Supporting Strategic and Operational Decision Making in Airlines, Airports and Air Traffic Control using Simulations

30th Anniversary Symposium of the Dutch Benelux Simulation Society

November 18, Delft

Arjen de Leege, PhD, MSc
Senior Aviation Consultant

to70

To70 Aviation Consultants

Consultancy and research services for aviation clients worldwide

- Airports
- Airlines
- Air Traffic Control

Our approach

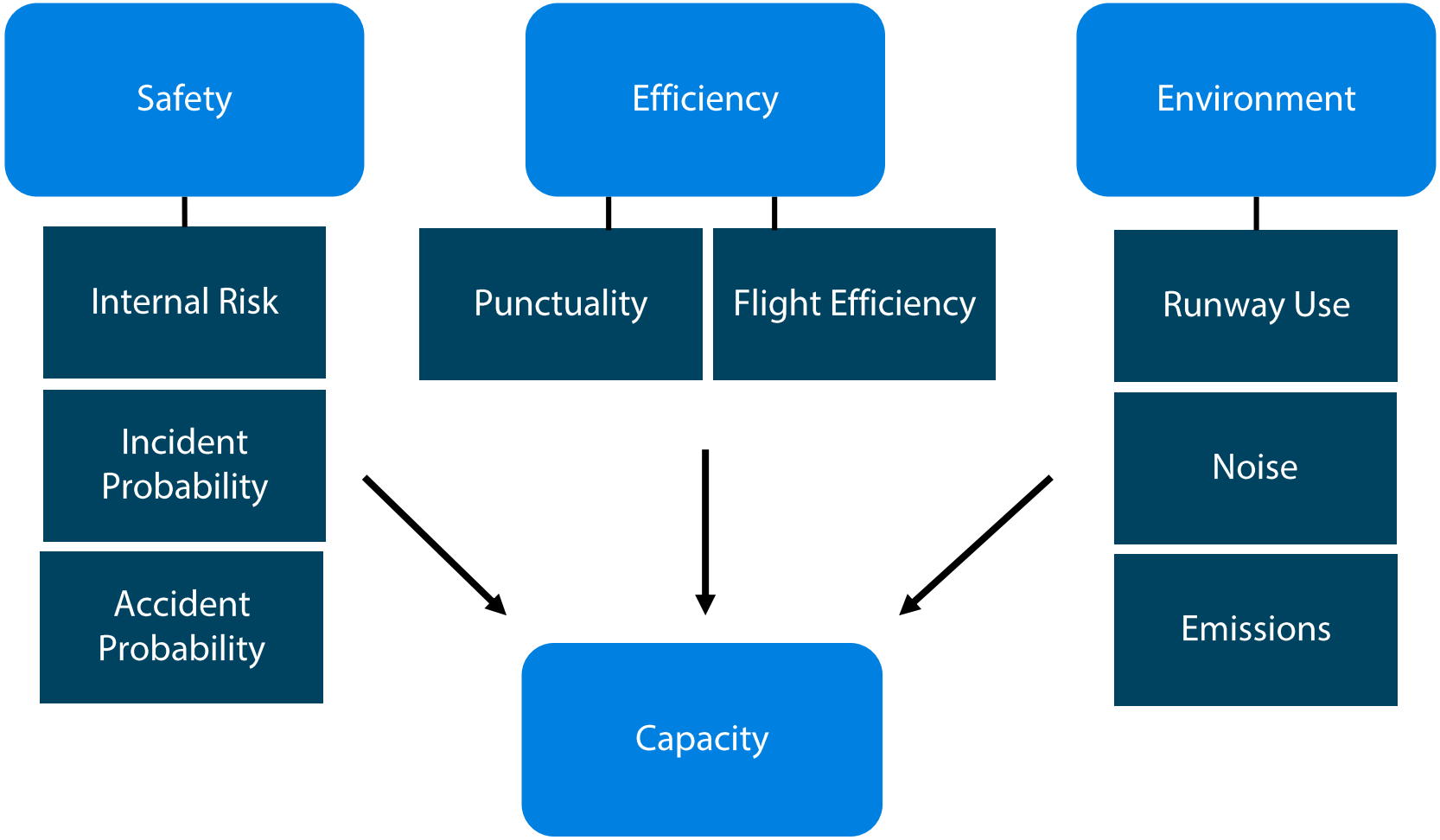
- Aviation expertise & analytics
- Aviation tools suite
- Aviation knowledge base

Our focus areas

- Capacity
- Safety
- Efficiency
- Environment

Established in 2000
8 offices, 4 continents
50 consultants and experts
1000+ projects

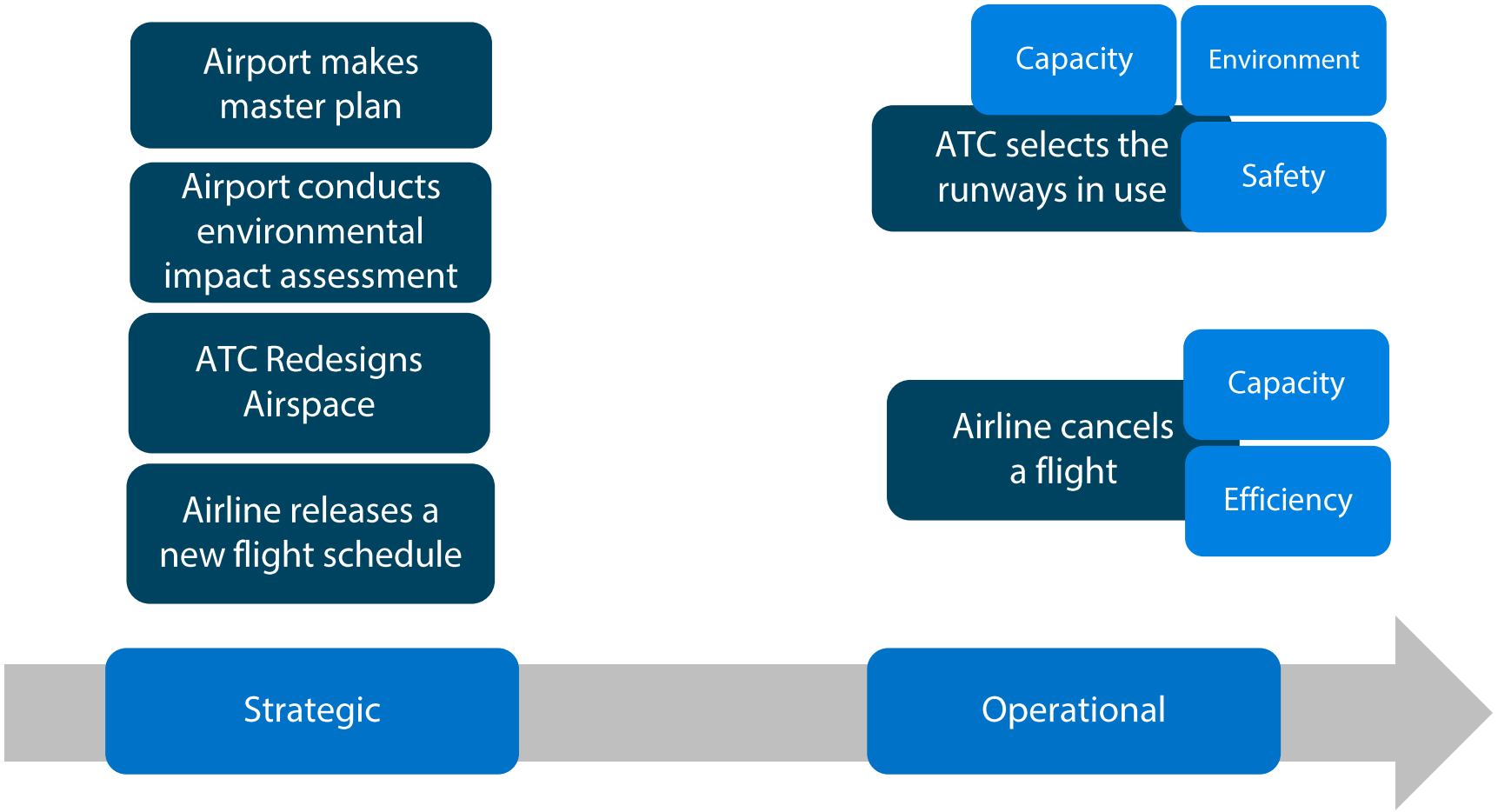
Key Performance Areas



- Before deciding on any changes to their operations airports, airlines, and air traffic control assess the impact on capacity, safety, efficiency and the environment

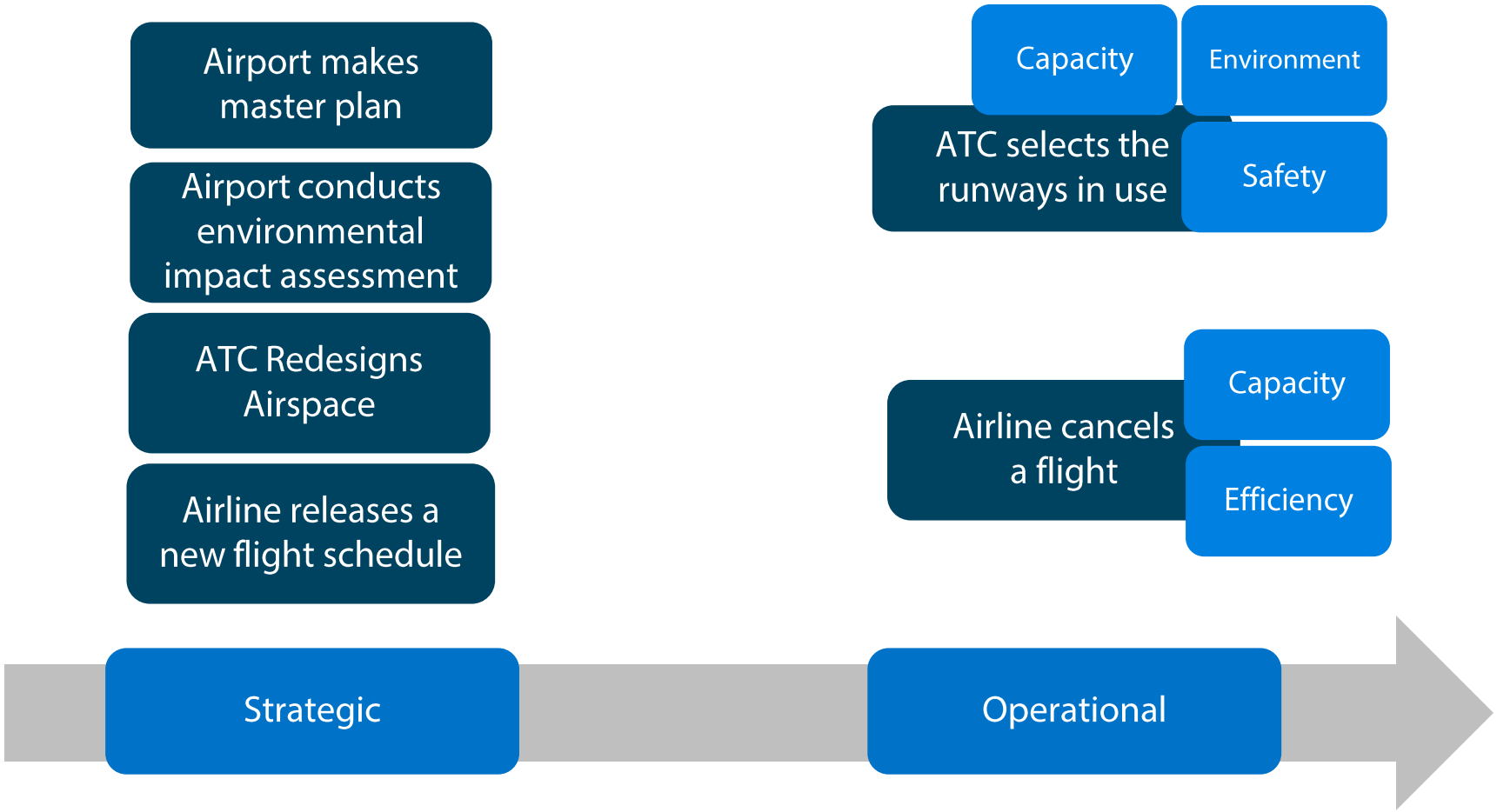
Adopted from LVNL VEM-framework

Decision Making at Strategic and Operational Levels



- Decisions at strategic and operational level

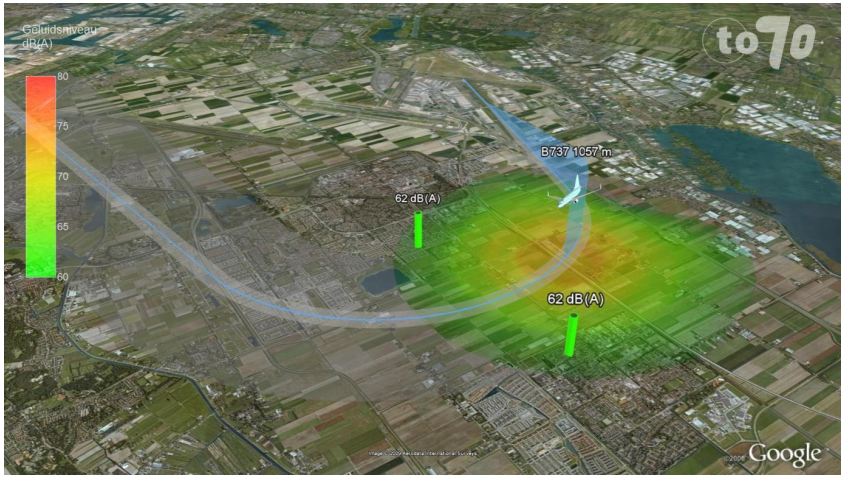
Decision Making at Strategic and Operational Levels



- All strategic decisions are taken with support of simulations
- The role of simulations in operational decision making is increasing

Examples of Simulations supporting Decision Making

Masterplan - Airport Expansion



Introducing a procedure affecting aircraft noise exposure

Actions required to maintain airport service levels under growth

Decision support at the operations control centre of an airline

Masterplan - Airport Expansion

Strategic

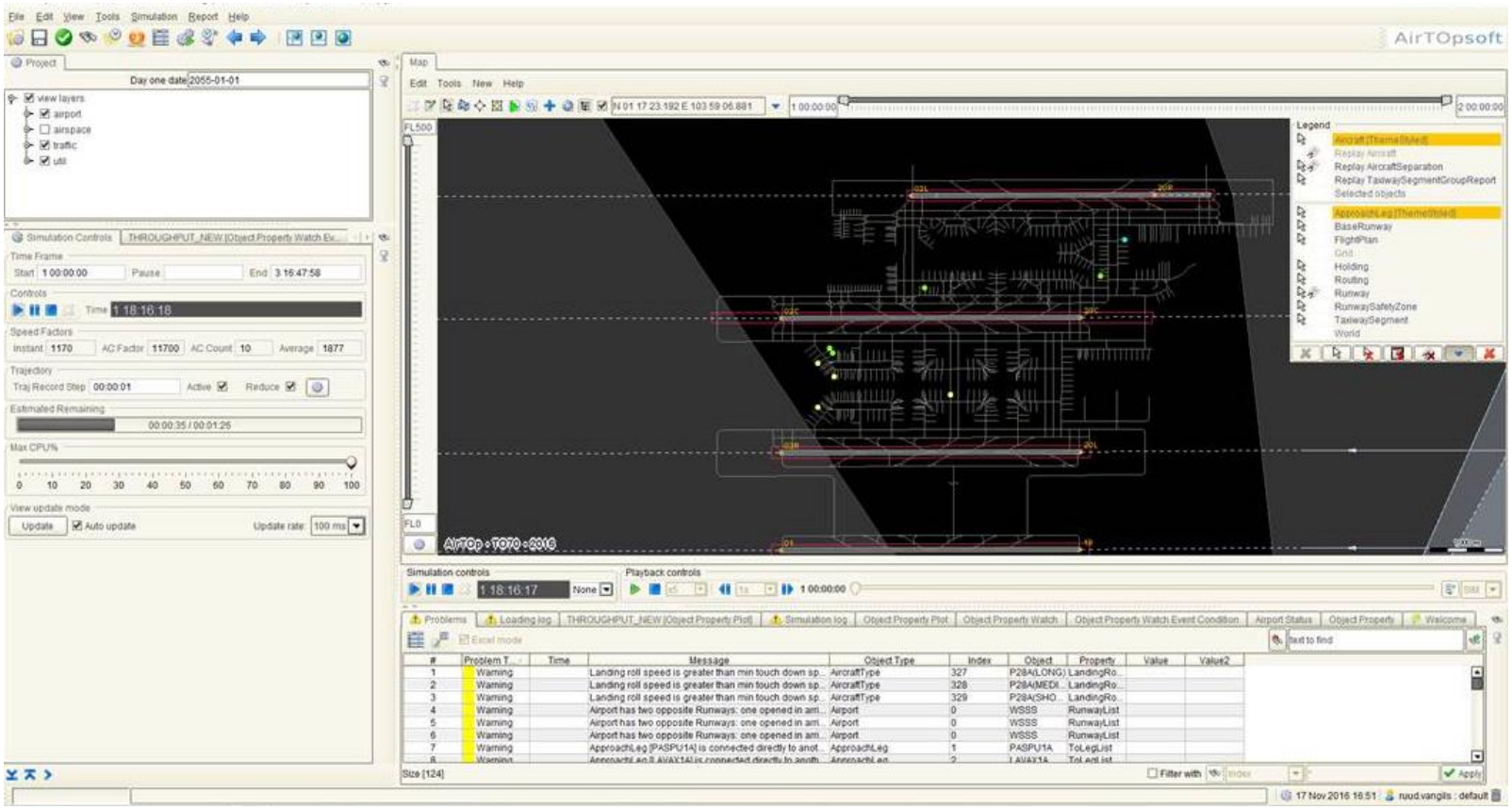
Capacity

Efficiency

Masterplan – Airport Expansion

- Does the new infrastructure provide the capacity required?
- Are there any bottlenecks in the design that need to be resolved?
- How to make best use of the new infrastructure?

Highly detailed simulation or airspace and airport operations

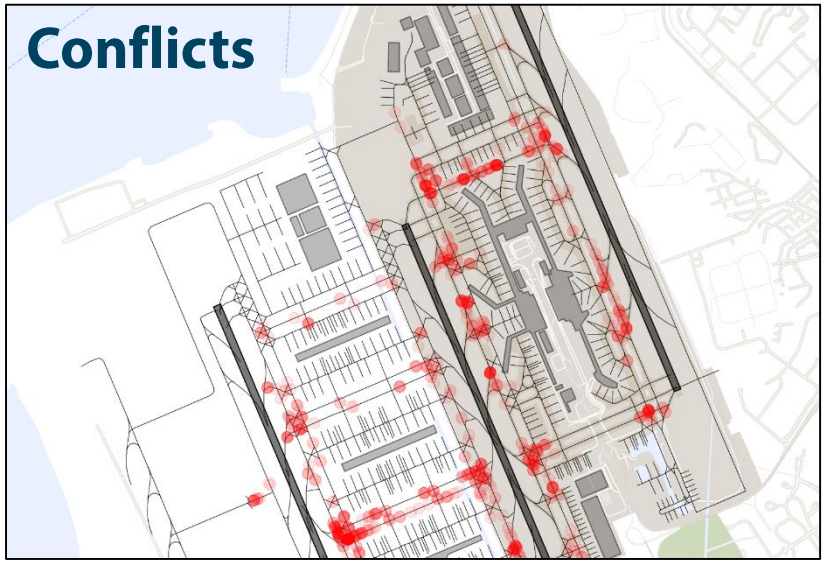


- Model the airspace and airport infrastructure, AutoCAD like drawing
- Define a ruleset to model the anticipated use of the airspace and airport
- Agent-based models represent aircraft and air traffic control

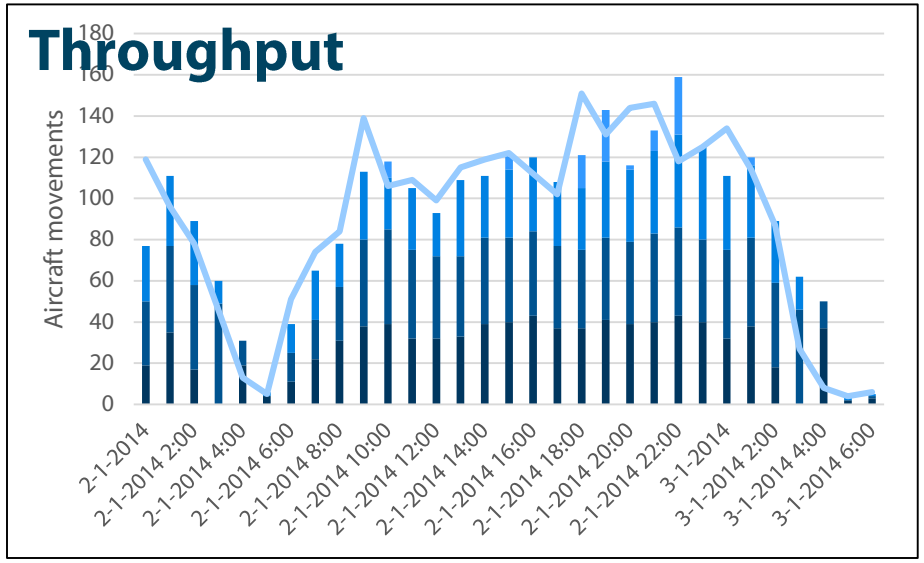
Example – Airspace Operations

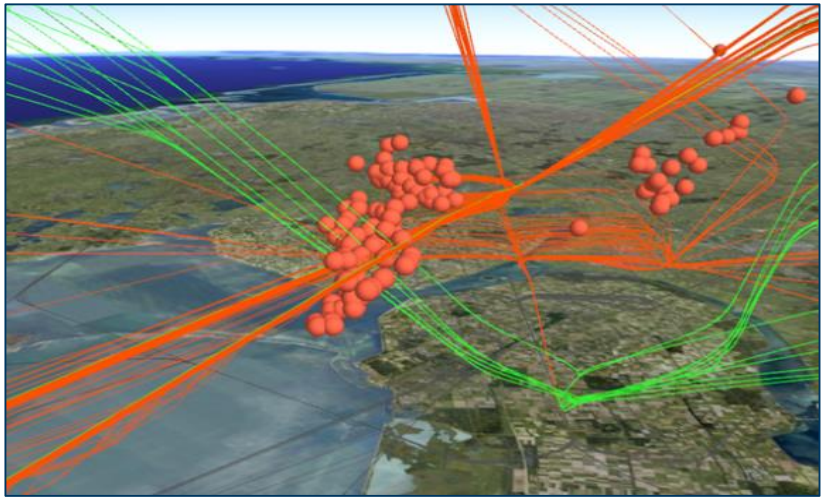
Analyze Simulation Data

Conflicts

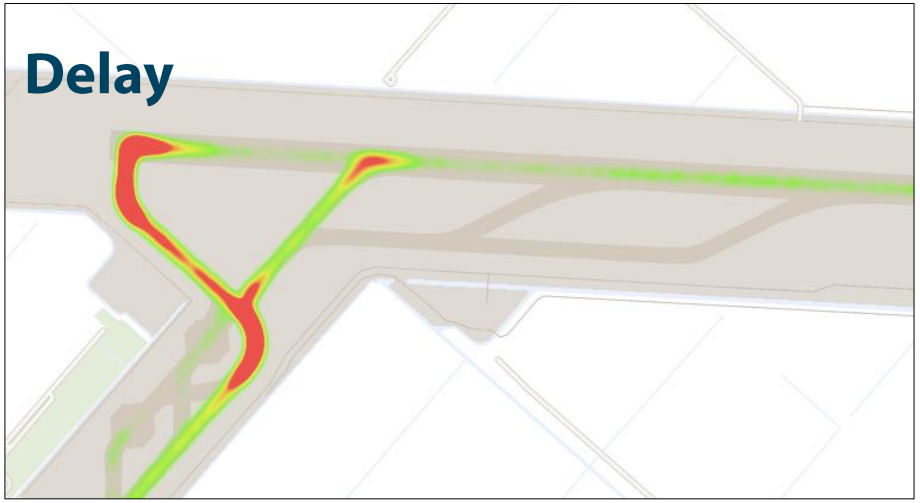


Throughput





Delay



Actions required to maintain airport service levels under growth

Strategic

Capacity

Efficiency

Airport Service Levels and Growth

Air transport is growing

- Pressure on airport infrastructure is increasing
- Pressure on levels of service (LoS) agreed with stakeholders
  - On Time Performance
  - Delay

Airport Operator Questions

- What growth can my airport accommodate whilst meeting LoS?
- What change in capacity is required to meet LoS?
- How sustainable are the operations (% of time LoS met)

Selecting the right simulation tool

- Technically AirTOp can be used, however
  - Spatial details not required
  - A lot of modelling effort required

Apply queuing theory

Airport model based on queuing theory

- Queues represent runways, taxiways, adjacent airspace etc.
- Simple logic to model the local situation
- Limiting modelling effort

Possible outcomes of a queuing model

- Capacity available, utilization
- Delay
- Punctuality

Best case, worst case, most likely case

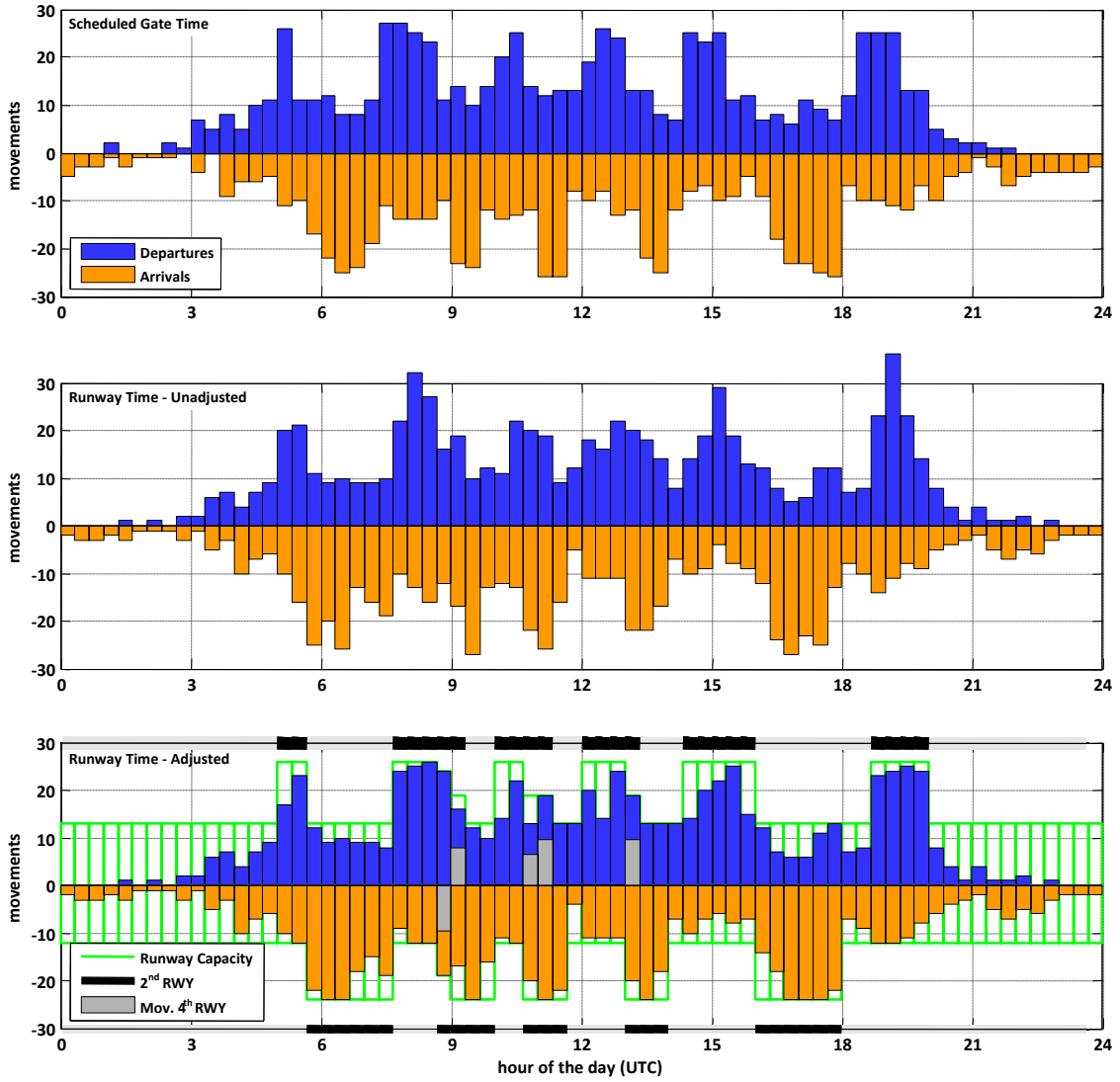
- Run Monte Carlo simulations to acquire range of possible outcomes
- Robustness, sustainability & risks

Example of a Queuing Model

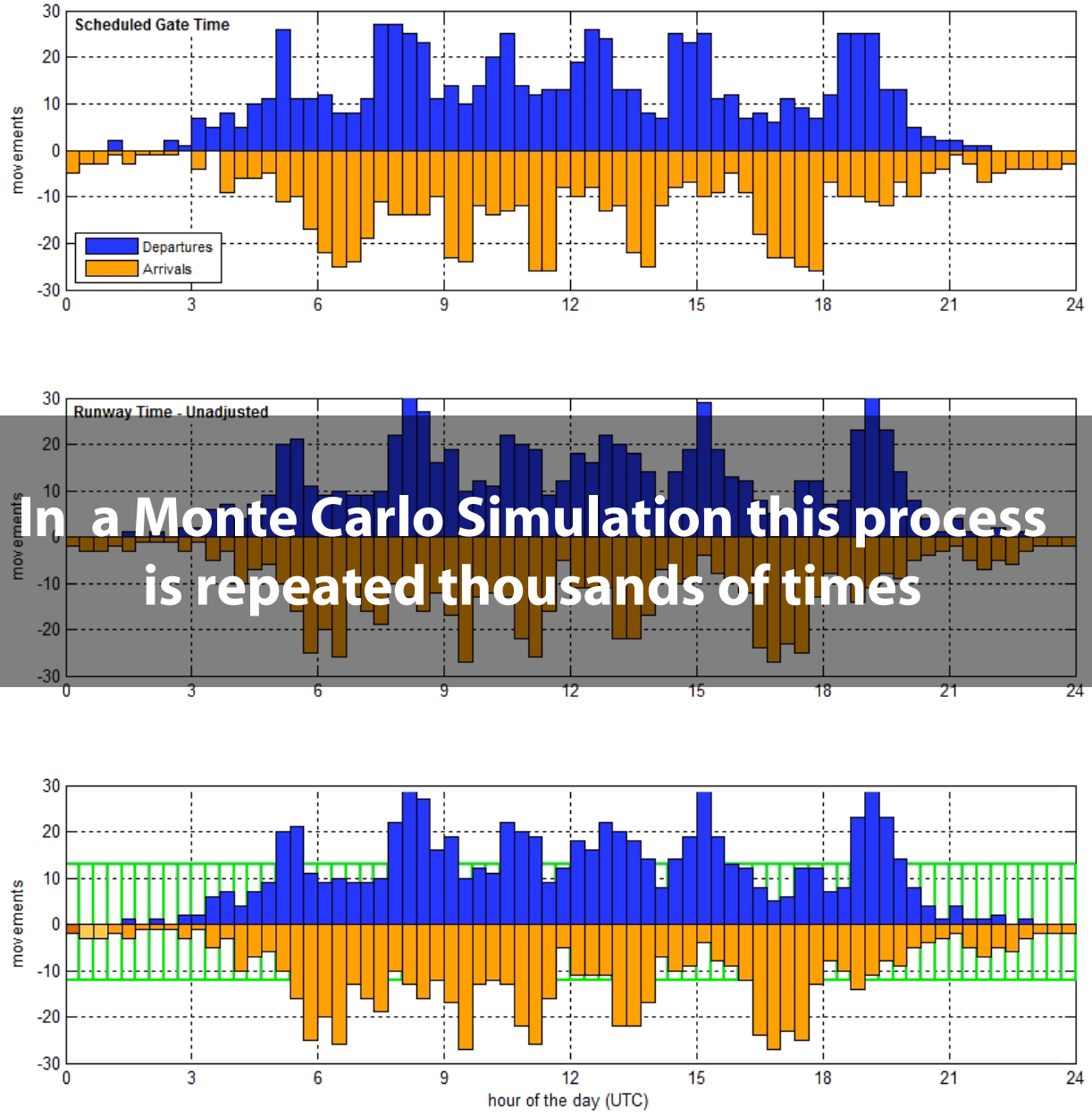
Traffic Schedule

Runway demand

Runway use



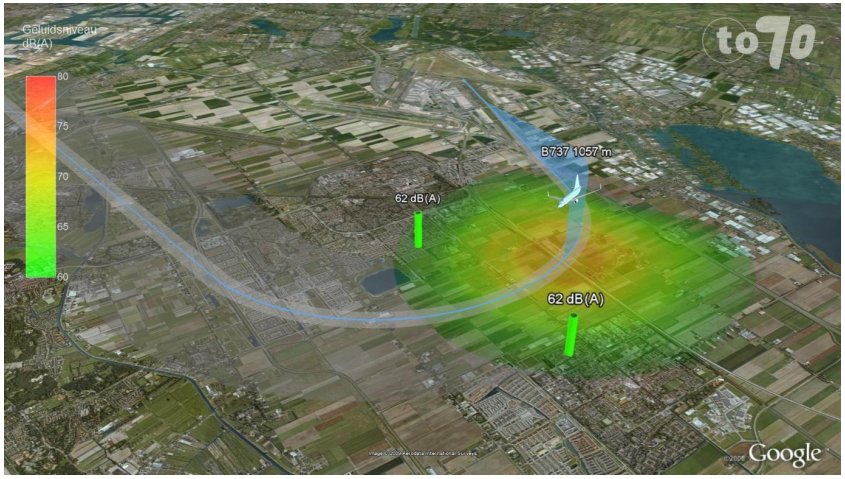
Departures (blue)
Arrivals (orange)



In a Monte Carlo Simulation this process is repeated thousands of times

Examples of Simulations supporting Decision Making

Masterplan - Airport Expansion



Introducing a procedure affecting aircraft noise exposure

Actions required to maintain airport service levels under growth

Decision support at the operations control centre of an airline

Introduction of a new procedure that has an impact on aircraft noise

Strategic

Environment

Introducing a new procedure with impact on aircraft noise

Requires consensus between all stakeholders

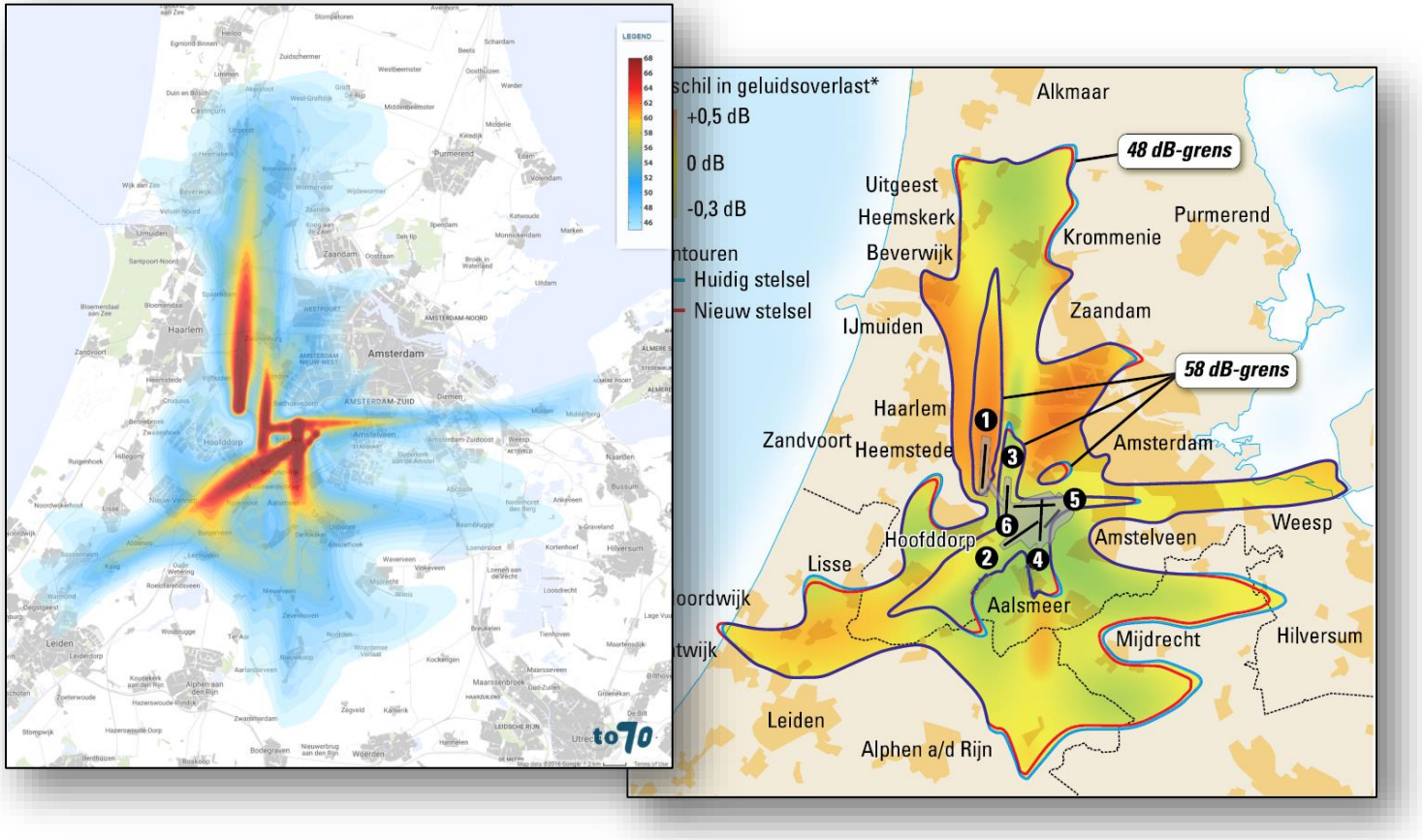
- Airport
- Air Traffic Control
- Airlines
- Government
- Local communities affected

Each stakeholder has different information needs with respect to noise

- Will the airport still be able to operate within the noise limits?
- What are the implications on land-use planning?
- What is the impact on aircraft noise exposure at my location?

- Typically noise contour charts are prepared using “traditional” aircraft noise models.

Contour charts do not meet all information needs



Strengths

Provide legally defendable basis

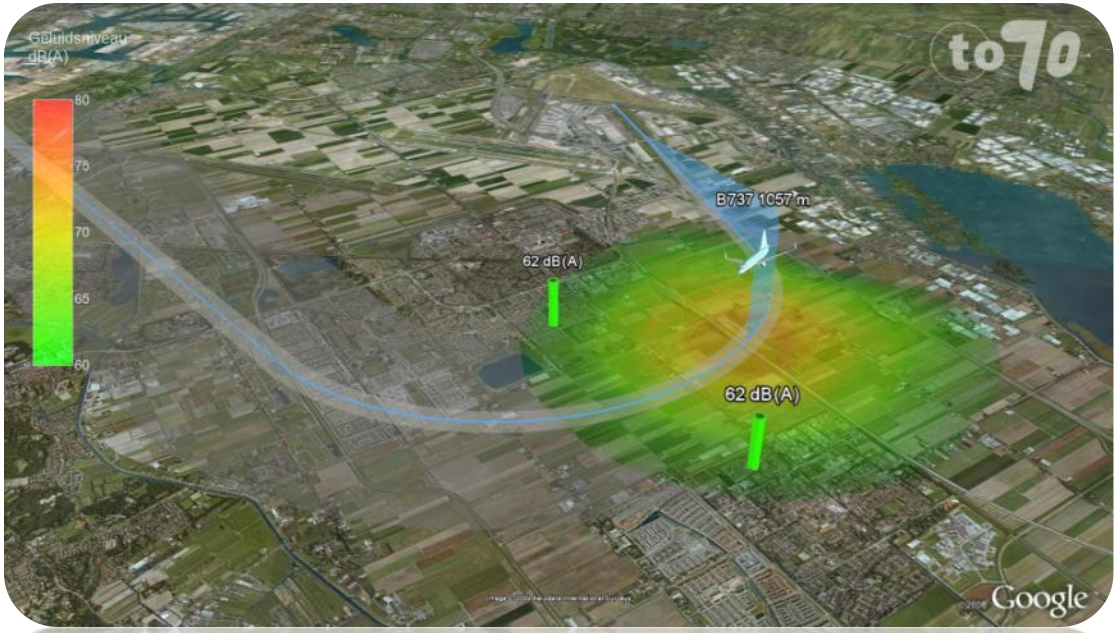
Useful in land-use planning

Weaknesses

Technical metrics, explanation required

No relation to personal experience of aircraft noise

Aircraft Noise Visualisations



Flight Simulation

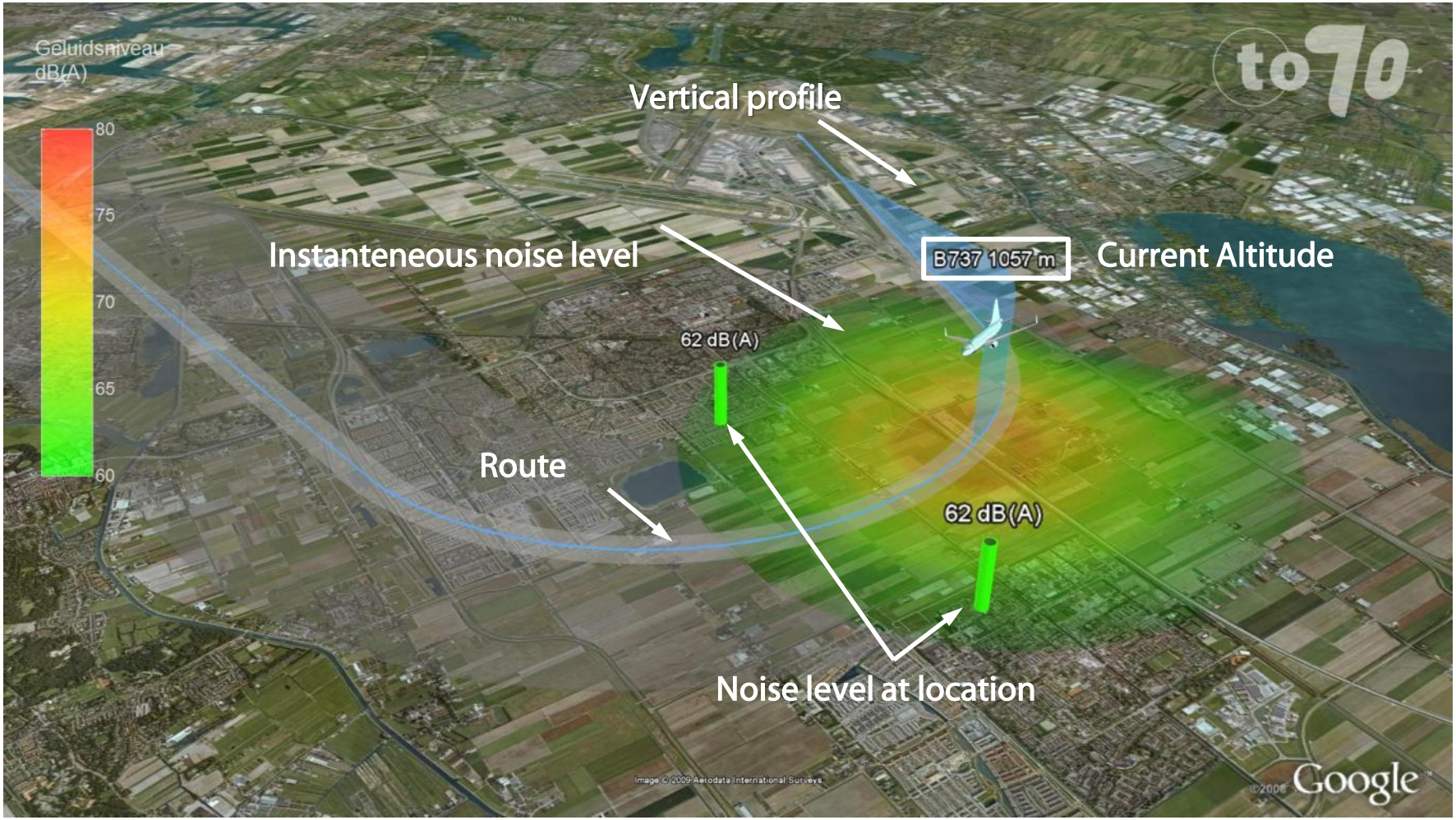
Noise simulation with a validated noise model

Visualisation

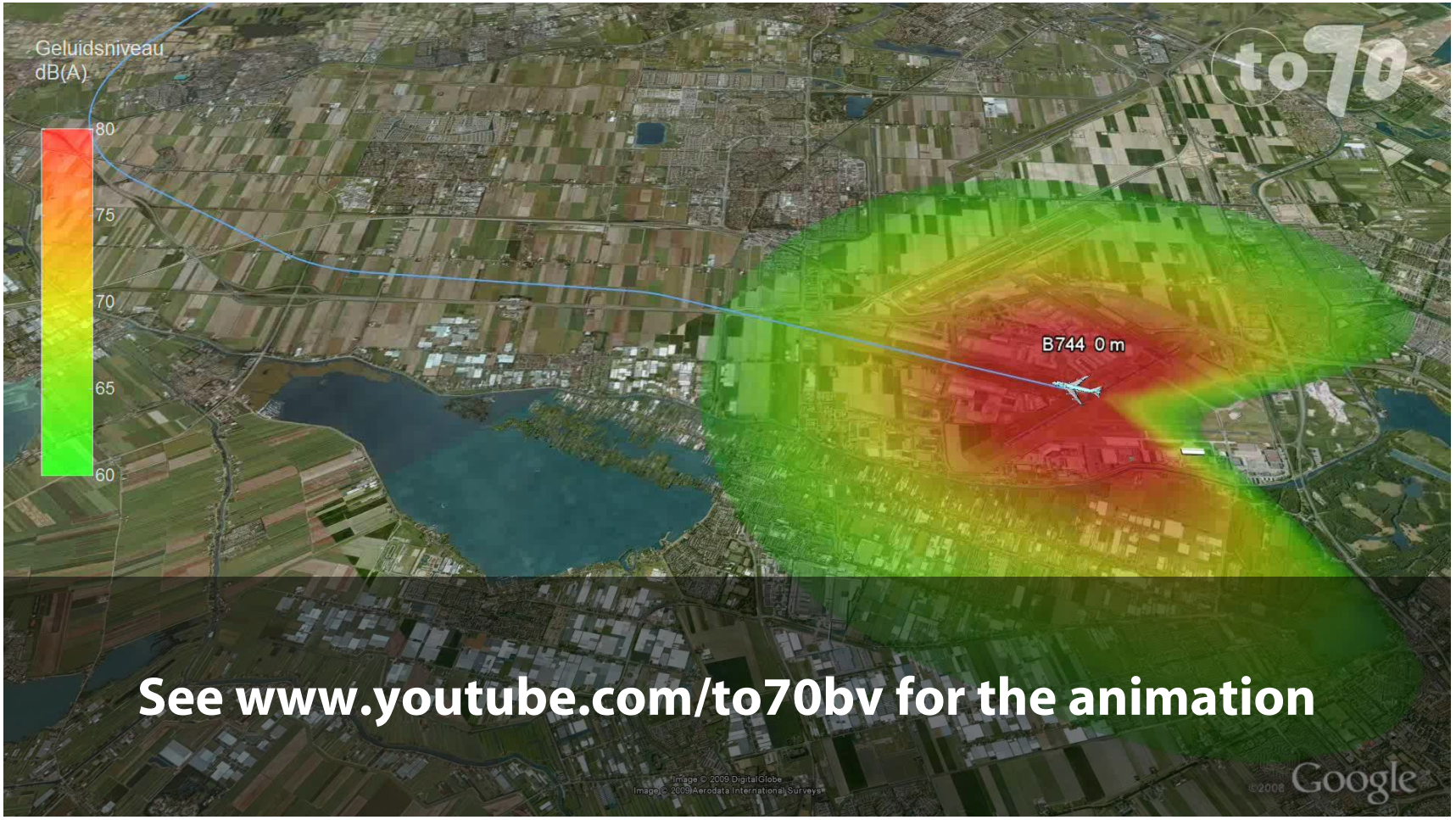
- Easy to understand
- Gives a better understanding of aircraft noise

New navigation technique to avoid over flying residential areas

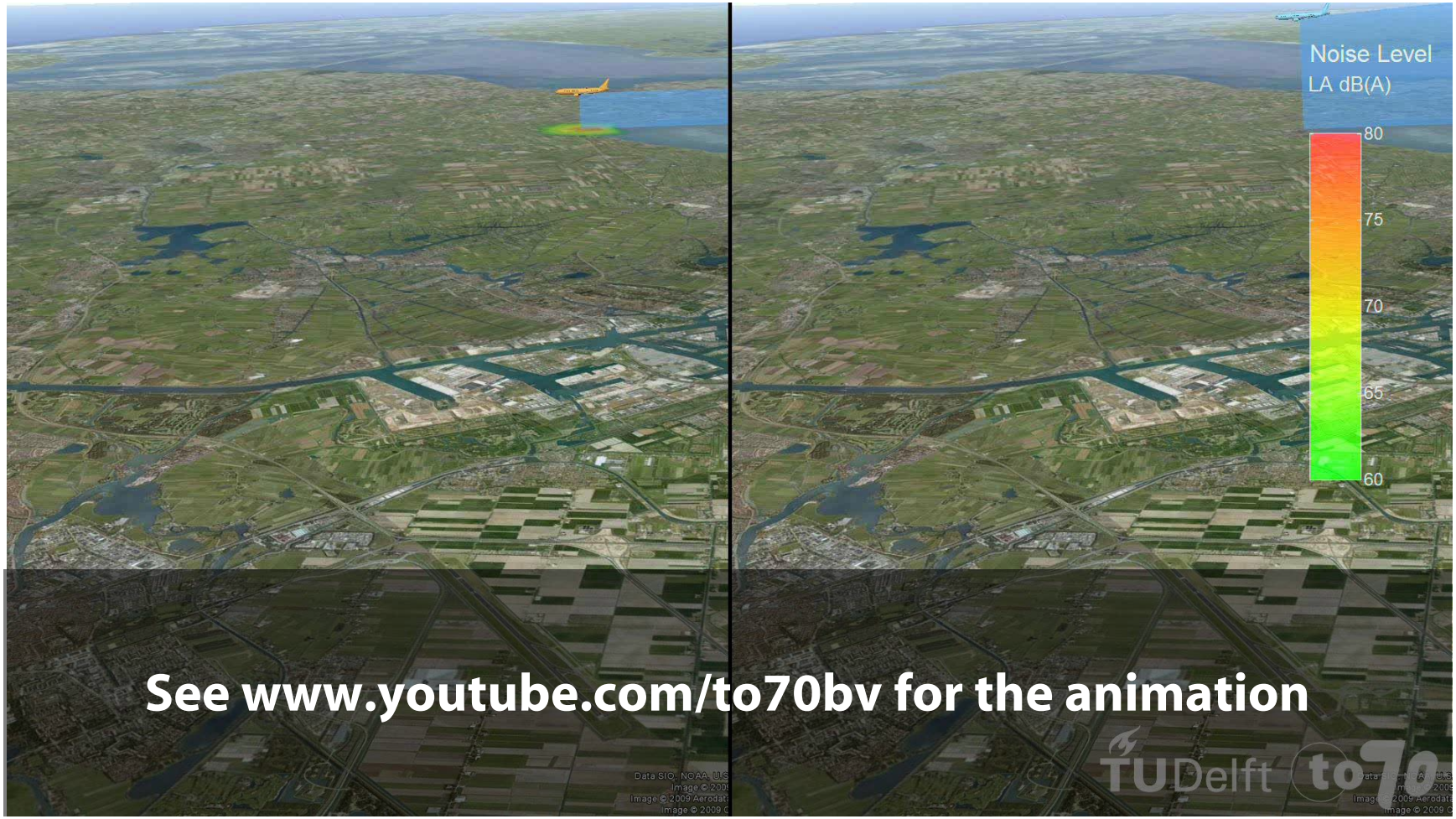
What's in the picture?



Maximum Noise Level

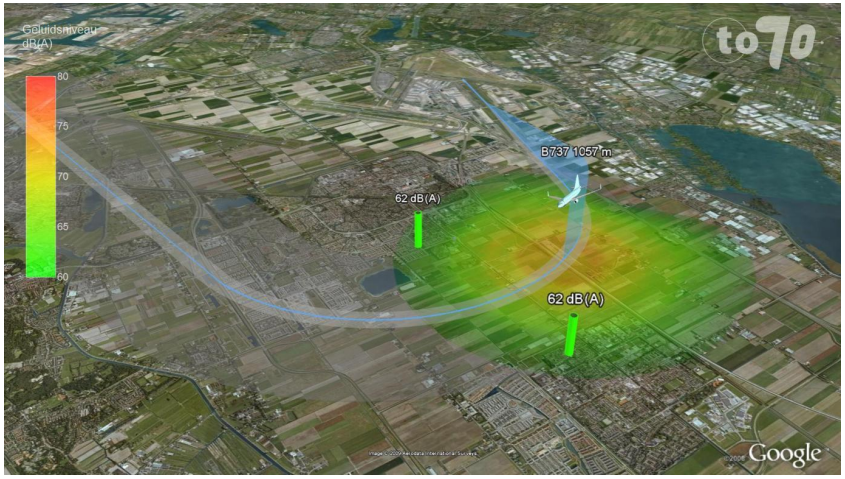


Compare two procedures



Examples of Simulations supporting Decision Making

Masterplan - Airport Expansion



Introducing a procedure affecting aircraft noise exposure

Actions required to maintain airport service levels under growth

Decision support at the operations control centre of an airline

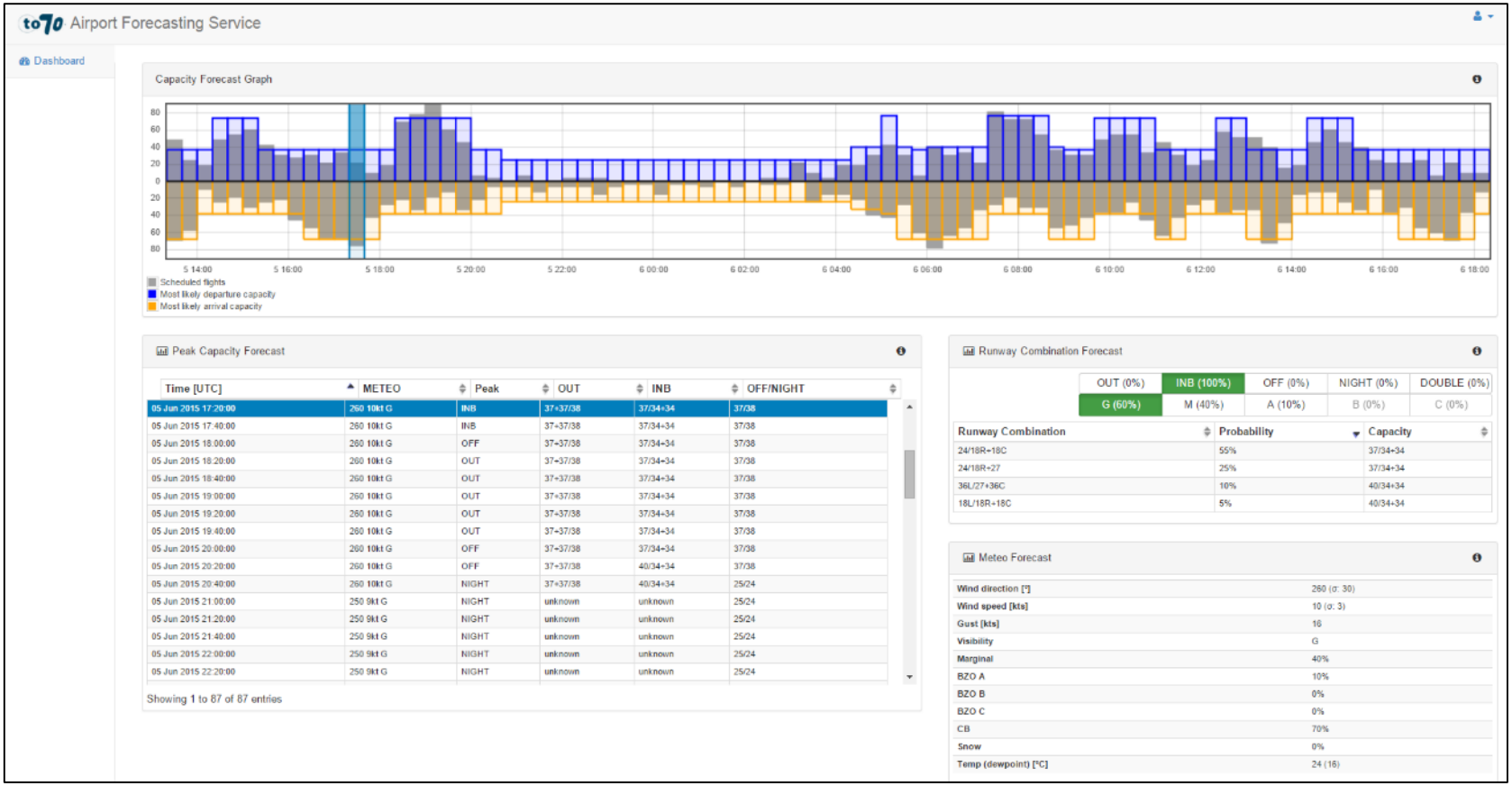
Decision Support System at an Airline Operations Control Centre

Operational

Capacity

Efficiency

Decision Support System



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

Runway Capacity and Configuration and Airline Performance

Two main factors impacting flight operations

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

The OCC takes actions when performance is 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 the expected runway capacity and configuration in use

Determining runway use at Schiphol is complex

Runway use at Schiphol

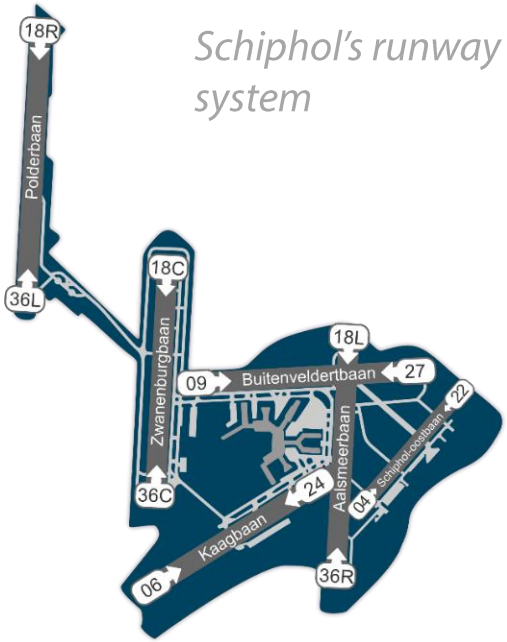
- 6 runways
- Used in 80+ different runway combinations
- Alternates between departure and arrival peaks
- Configuration changes at least 14x per day

Runway selection

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

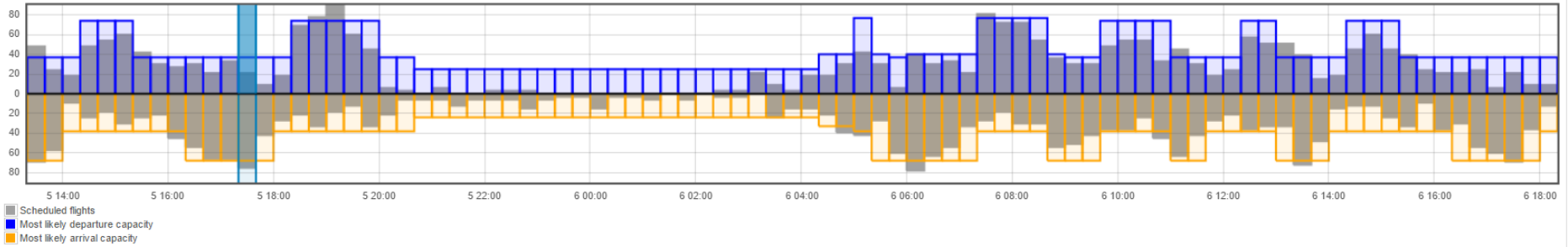
Adding to the complexity

- Uncertainty in the meteorological forecasts
- Day-to-day variations in runway selection



Schiphol's runway system

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
05 Jun 2015 18:20:00	260 10kt G	OUT	37+37/38	37/34+34	37/38
05 Jun 2015 18:40:00	260 10kt G	OUT	37+37/38	37/34+34	37/38
05 Jun 2015 19:00:00	260 10kt G	OUT	37+37/38	37/34+34	37/38
05 Jun 2015 19:20:00	260 10kt G	OUT	37+37/38	37/34+34	37/38
05 Jun 2015 19:40:00	260 10kt G	OUT	37+37/38	37/34+34	37/38
05 Jun 2015 20:00:00	260 10kt G	OFF	37+37/38	37/34+34	37/38
05 Jun 2015 20:20:00	260 10kt G	OFF	37+37/38	40/34+34	37/38
05 Jun 2015 20:40:00	260 10kt G	NIGHT	37+37/38	40/34+34	25/24
05 Jun 2015 21:00:00	250 9kt G	NIGHT	unknown	unknown	25/24
05 Jun 2015 21:20:00	250 9kt G	NIGHT	unknown	unknown	25/24
05 Jun 2015 21:40:00	250 9kt G	NIGHT	unknown	unknown	25/24
05 Jun 2015 22:00:00	250 9kt G	NIGHT	unknown	unknown	25/24
05 Jun 2015 22:20:00	250 9kt G	NIGHT	unknown	unknown	25/24

Showing 1 to 87 of 87 entries

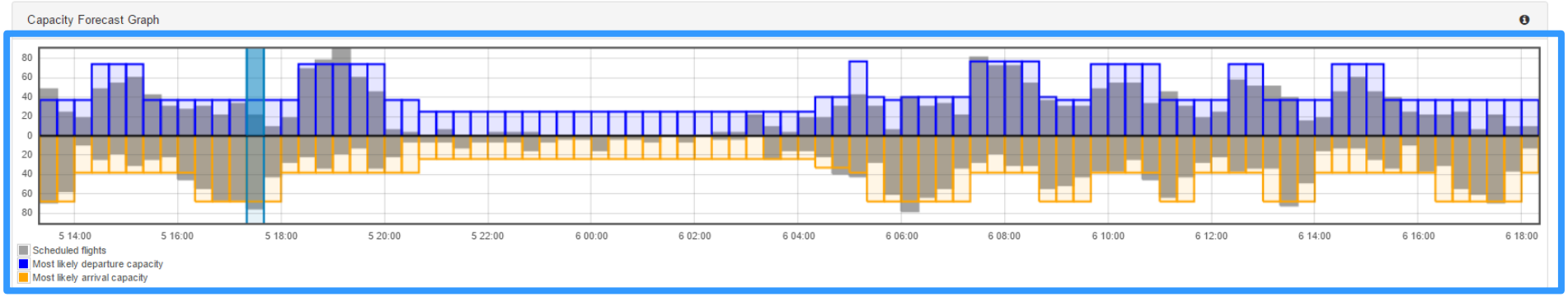
Runway Combination Forecast

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)



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
05 Jun 2015 18:20:00	260 10kt G	OUT	37+37/38	37/34+34	37/38
05 Jun 2015 18:40:00	260 10kt G	OUT	37+37/38	37/34+34	37/38
05 Jun 2015 19:00:00	260 10kt G	OUT	37+37/38	37/34+34	37/38
05 Jun 2015 19:20:00	260 10kt G	OUT	37+37/38	37/34+34	37/38
05 Jun 2015 19:40:00	260 10kt G	OUT	37+37/38	37/34+34	37/38
05 Jun 2015 20:00:00	260 10kt G	OFF	37+37/38	37/34+34	37/38
05 Jun 2015 20:20:00	260 10kt G	OFF	37+37/38	40/34+34	37/38
05 Jun 2015 20:40:00	260 10kt G	NIGHT	37+37/38	40/34+34	25/24
05 Jun 2015 21:00:00	250 9kt G	NIGHT	unknown	unknown	25/24
05 Jun 2015 21:20:00	250 9kt G	NIGHT	unknown	unknown	25/24
05 Jun 2015 21:40:00	250 9kt G	NIGHT	unknown	unknown	25/24
05 Jun 2015 22:00:00	250 9kt G	NIGHT	unknown	unknown	25/24
05 Jun 2015 22:20:00	250 9kt G	NIGHT	unknown	unknown	25/24

Showing 1 to 87 of 87 entries

Runway Combination Forecast

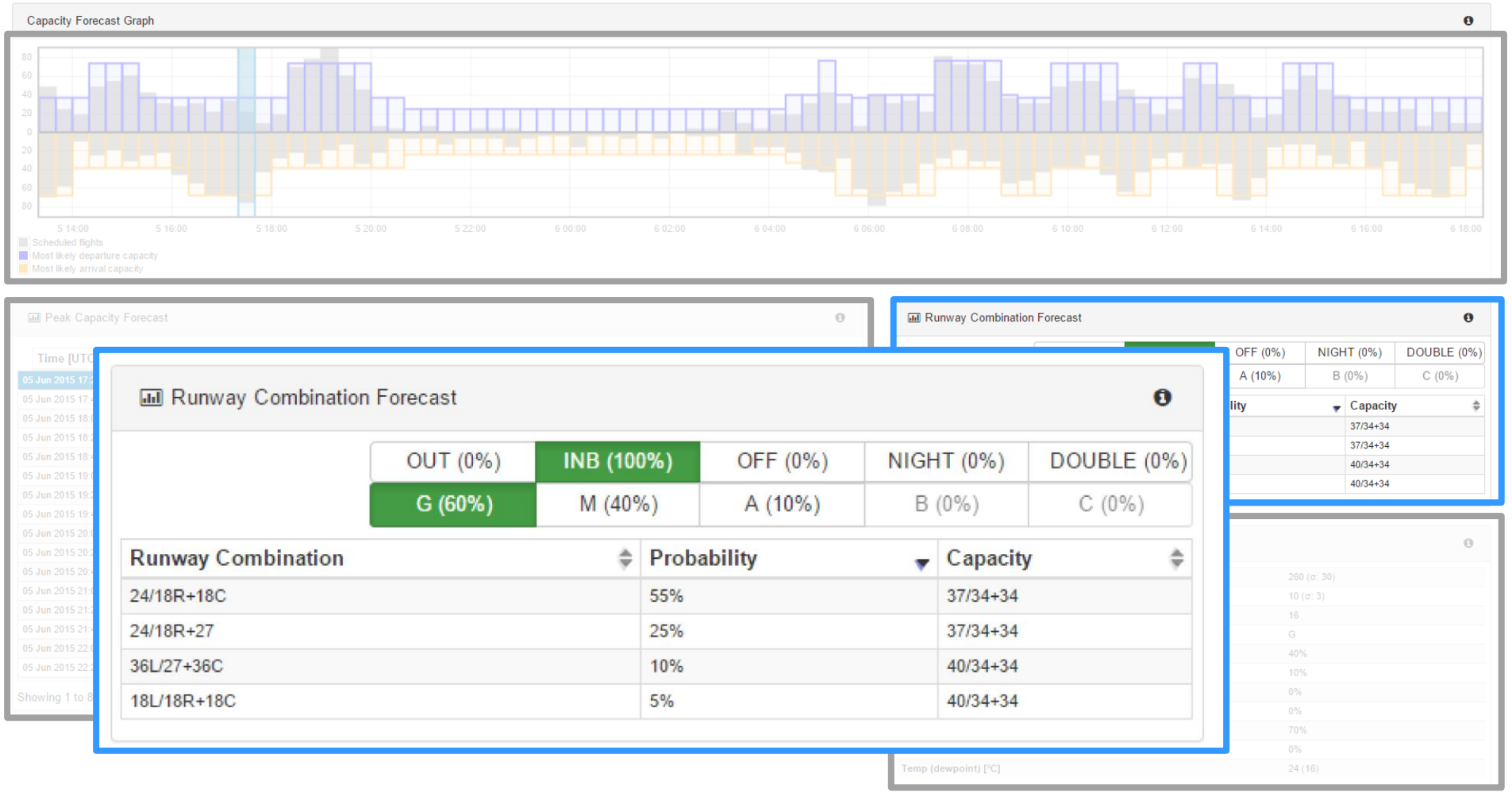
OUT (0%)	INB (100%)	OFF (0%)	NIGHT (0%)	DOUBLE (0%)
G (60%)	M (40%)	A (10%)	B (0%)	C (0%)

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)

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



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)

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.

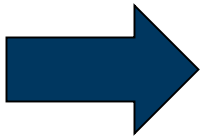
Source: KNMI

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

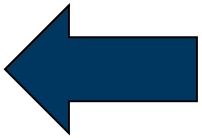
Probability Forecast Runway Use

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

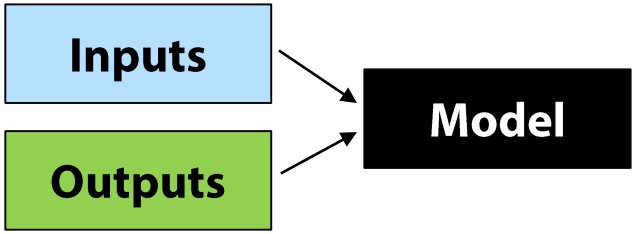
- Available runways
- Number of departure and arrival runways needed
- Wind direction, wind speed and gust
- Visibility (horizontal & cloud base)
- Daylight conditions (yes/no)

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

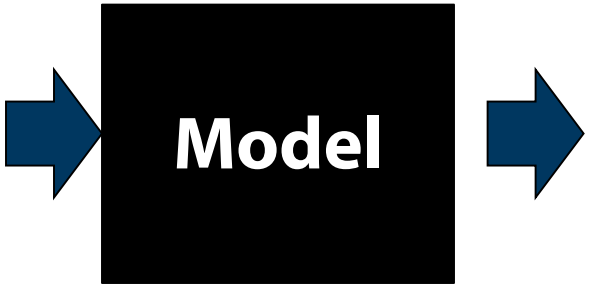
Wind	Visibility (GMB)	UDP (Y/N)
320 10kt	G	Y
320 10kt	G	Y
310 10kt	G	Y
310 10kt	G	Y
310 10kt	G	Y
…	…	…
180 6kt	M	Y

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

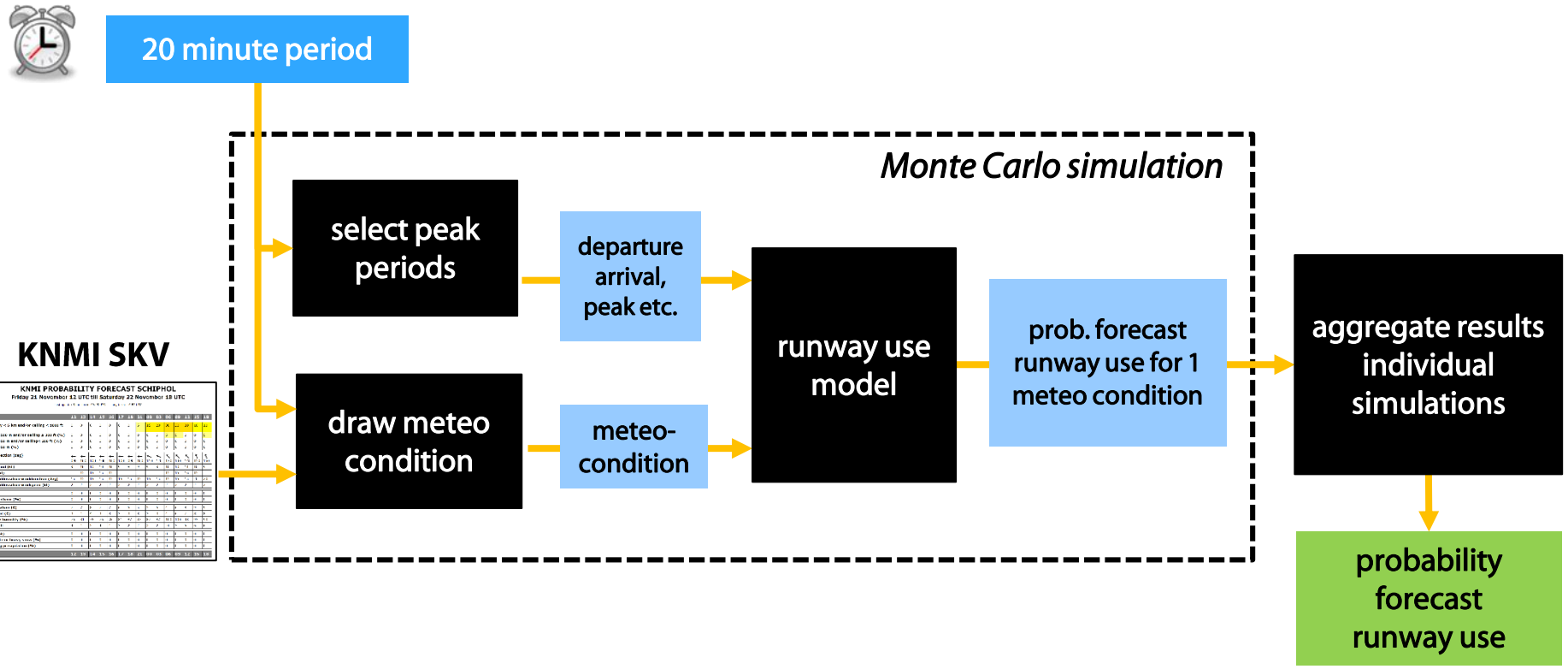
Prediction phase (use)

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%

Monte Carlo simulations with runway use model



"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

Positive effect on decision making

- Fuel advices later
- Cancellations earlier
- More targeted decision making
  - Fuel advices per fleet segments (EUR/ICA) and time frame

For more information and results, see the paper presented at the SESAR Innovation Days 2016

http://www.sesarinnovationdays.eu

Final Remarks

Various applications of simulations to support decision making at airports, airlines and air traffic control

- Strategic and operational level
- Key areas are capacity, safety, efficiency, and environment

Selecting the right simulation is key

- What decision information should the simulation provide?
  - Performance areas and indicators
  - Deterministic or probability (stochastic)?

- Other considerations
  - Model availability
  - Model fidelity
  - Time and Budget
  - Compliance

Supporting Strategic and Operational Decision Making in Airlines, Airports and Air Traffic Control using Simulations

30th Anniversary Symposium of the Dutch Benelux Simulation Society

November 18, Delft

Arjen de Leege, PhD, MSc
Senior Aviation Consultant

to70