
- Uncertainties

Probabilistic Forecast

**Probabilistic
Meteorological Forecast**

X

**Probabilistic
Runway Use Forecast**

“probabilistic meteo forecast x probabilistic runway use forecast”

- Run Monte Carlo simulations with the runway use model
- Vary meteorological conditions based on meteo forecast
- Aggregate simulation results to obtain the probability forecast

Probability Forecast Schiphol

KNMI PROBABILITY FORECAST SCHIPHOL Friday 21 November 12 UTC till Saturday 22 November 18 UTC

Last update: Short term: 09:45 UTC Long term: 10:57 UTC

	12	13	14	15	16	17	18	21	00	03	06	09	12	15	18
Visibility < 5 km and/or ceiling < 1000 ft (%)	0	0	0	0	0	0	0	5	15	20	30	30	30	10	10
RVR < 1500 m and/or ceiling ≤ 300 ft (%)	0	0	0	0	0	0	0	0	0	0	5	5	0	0	5
RVR < 550 m and/or ceiling < 200 ft (%)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
RVR < 350 m (%)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Winddirection (deg)	← 090	← 100	← 100	← 100	← 100	← 100	← 090	← 100	↖ 110	↖ 120	↖ 130	↖ 140	↖ 140	↖ 150	↖ 150
Windspeed (kt)	9	10	10	10	10	9	8	9	9	9	10	10	11	10	9
Gusts (kt)		15	15	15	15						15	15	16	15	
Standarddeviation winddirection (deg)	15	15	15	15	15	15	15	15	15	15	15	15	15	20	20
Standarddeviation windspeed (kt)	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
CB (%)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Thunderstorm (%)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Temperature (C)	7	7	8	7	7	6	5	5	5	5	4	6	8	9	9
Dewpoint (C)	3	4	4	3	3	3	3	3	3	3	4	6	7	8	8
Relative humidity (%)	76	81	76	76	76	81	87	87	87	87	100	100	93	93	93
Windchill	4	4	5	4	4	3	2	2	2	2	-0	3	5	6	6
Snow (%)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Moderate or heavy snow (%)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Freezing precipitation (%)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	12	13	14	15	16	17	18	21	00	03	06	09	12	15	18

Visibility Probability

Wind direction, speed and gust

Standard deviation wind direction and speed

Showers, temperature, dew point, humidity, snow, etc.

Source: KNMI

- Product of the Royal Netherlands Meteorological Institute (KNMI)
- Probability forecast up to 30 hours
- Updated every hour

Probability Forecast Runway Use

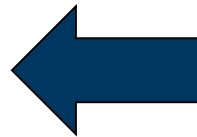
give runway combination and probability for the following conditions:

- 1 Landing +1 Take-off
- Wind 310° 10 kts
- Good visibility, in UDP



**Runway Use
Model**

runway combination	probability
36L/06	60%
36L/36R	30%
36L/27	10%



Model Predictors

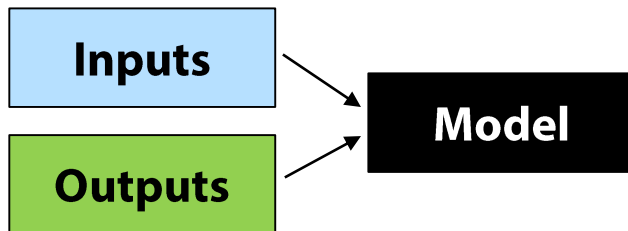
- Available runways
- Number of departure and arrival runways needed
- Wind direction, wind speed and gust
- Visibility (horizontal & cloud base)
- Daylight conditions (yes/no)

Machine Learning

Supervised Machine Learning

- The computer is presented with example inputs and their desired outputs, given by a 'teacher', and the goal is to learn a general rule that maps inputs to outputs.

1 – Training phase



2 – Prediction phase



Multinomial Logistic Regression

- Predicts the probabilities of all possible runway combinations
- The runway combination is considered a nominal dependent variable
 - the number of categories is limited (i.e., 82 unique runway combinations),
 - there is no ordering in any meaningful order
 - all categories are known

Machine Learning Runway Use Model

Training phase (prior to use)

Weather

Wind	Visibility (GMB)	UDP (Y/N)
320 10kt	G	Y
320 10kt	G	Y
310 10kt	G	Y
310 10kt	G	Y
310 10kt	G	Y
...	...	...
180 6kt	M	Y



Runway Use

Runways in Use	Runway Combination
1+1	36L/06
1+1	36L/06
1+1	36L/36R
1+1	36L/36R
1+1	36L/36R
1+1	...
1+1	24/18R



Prediction phase (use)

give runway combinations and probability for the following conditions:

- 1 dep runway and 1 arr runway
- Wind 310 10 kts
- good visibility, within UDP



combination	prob.
36L/06	60%
36L/36R	30%
36L/27	10%



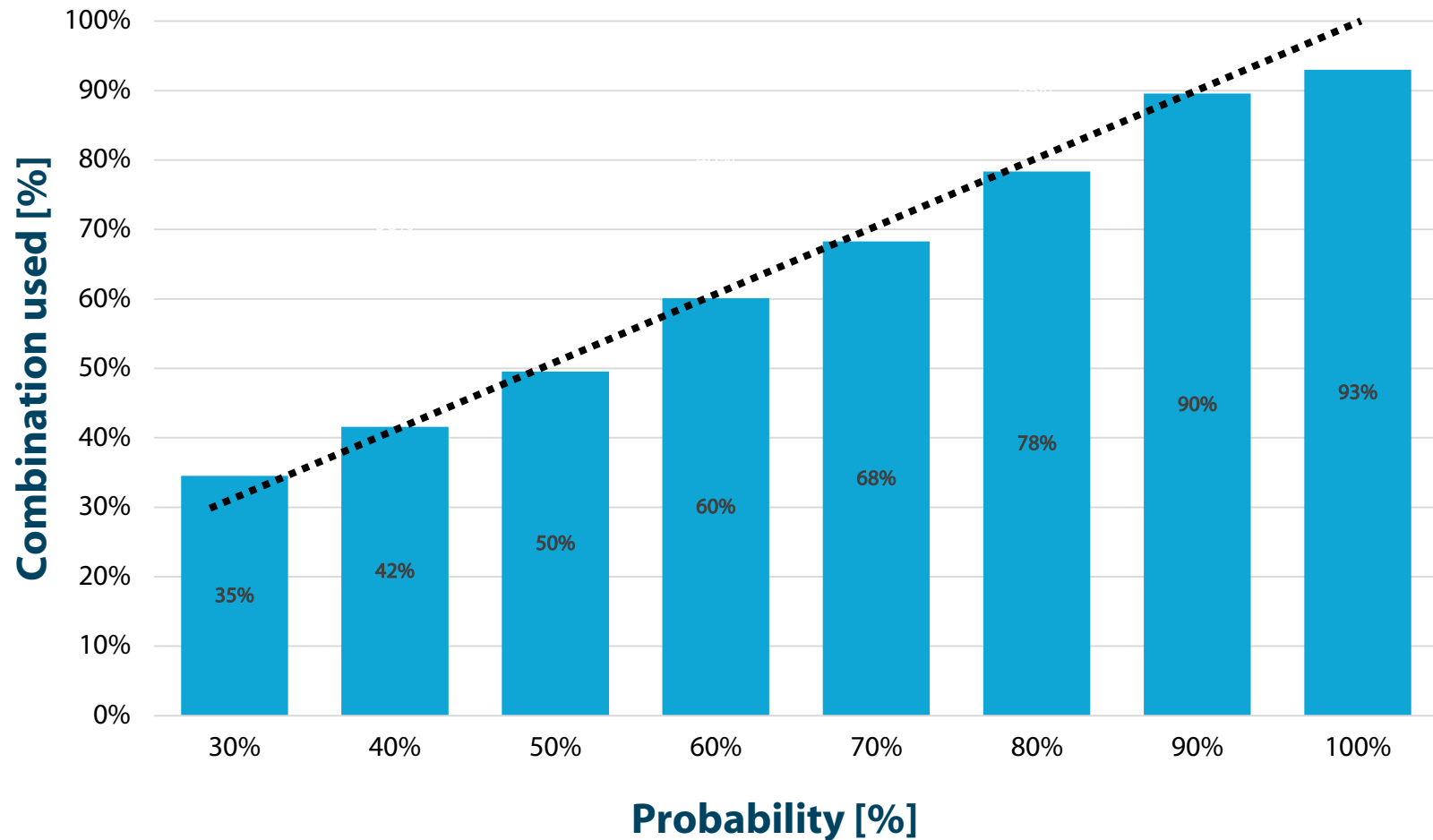
- “probability forecast meteo x probability forecast runway use”**
- Series of Monte Carlo simulations with runway use model
 - Varying meteorological conditions based on probabilistic forecast
 - Runway model gives probabilistic forecast for one meteo condition



Predictive Power

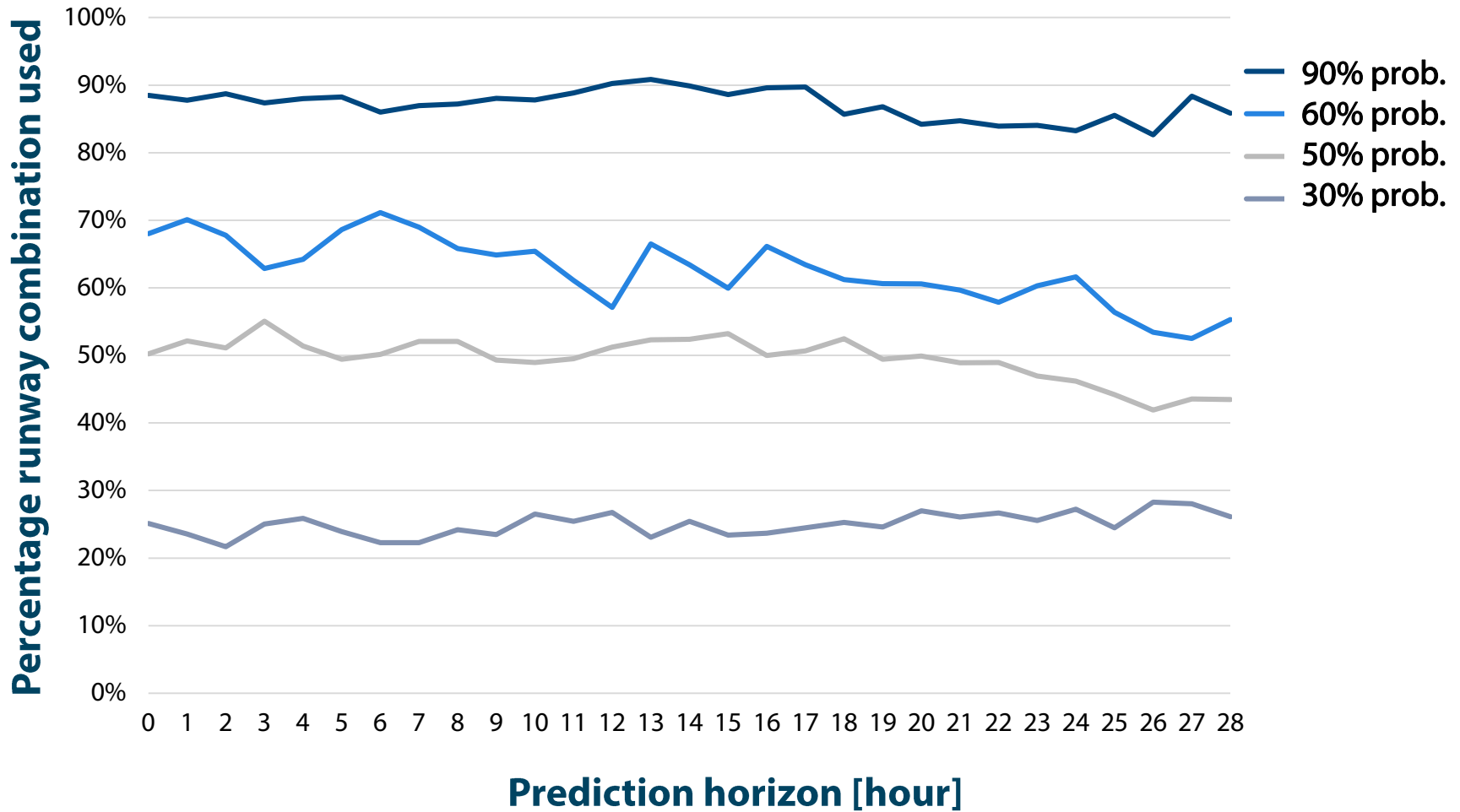
- Reliability of the model
- “Confidence” of the model
- Trained model using 2013 data
- Generated probability forecasts for 2014
- Compared the forecast with actual runway use

Forecast vs. Actual Use – runway use model only



- Strong correlation between forecast and actual use

Forecast vs. Actual use against the prediction horizon





Impact on Decision Making

- User experiment
 - Type of decision made
 - Time a decision was made
-
- Use of the system
 - Get feedback on the design and functionality

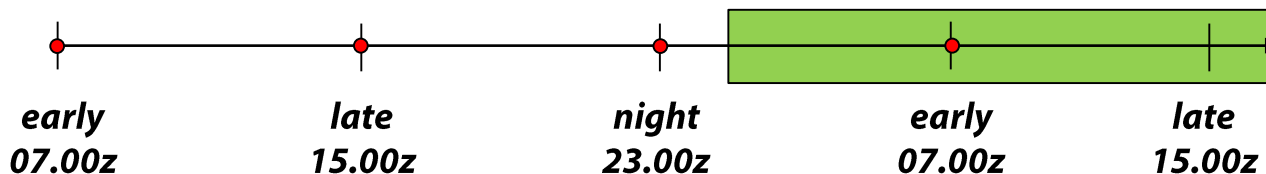
Impact on Decision Making

- KLM selected 5 days to assess the impact on decision making in an experiment
 - Storm, snow, showers, bad visibility
- Three participants
 - 2 x Supervisor Flight Dispatch
 - 1 x Flow Controller
 - No experience with the system
- Impact on decision making
 - Fuel advice (e.g., extra fuel for expected holding)
 - Inform 'network operations' (e.g. cancel flights)
 - Compare decisions taken during the experiment run and the actual operation



Experiment Setup

- Scenario starts at 7:00z the day before (D -1)
- The participant is asked to assess the situation using the DSS system. Also available to the participant are weather information and the latest briefing
- The participant is asked to:
 1. Describe the situation
 2. Indicate which conclusions he/she draws based on the information
 3. Indicate if operational decisions should be taken.
If yes, indicate which operational decisions.
- The steps above are repeated at 15:00z (D -1), 23:00z (D -1), 7:00z (D 0) at the day itself.
- Same steps as in the actual operation



Comparison of Decisions Taken

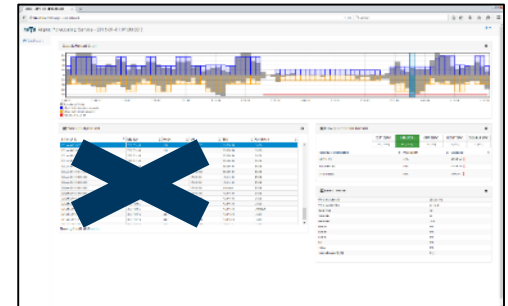
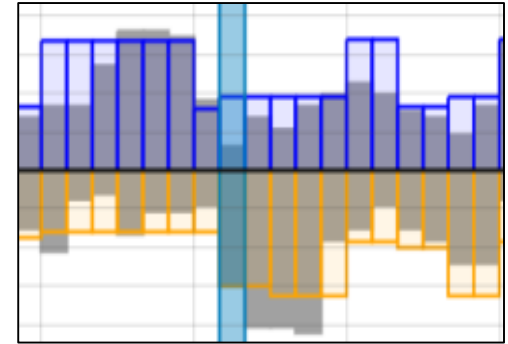
- No impact on the 'type' of operational decisions that are made
 - Fuel advices more targeted to fleet segments (EUR/ICA) and time frame
- Possible effect on the moment decisions are made
 - Fuel advices later
 - Cancellations earlier
- Sample size is too small to draw any statistical significant conclusions

Datum + dienst	Werkelijk	1	2	3
01-01-2015 0700z				
01-01-2015 1500z		EUR ICA		
01-01-2015 2300z	EUR		EUR	ICA 18Z
02-01-2015 0700z		EUR 18Z		EUR 18Z

Comparison for 1 scenario

User Feedback & Interface Use (selection)

- The capacity graph works as a trigger. When demand exceeds capacity, users explore the situation further.
- The system enables more targeted decision making.
- More focus on the middle of the day.
- Capacity table adds little information, can be removed.
- Difficult to see how the weather is changes over time, requires many mouse clicks.
- Crosswind per runway and capacity penalty due to headwind would be a valuable addition.



Main Conclusions

- Combining the probabilistic runway use forecast with a probabilistic meteorological forecast results in a probabilistic forecast that accounts for both the uncertainty in the weather forecast and runway selection.
- Probabilities forecast have strong correlation with the percentage of time a runway is actually used.
- Indication that the system has a positive effect on decision making
 - decisions to cancel flights are taken earlier.
 - decisions to take extra fuel onboard later.
 - more targeted decision making



This project was funded by



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