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Learnings from ATM-KPIs - MET-potentials for arrival- and departure management

MET4LOWW Workshop
11 April 2018, Vienna International Airport, Austria

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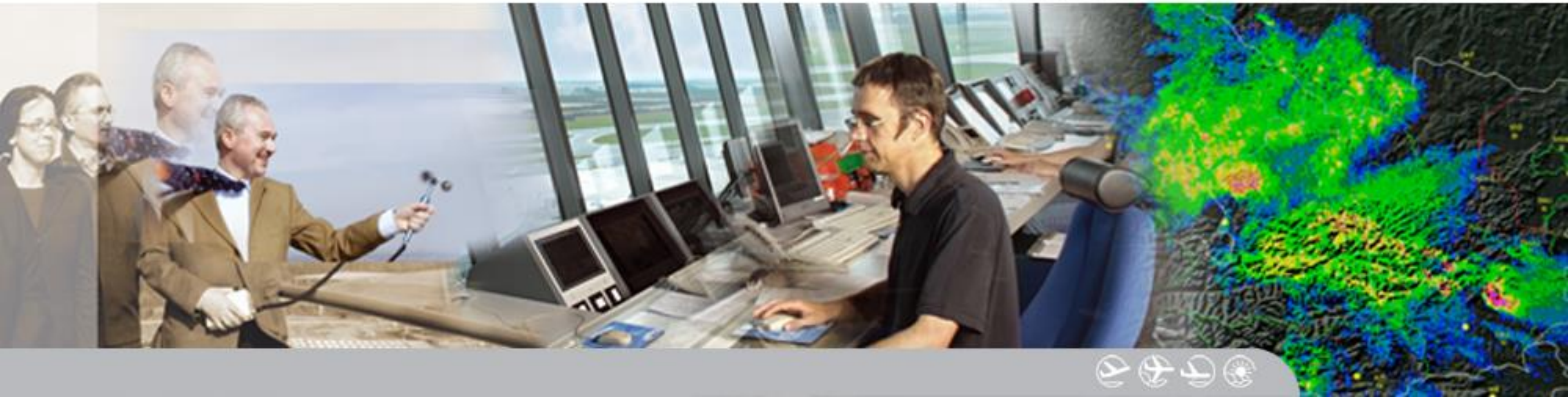
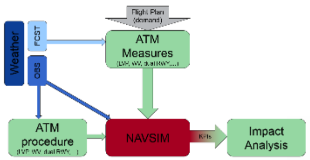
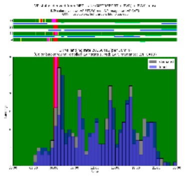
SICHERHEIT LIEGT IN DER LUFT



Outline

- The Motivation
  - Why are we doing it…
- The Method
  - How are we doing it…
- The Tool
  - What do we use to do it…
- Case Studies
  - What we do in action…
- The way forward
  - How to use the results…





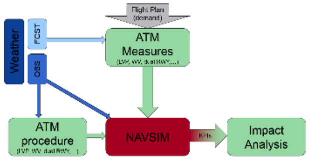
The Motivation

Weather impact on Air Traffic Management

- Weather especially wind, thunderstorms and low visibility have big impact on airport capacity
- Weather cannot be changed but accurate forecasts help to be prepared and to minimize weather impact
- Project objective: Quantify weather impact to identify mitigation potentials
- Weather impact in numbers:
  - Vienna International airport:

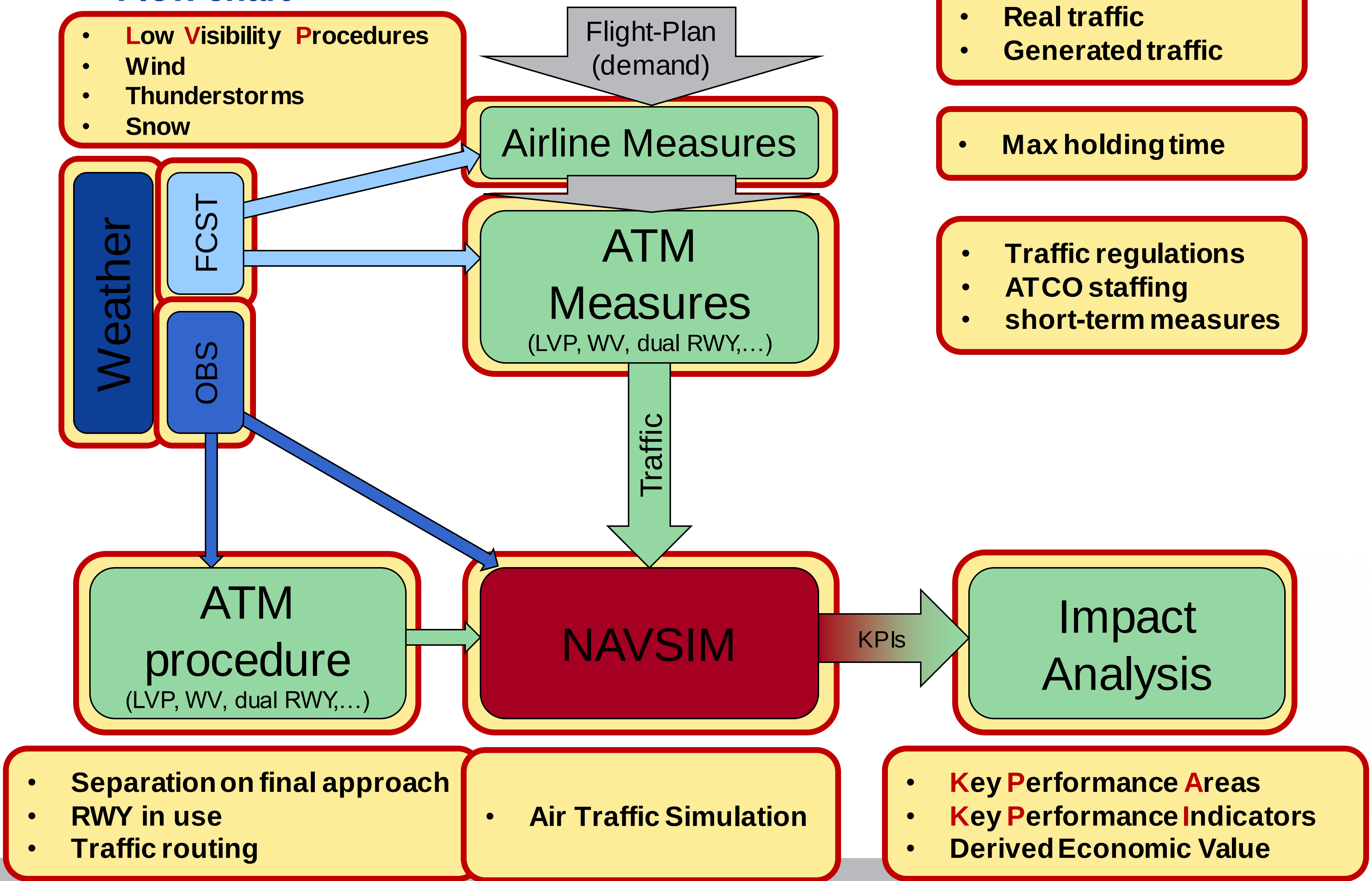
Delays LOWW ARR Oct. 2015 - Mar. 2016			
	minutes	min/flight	percentage
Weather	66 214	0,59	89%
Total	74 121	0,66	

The Method


Flight Plan (demand)
Weather
FCST
OBS
ATM Measures
ATM procedure
NAVSIM
KPIs
Impact Analysis

Weather impact analysis

Flow chart



Weather impact analysis
Methodology

- Cost matrix based on air traffic simulations

Weather event occurs in simulation

Weather event does NOT occur in simulation

		Observed	
		Yes	No
Action taken	Yes	***COST**hit*	***COST**false alarm*
	No	***COST**missed*	***COST**none*

Reduced traffic according WX-FCST

full traffic

Weather impact analysis
Challenges

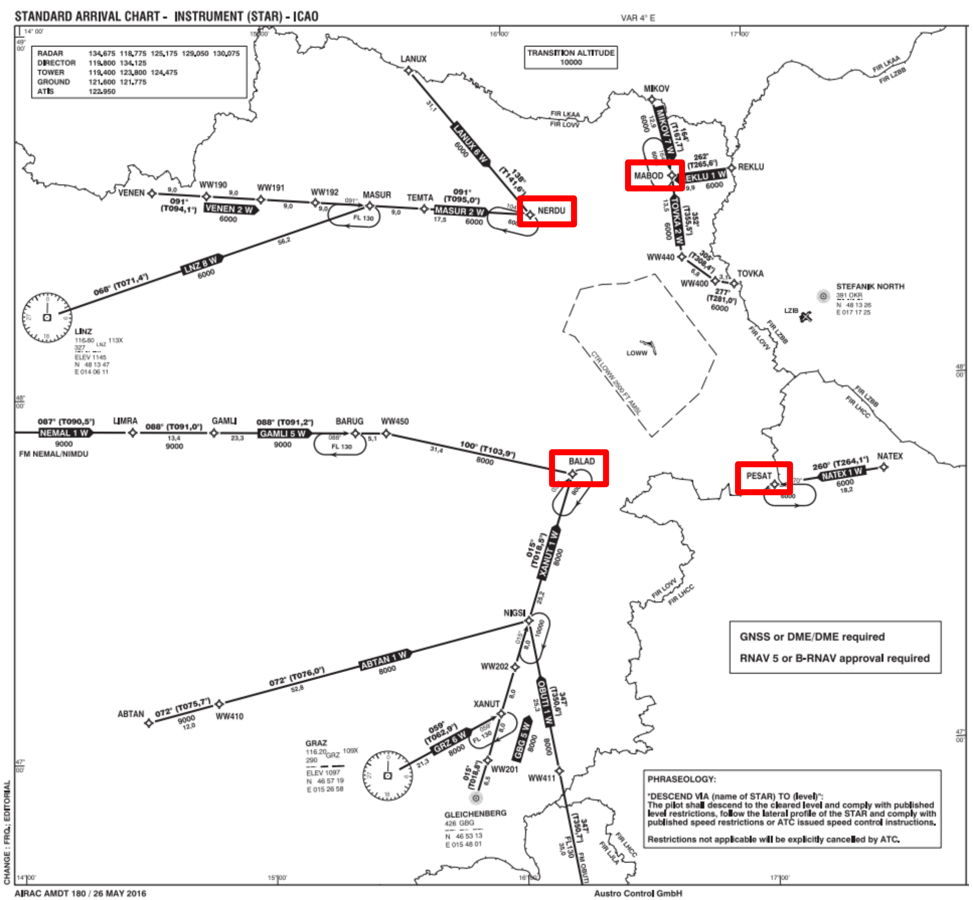
- Not everything can be readily measured in terms of money, e.g.:
  - ATM workload
  - safety
- Optimization criteria are contradictory, e.g.:
  - trade-off between maximizing capacity and optimizing workload
  - trade-off between optimizing workload and minimizing flight delays
  - etc…
- Different stakeholders (ANSP, airlines, airports,…) prioritize optimization criteria differently
  - e.g. ATM workload is not airlines' first priority
- To quantify the impact on the overall air traffic management system all stakeholders' requirements must be considered and balanced

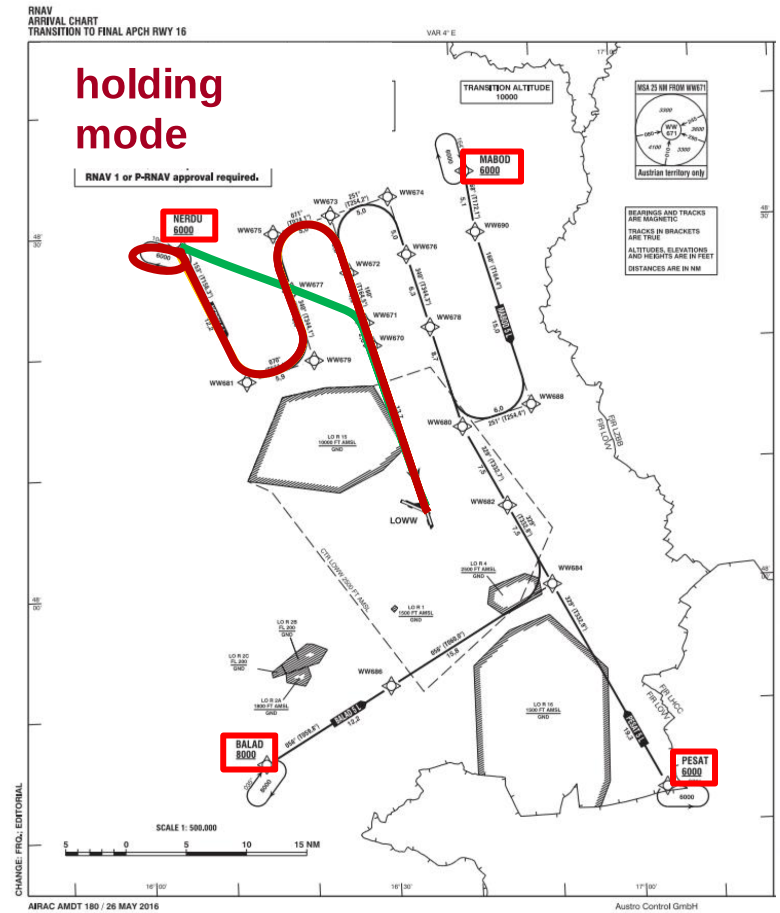
The Tool

NAVSIM / AMAN
Air traffic simulation

- Detailed simulation of arrival procedures
  - Simulation is initialized with traffic at STAR endpoints
  - Weather (wind, LVP, TS) is realistically considered
  - Detailed performance analysis based on various KPIs

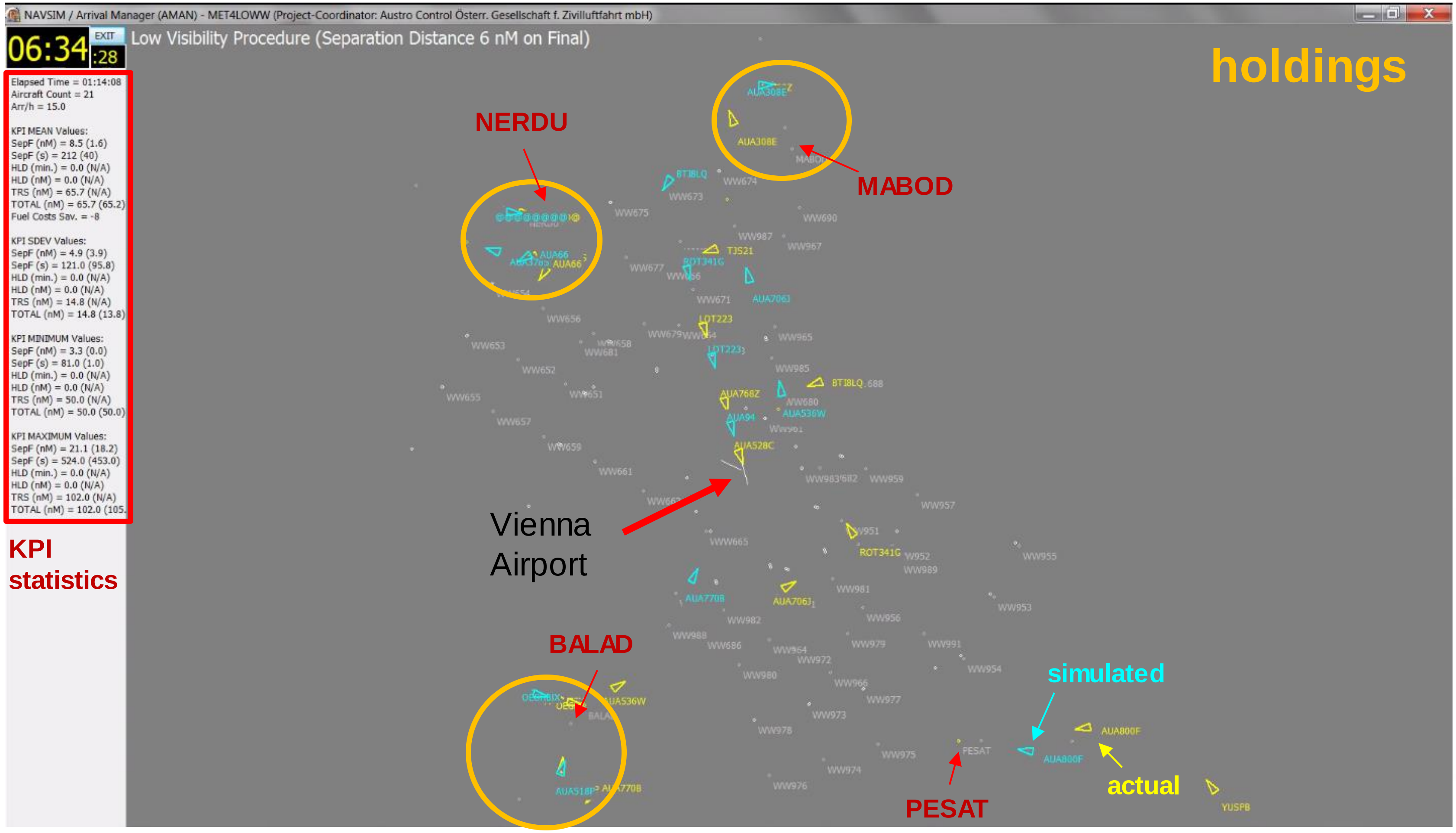
<u>Note</u>: NAVSIM ATM/ATC/CNS Tool developed by Mobile Communications Research & Development Forschungs GmbH in co-operation with USBG





NAVSIM / AMAN
Validation

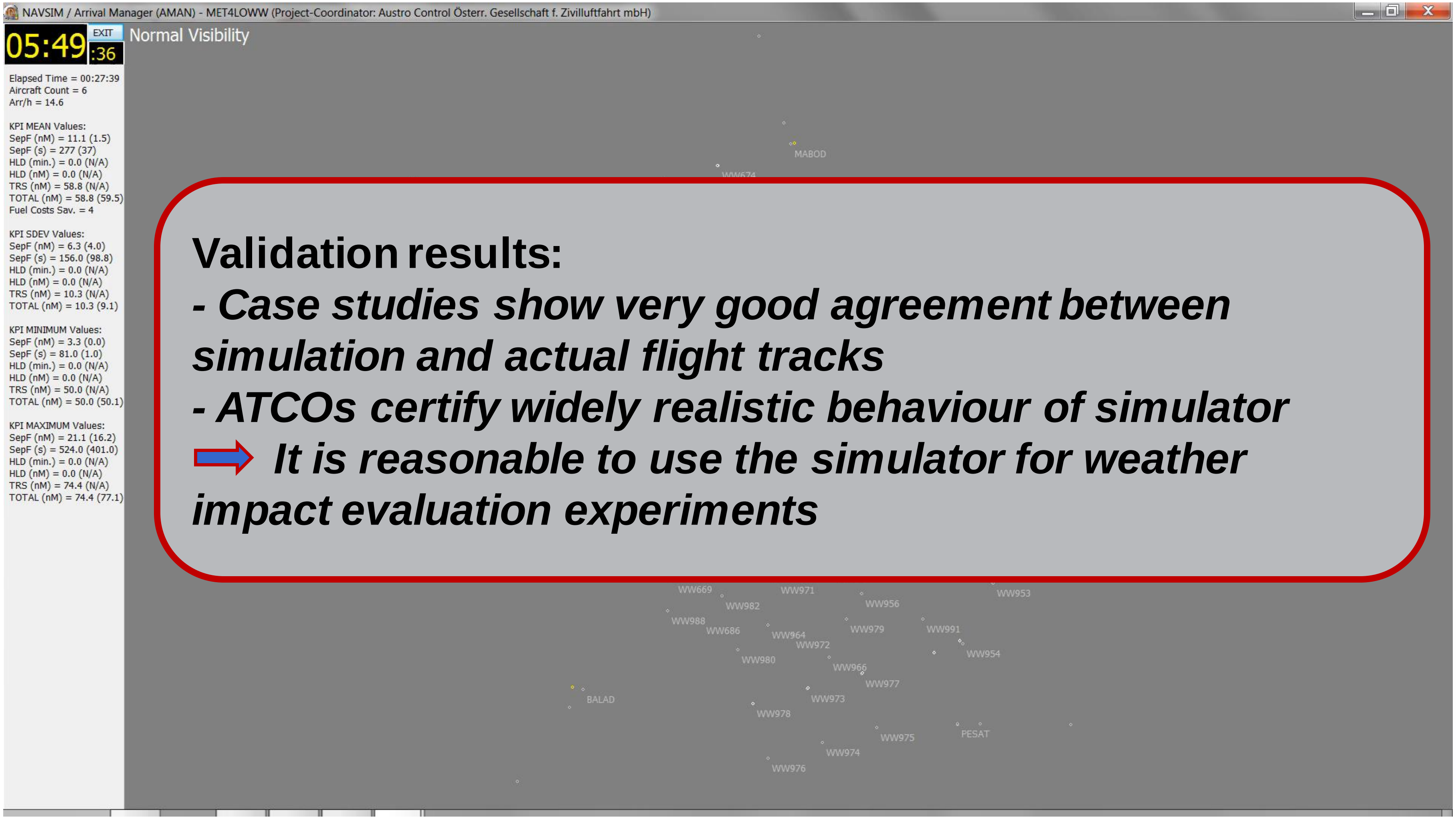
- Compare actual flight path to simulated flight path
  - Simulation is initialized with actual traffic at STAR endpoints
  - Compare simulation and actual flight paths between STAR endpoints and touchdown



yellow: CPR; blue: simulated

NAVSIM / AMAN
Validation - video

- Low Visibility Procedures (LVP) during morning rush hour



Validation results:

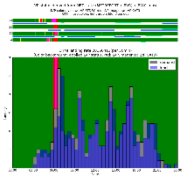
- Case studies show very good agreement between simulation and actual flight tracks

- ATCOs certify widely realistic behaviour of simulator

➡ It is reasonable to use the simulator for weather impact evaluation experiments

yellow: CPR; blue: simulated

Case Studies



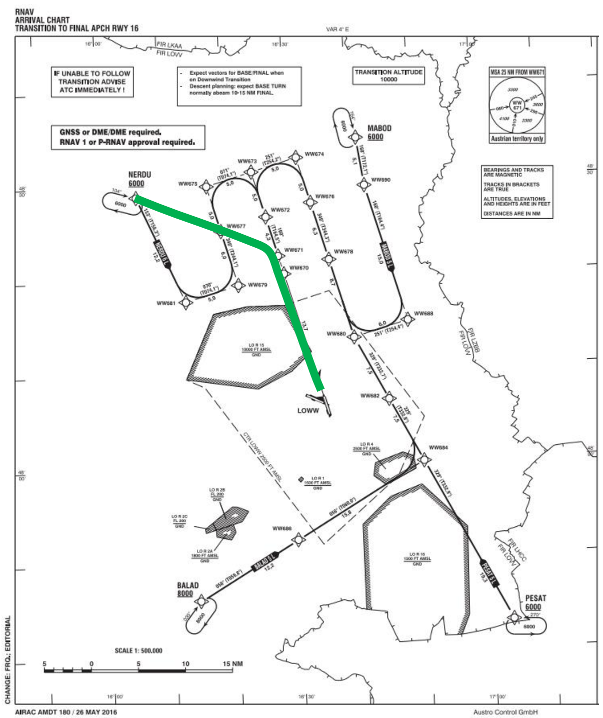
KPIs explained

- Short introduction to **K**ey **P**erformance **I**ndicators used for impact evaluation

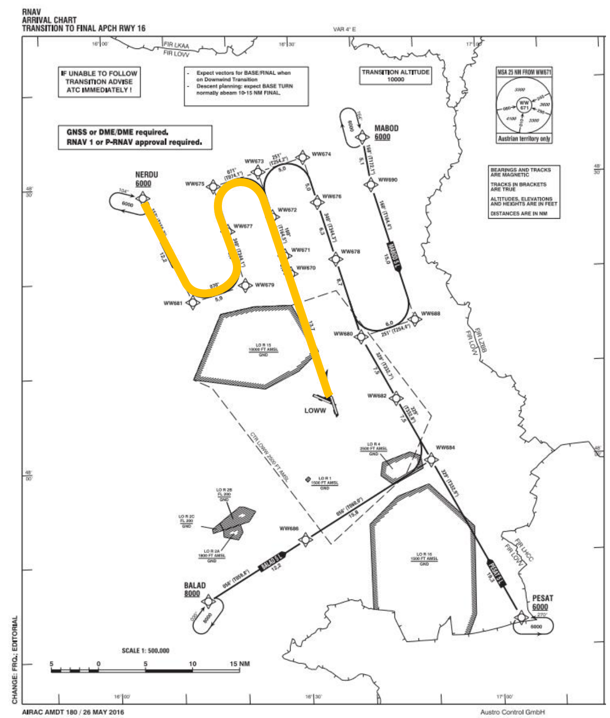
"Trackmiles" explained

- Flown distance from entry into APP sector until touchdown

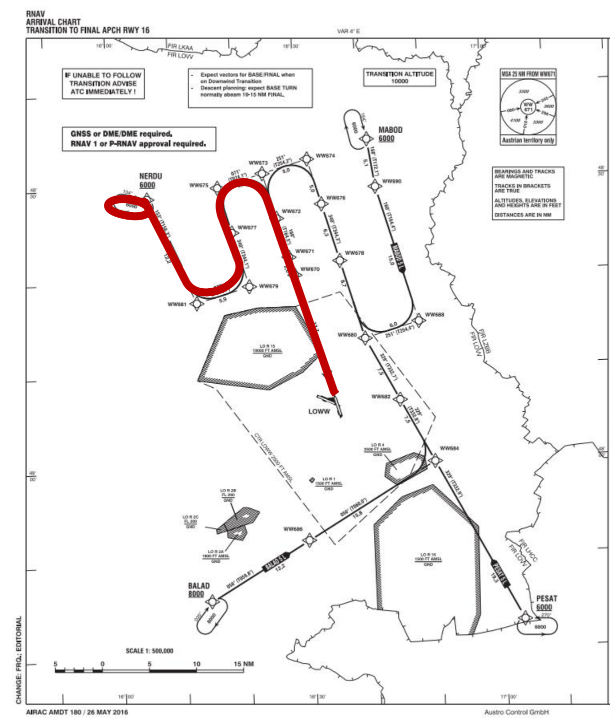
direct mode



transition mode



holding mode

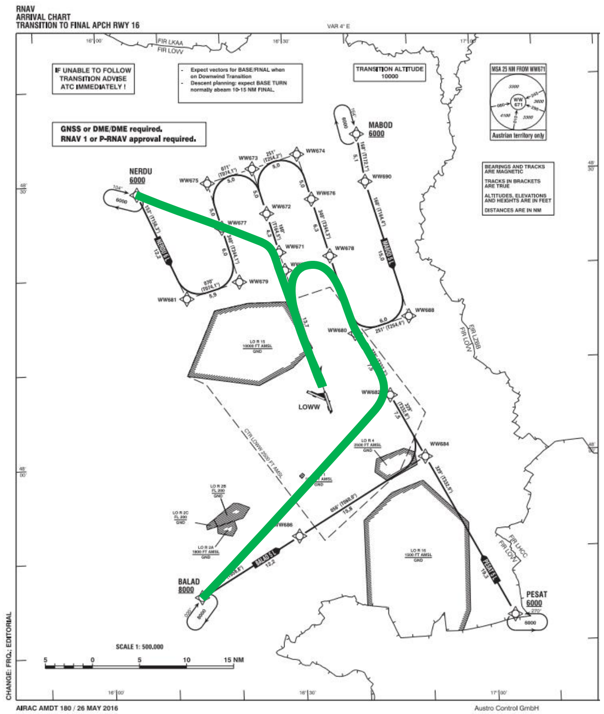


"Lateral efficiency" explained

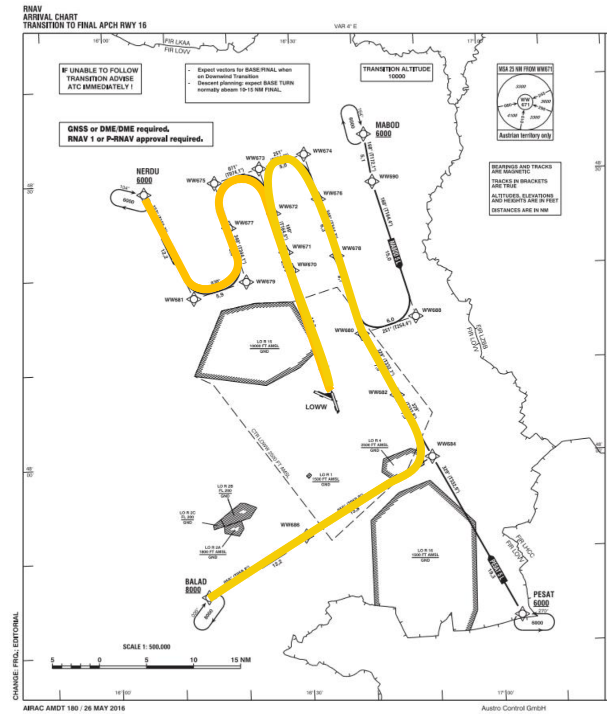
- Excess distance an aircraft flies in arrival phase compared to ideal case

$$\text{Lateral efficiency} = \frac{\text{Flown distance}}{\text{Ideal distance}}$$

ideal distance

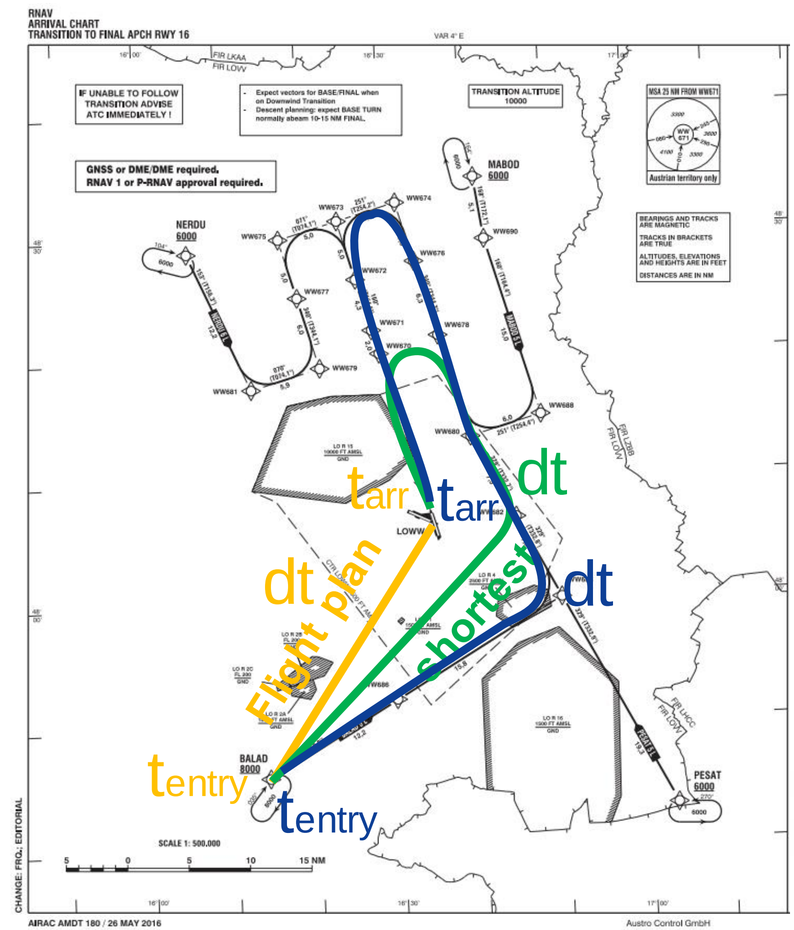


Flown distance



“Arrival delay” vs. “Regulated delay” explained

- “Regulated delay”
  - Delay on ground at origin due to traffic regulation (ATFM delay)
    $t_{entry} = t_{entry} + \text{RegDelay}$
- “Arrival delay”
  - Delay airborne in arrival sector due to holding or longer transition
    $\text{ArrDelay} = dt - dt$
  - Arrival delay always bigger than 0 because dt is constant (not RWY specific; no wind)
  - In evaluation arrival delay relative to base scenario



“Cost of delay” and “Cost of diversion” explained

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- Cost of Delay

A. Cook, G. Tanner, *European airline delay cost reference values, updated and extended values*. Version 4.1, https://www.eurocontrol.int/publications/european-airline-delay-cost-reference-values (2015).

  – Regulated delay cost

Table 26. AT-GATE / BASE / full tactical costs

Delay (mins)	5	15	30	60	90	120	180	240	300
B733	70	430	1 550	7 020	19 160	36 220	49 040	66 480	89 310
B734	80	480	1 740	7 930	21 690	40 960	55 340	74 780	100 040
B735	70	390	1 400	6 280	17 110	32 350	43 900	59 720	80 590
B738	90	540	1 940	8 860	24 270	45 750	61 740	83 220	110 920
B752	100	620	2 290	10 620	29 250	55 150	74 240	99 700	132 200
B763	170								
B744	240								
A319	70								
A320	80								
A321	100								
AT43	30								
AT72	40								
DH8D	40								
E190	60								
A332	180								

  – Arrival delay cost

Table 29. ARRIVAL MGT / BASE / full tactical costs

Delay (mins)	5	15	30	60	90	120	180	240	300
B733	210	850	2 400	8 710	21 690	39 580	54 090	73 210	97 720
B734	250	980	2 730	9 910	24 670	44 930	61 300	82 730	109 970
B735	180	740	2 090	7 680	19 200	35 140	48 090	65 310	87 580
B738	250	1 020	2 910	10 790	27 160	49 610	67 530	90 940	120 570
B752	290	1 180	3 420	12 880	32 640	59 670	81 010	108 730	143 480
B763	480	1 830	5 070	18 510	45 560	92 770	133 090	167 800	210 660
B744	710	2 760	7 780	29 000	72 060	147 460	211 020	264 690	330 020
A319	220	890	2 510	9 130	22 760	41 470	56 660	76 660	102 220
A320	250	1 000	2 820	10 370	25 940	47 270	64 460	86 940	115 440
A321	280	1 130	3 260	12 210	30 880	56 400	76 670	103 060	136 260
AT43	70	290	830	3 030	7 590	14 130	19 830	28 060	39 730
AT72	90	370	1 090	4 130	10 490	19 490	26 980	37 480	51 870
DH8D	110	450	1 280	4 690	11 720	21 570	29 840	41 270	56 710
E190	180	690	1 880	6 600	16 150	29 350	40 430	55 240	74 620
A332	470	1 840	5 250	19 880	49 730	102 150	146 340	184 100	230 690

- Cost of diversion

Standard Inputs for EUROCONTROL Cost-Benefit Analyses. Edition Number: 8.0. Edition Date: January 2018

Type of flight	Cost of flight diverted (€)
Regional flights	830 – 5 900
Continental flights	1 180 – 8 900
Intercontinental flights	5 900 – 65 000

Other KPIs

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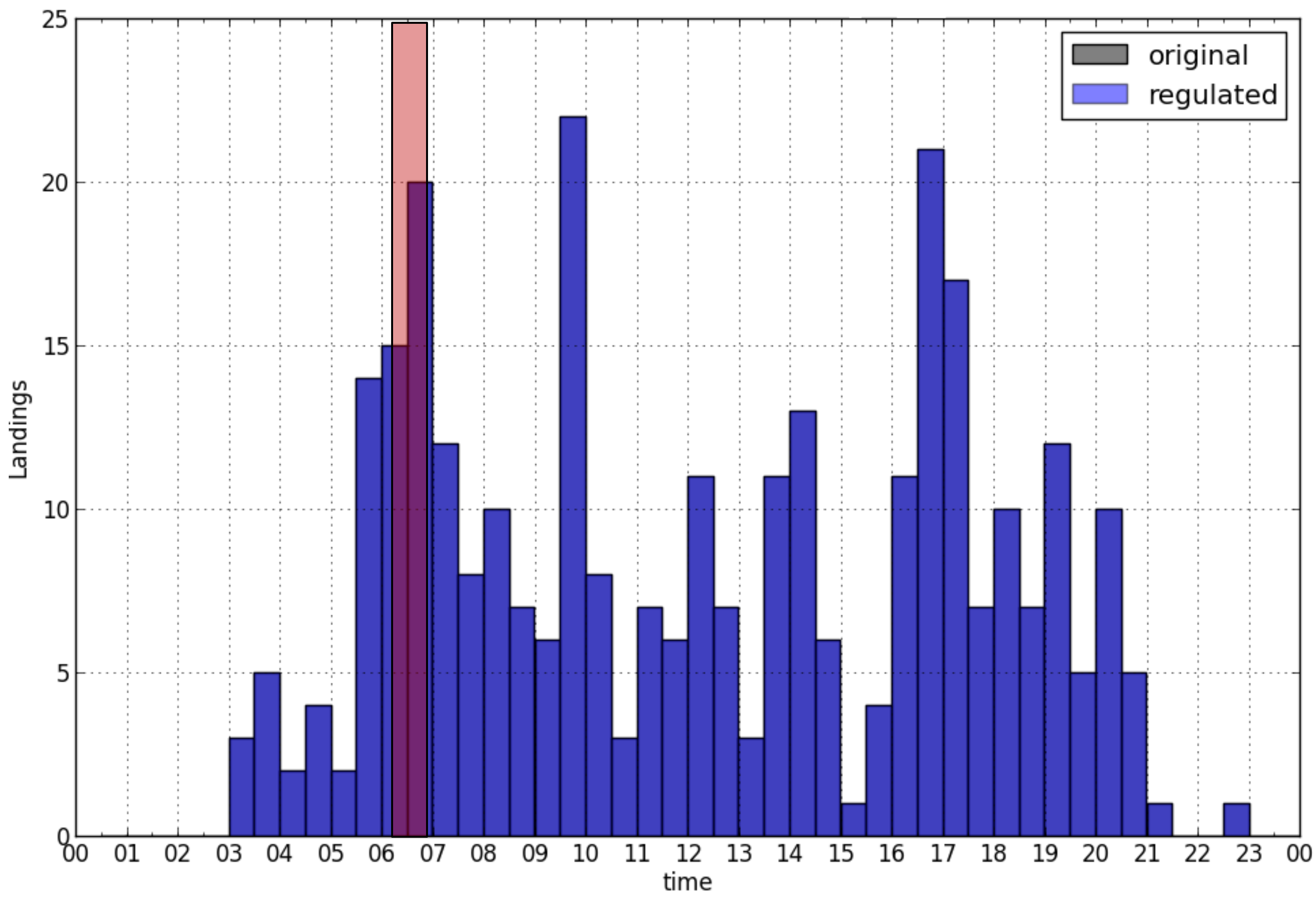
- Mean spacing at touchdown
  - Mean of distance to leader at leader touch-down
- Number of diverts
  - Number of flights diverted, because holding time exceedes max. holding time (default = 20 minutes)
- Ground speed variance
  - Variance of ground speed from all aircraft positions in time range
- Traffic variability
  - Peak traffic (flights airborne) and average traffic (flights airborne) during the simulation
- ATCO command/phrases
  - Evaluate commands/phrases related to traffic and derive frequency occupation from it

Workload

RWY - closure

RWY - closure

- Arrival runway is closed for 45 minutes during morning peak
  (synthetic example)



Case study
Runway closure – synthetic example

- Cost matrix scenarios were simulated:

		Observed	
		Yes	No
Action taken	Yes	***hit:*** RWY closure and forecasted	***false alarm:*** No RWY closure, but forecasted
	No	***miss:*** RWY closure, but not forecasted	***none:*** No RWY closure and none forecasted

Case study

Runway closure – synthetic example

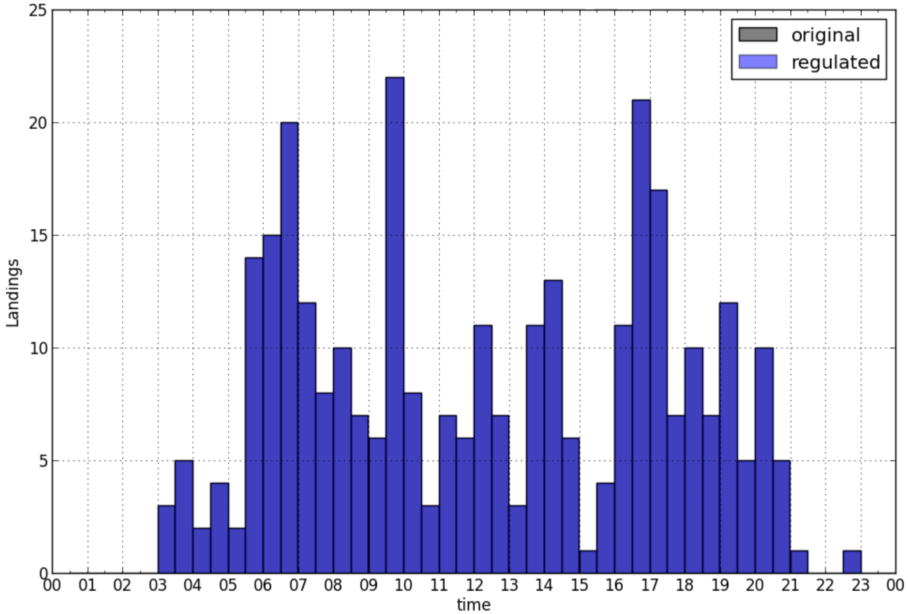
- No action taken
  - No traffic regulation applied
  - Average possible maximum holding time: 20 minutes

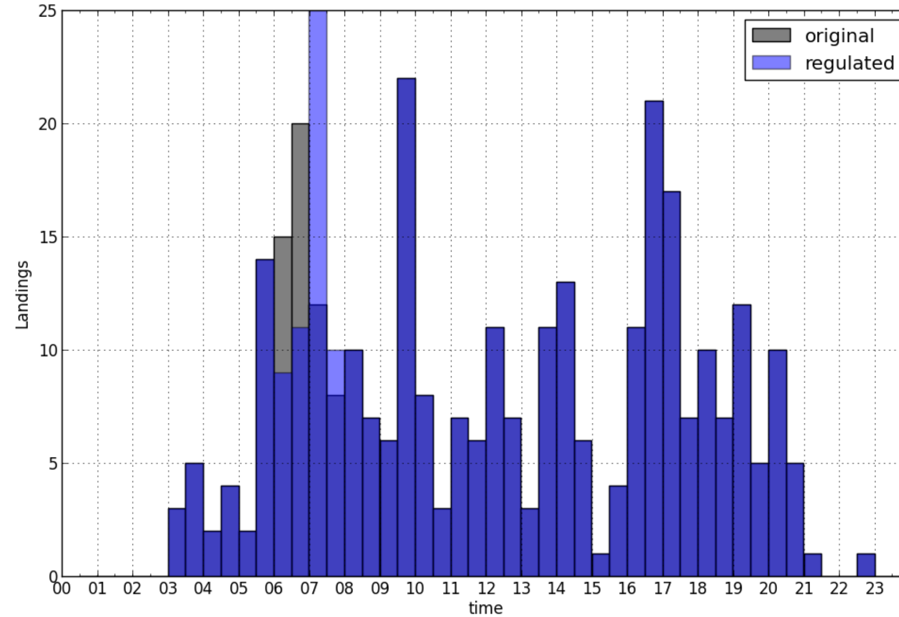
- Action taken
  - Traffic regulated

    Regulation issued at 05:00:

    06:10 to 06:55: acceptance rate 0
  - Average possible maximum holding time: 30 minutes

Simplified assumptions:
- in m case regulation would be applied once event happens
- in f case regulation would be cancelled once event does not happen

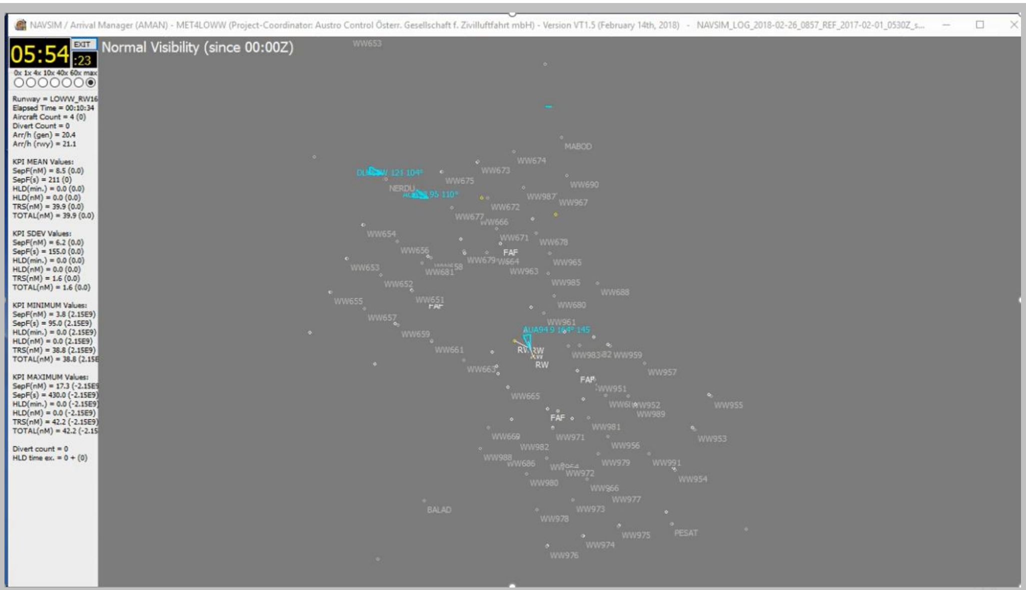




Simulation
RWY closure well forecasted

RWY closure well forecasted
- Extra fuel reserve – less diverts
- Traffic regulation

RWY closure not forecasted
- Normal fuel reserve - more diverts
- No traffic regulation – longer holding time



Case study
Runway closure – synthetic example

KPIs:

2.5 hours
75 flights

	none	false alarm	miss	hit
Diversions	0	0	15	3
Trackmiles / flight [NM]	64.3	70.8	67.8	84.5
Holding time [min]	46	71	239	291
Holding time / flight [min]	0.62	0.95	3.19	3.89
Regulated delay [min]	0	823	0	823
Regulated delay / flight [min]	0	11	0	11
Regulated delay cost [€]	0	19,710	0	19,710
ARR delay cost [€]	0	1,630	10,090	20,060
Diversion cost [€]	0	0	124,500	23,700
Total cost [€]	0	21,340	134,590	63,470
Total cost / flight [€]	0	285	1,795	846

- Cost estimates based on:
  - Delay costs:
    A. Cook, G. Tanner, *European airline delay cost reference values, updated and extended values*. Version 4.1, https://www.eurocontrol.int/publications/european-airline-delay-cost-reference-values (2015).
  - Diversions:
    Standard Inputs for EUROCONTROL Cost-Benefit Analyses. Edition Number: 8.0. Edition Date: January 2018

Case study
Runway closure – synthetic example

- How do results relate to weather forecasts?
  - Cost / Loss ratio can be derived from cost matrix – important when using probability forecasts
  - Together with contingency table of specific forecast the forecast value can be derived
- Other insights from this analysis method
  - Impact of different actions can be evaluated
  - Decision processes and weather forecasts can be aligned

Cost matrix:

		Observed	
		Yes	No
Action taken	Yes	***63,470 €***	***21,340 €***
	No	***134,590 €***	***0 €***

Cost / Loss ratio in this example: 0.23

Forecast contingency table:

		Observed	
		Yes	No
Forecasted	Yes	***h***it	***f***alse alarm
	No	***m***issed	Correct ***n***egative
		o = h + m	1 - o

Time Based Separation

The concept

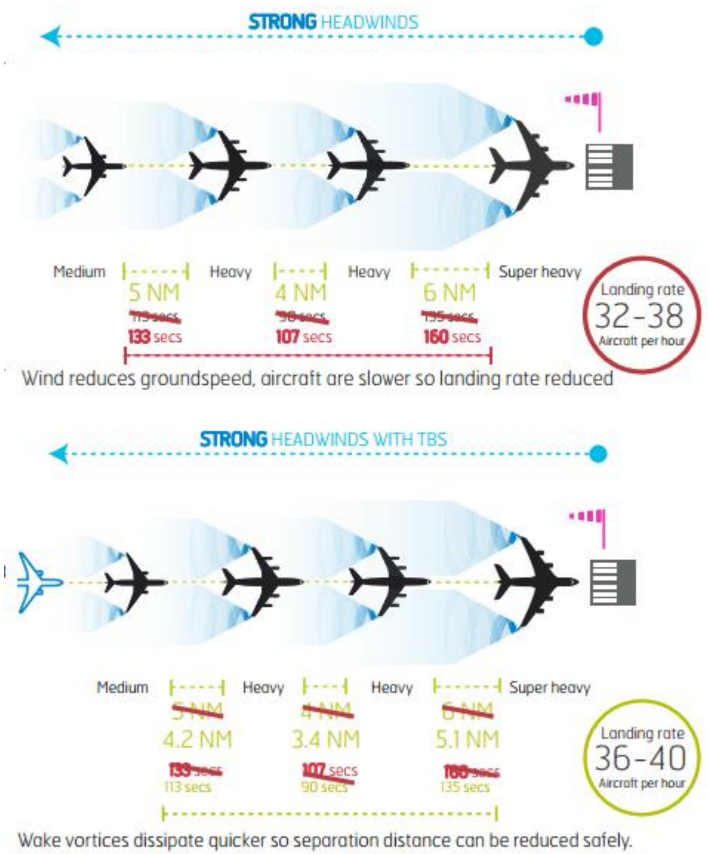


Diagram from NATS leaflet at
http://www.nats.aero/wp-content/uploads/2014/12/TBS-Crew-Fact-Sheet1.pdf

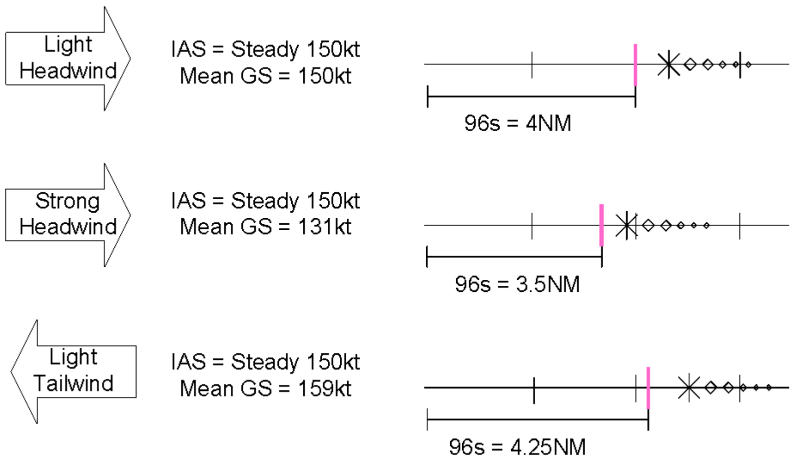


Figure 3: Variation of the Distance Separation of the TBS with Headwind Conditions

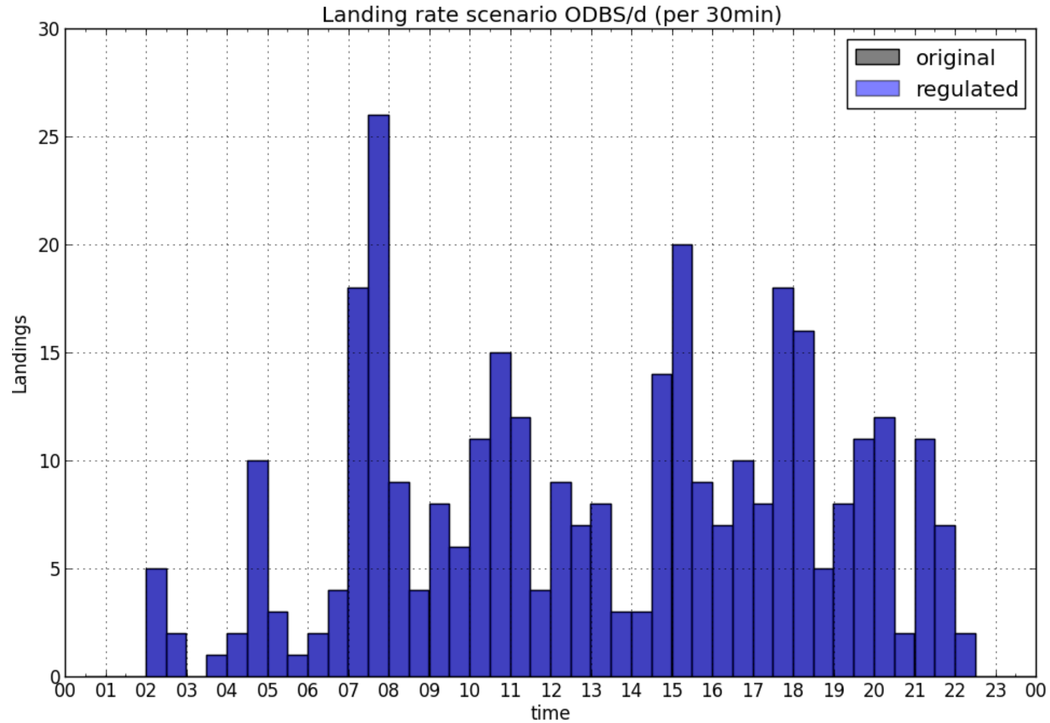
Mean Headwind	Time Spacing Impact
15kts	6.7 %
25kts	14.3 %
35kts	23.1 %

Table 7: Time Spacing Impact of Headwind Conditions

SESAR 06.08.01 D05 - Operational Service and Environment Definition (OSED) for Time Based Separation for Arrivals (TBS)

Case study
Distance Based (DBS) vs. Time Based (TBS) Separation

- Traffic:



- Head wind speed [kt] time series:

height	06:00	07:00	08:00	09:00	10:00	11:00	12:00	13:00	14:00	15:00	16:00	17:00	18:00	19:00	20:00	21:00	22:00
0 ft	11	11	12	14	16	11	8	12	14	12	8	5	5	7	5	7	7
300 ft	15	15	16	18	21	15	12	16	18	16	11	8	8	10	9	11	11
700 ft	19	19	19	22	25	18	15	19	21	18	13	11	10	12	12	14	12
1000 ft	22	22	22	24	27	21	18	21	22	20	15	14	12	14	15	16	13
1300 ft	26	25	25	27	30	25	20	23	23	21	16	16	14	14	18	18	15
1600 ft	28	27	29	31	33	29	23	25	24	22	18	18	16	15	20	20	16
2000 ft	27	27	32	34	36	32	26	26	25	23	20	20	18	16	21	22	19
2300 ft	25	24	34	37	39	36	30	28	26	24	22	21	20	17	22	24	20
2600 ft	22	21	33	34	40	37	34	28	27	25	24	23	20	17	22	26	20
3000 ft	21	20	29	29	40	39	35	29	29	27	26	24	20	18	22	26	20

Case study
Distance Based (DBS) vs. Time Based (TBS) Separation

Wind conditions:
RWY headwind: ~ 15kt
600ft headwind: ~ 25kt

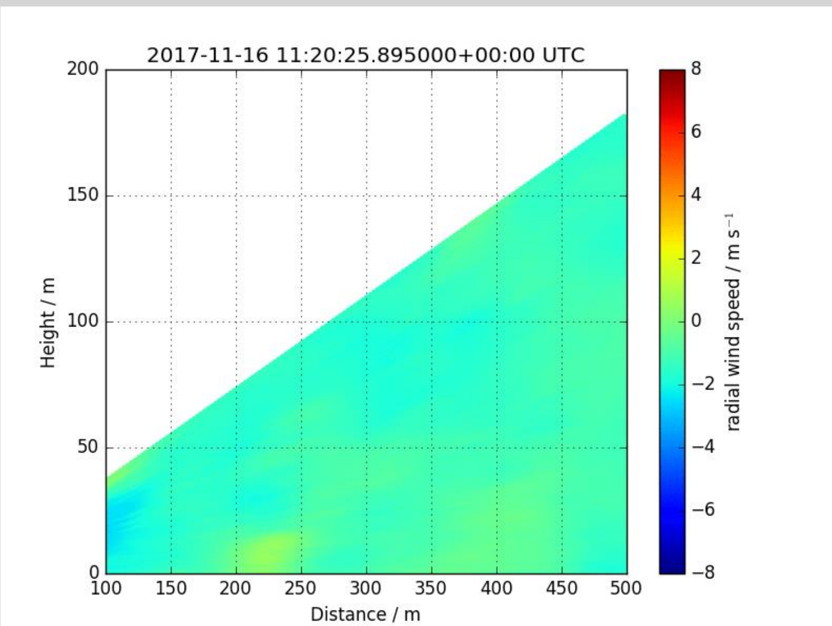
KPIs:
16 hours
305 flights

	DBS	TBS	DBS no wind
Trackmiles / flight	63.7	58.0	60.2
Holding time [min]	205	52	105
Holding time / flight [min]	0.68	0.17	0.34
ARR delay [min]	625	186	0
ARR delay / flight [min]	2.0	0.6	0
ARR delay cost [€]	44,330	13,480	0
ARR delay cost / flight [€]	145.3	44.2	0
Mean spacing at touchdown [NM]	4.1	3.9	4.3
Lateral efficiency [ ]	1.197	1.070	1.117

Wake Vortex Separation

- Wake Vortex separation is an important constraint for TBS procedures
- Pairwise weather dependent separation can be used to optimize separation/RWY throughput

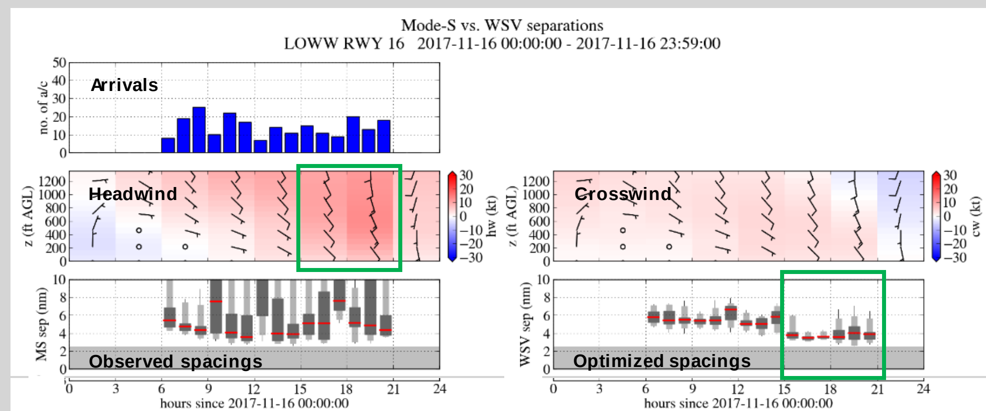
- WV measurements for SESAR2020 Plate Lines project
- A380 wake measured by DLR-LIDAR



Animation starts at 11:20:25

- DLR WSBVS* Wake Vortex Prediction System
- separation calculation for individual aircraft pairings (leader + follower) based on atmospheric conditions

16 November 2017
Arrivals at Vienna Airport, RWY 16



As the wind strengthens, the separation distance can be reduced …

* WSBVS: Wirbelschleppen Beobachtungs- und Vorhersagesystem

Low visibility Procedures

- What are **L**ow **V**isibility **P**rocedures

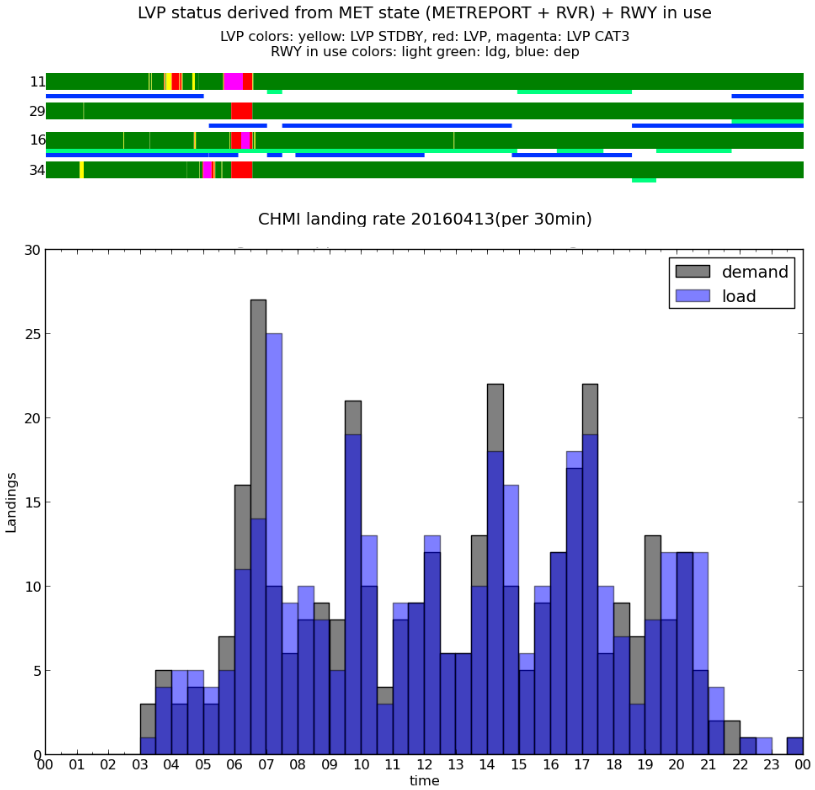
LVP state	RVR	Ceiling	Spacing	Capacity
normal			2.5NM	>40
LVP	< 600m	BKN < 200ft	4NM	25
LVP CATIII	< 350m		6NM	18

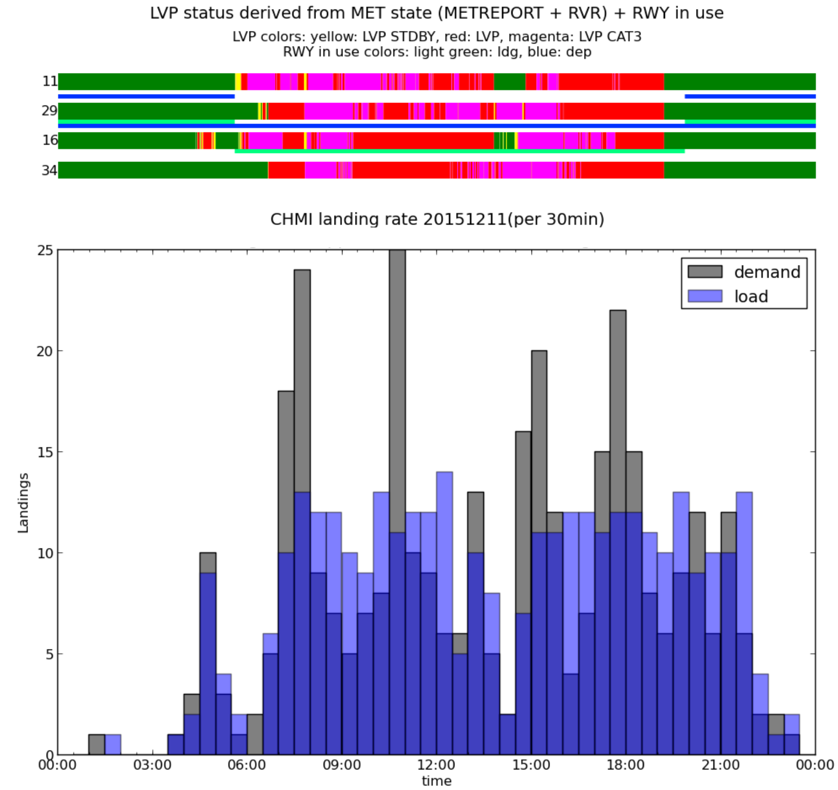
- LVP seen from the cockpit: https://www.youtube.com/watch?v=mSNE3SmYA-8

- ~44.000 delay minutes at LOWW in 2017 because of LVP

Case studies
Low Visibility Procedures

- Simulation of two scenarios
  - Short period (1.5h) of LVP during morning peak
  - Long period (13h) of LVP during daytime





Case studies
Low Visibility Procedures

- For both scenarios the cost matrix scenarios were simulated :

		Observed	
		Yes	No
Take action	Yes	***hit:*** LVP observed and forecasted. Traffic regulated according forecast.	***false alarm:*** No LVP observed, but forecasted. Traffic regulated according forecast.
	No	***miss:*** LVP observed, but not forecasted. Traffic is regulated once LVP observed.	***none:*** No LVP observed and none forecast. No traffic regulation (i.e. full traffic).

Case studies
Low Visibility Procedures - KPIs

Short event:

1.5 hours
103 flights

	none	false alarm	miss	hit
Diversions	0	0	0	0
Trackmiles / flight [NM]	64.8	61.7	66.8	63.0
Holding time [min]	54	33	77	37
Regulated delay [min]	0	175	215	276
Regulated delay cost [€]	0	1,010	3,790	2,940
ARR delay cost [€]	0	-6,130	-270	-4,510
Diversion cost [€]	0	0	0	0
Total cost [€]	0	-5,120	3520	-1,570
Total cost / flight [€]	0	-50	34	-15

Long event:

13 hours
314 flights

	none	false alarm	miss	hit
Diversions	0	0	4	0
Trackmiles / flight [NM]	68.9	65.1	72.7	69
Holding time [min]	294	92	457	184
Regulated delay [min]	0	899	3744	6395
Regulated delay cost [€]	0	9,570	163,900	208,0100
ARR delay cost [€]	0	-19,420	15,340	-220
Diversion cost [€]	0	0	35,600	0
Total cost [€]	0	-9,850	214,840	207,790
Total cost / flight [€]	0	-31	684	662

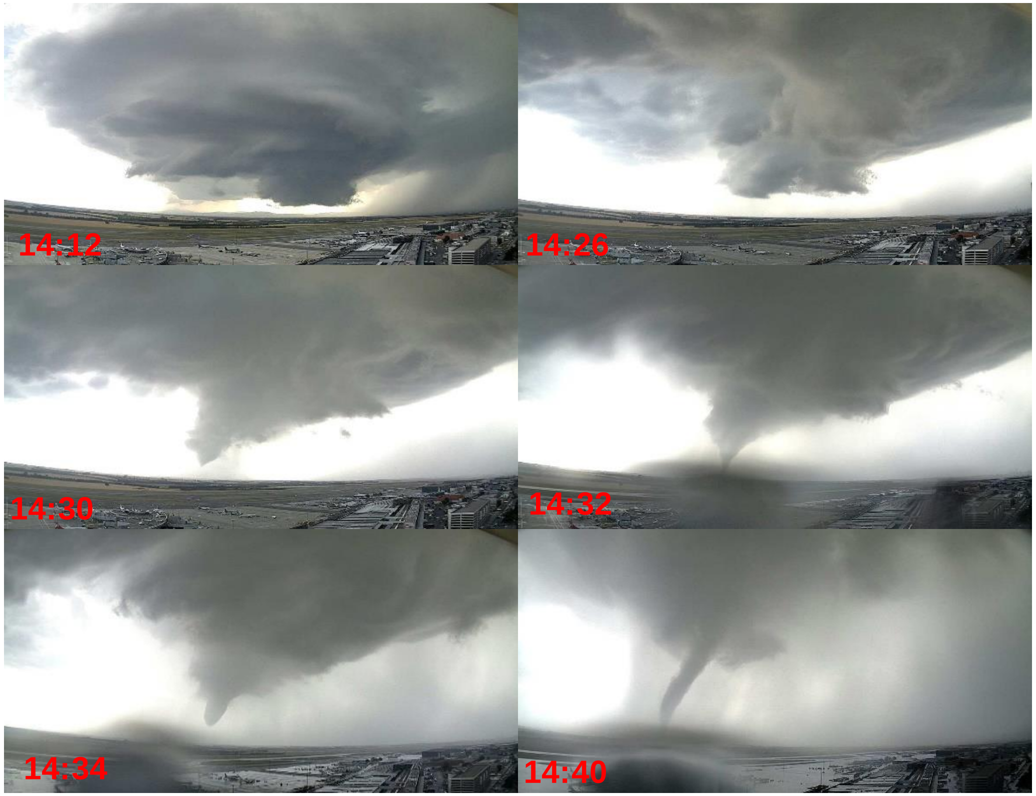
Simulation

LVP observed vs. not observed

No LVP

Long LVP

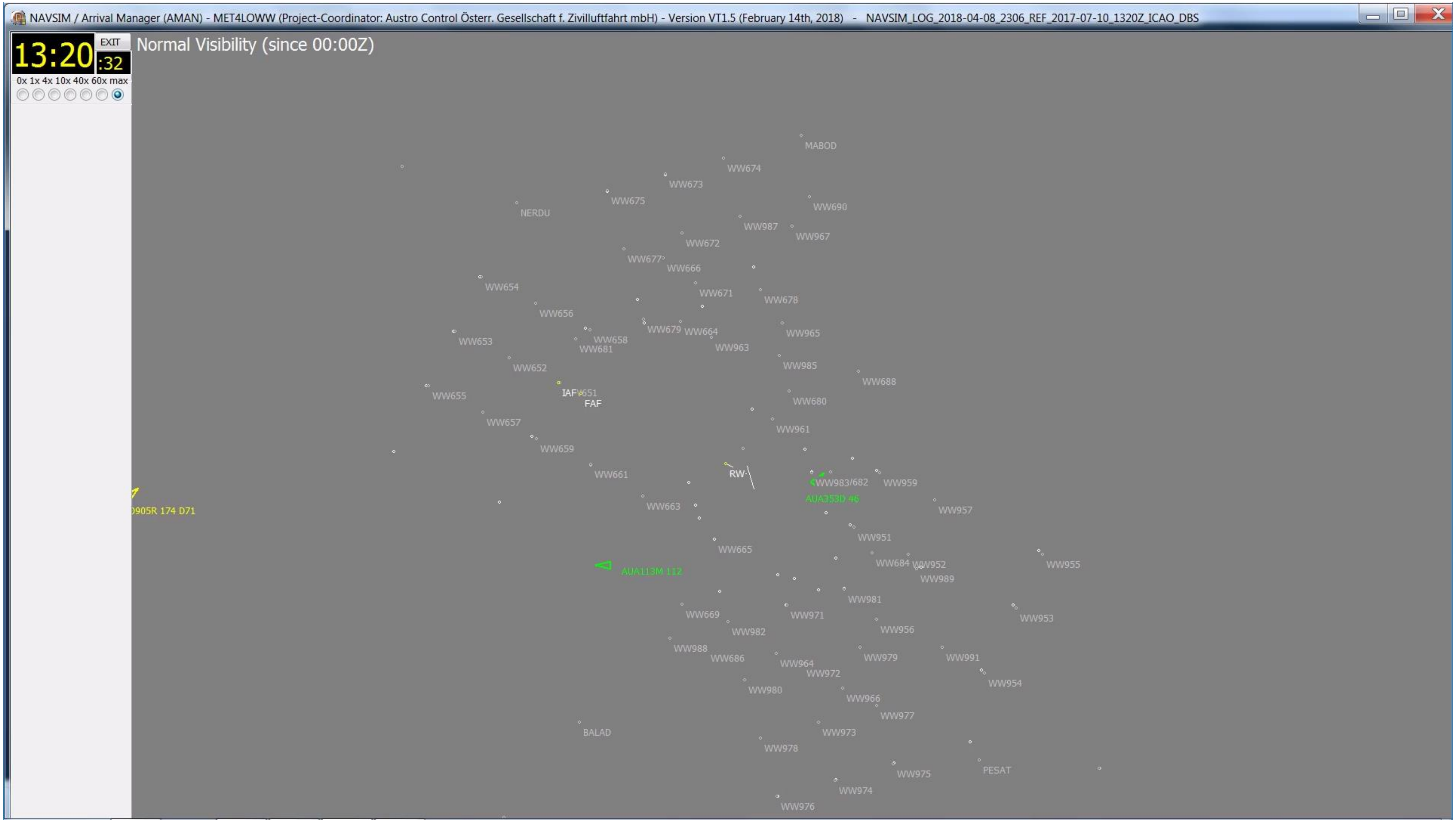
Thunderstorms



- 10.7.2017 an exceptional event at LOWW (3485 delay minutes; 8 diverts)
- ~52.000 delay minutes at LOWW in 2017 because of thunderstorms

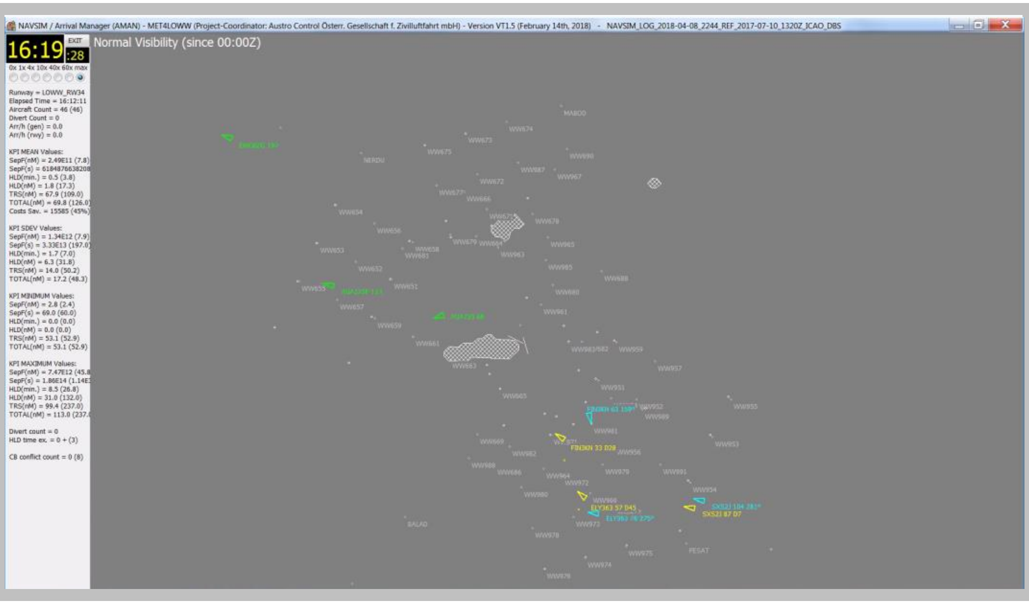
Simulation

Thunderstorm – CPR vs. simulation



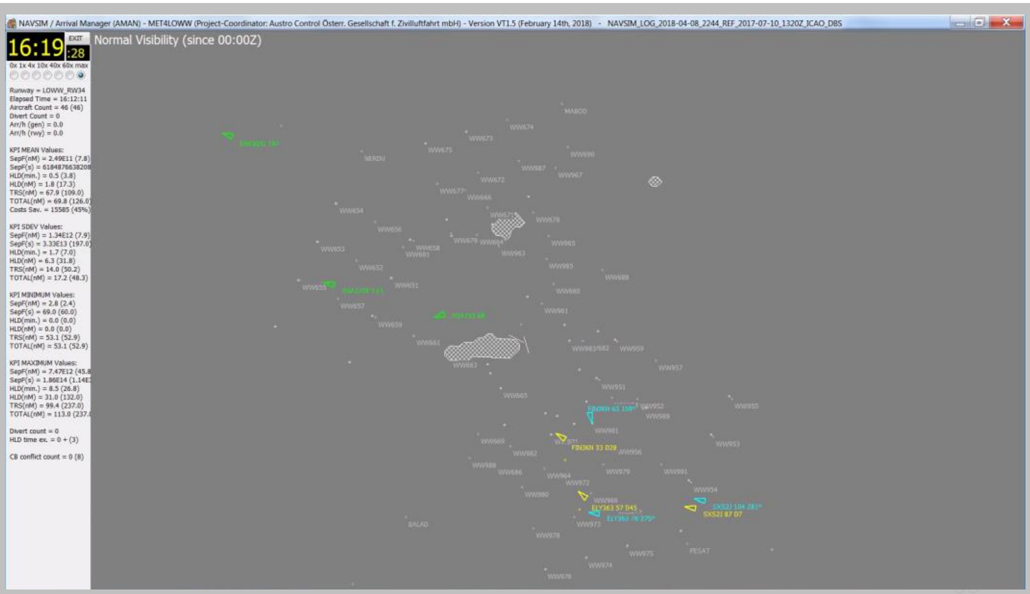
Identified potential

Better recovery after thunderstorm at airport



- Recovery in simulation as in reality
- No landings between 16:28 and 17:10

- Earlier recovery in simulation than in reality
- No landings between 16:28 and 16:41



Case study
Recovery potential in numbers

- Flights entering sector between 16:00 and 17:30

	Optimal recovery	Recovery as OBS (20 min max HLD-Time)	Recovery as OBS (50 min max HLD-Time)
Flights	23	23	23
Diversions	0	3	0
Trackmiles / flight [NM]	69.3	115.0	157.5
Lateral efficiency	1.28	2.46	2.99
Holding time [min]	0	189	370
Holding time / flight [min]	0	8.22	16.11
ARR delay cost [€]	0	9,980	21,890
Diversion cost [€]	0	26,700	0
Total excess cost [€]	0	36,680	21,890

The way forward

Summary
Main learnings

- The applied method using the air traffic simulator is suitable to quantitatively evaluate impact of weather and weather forecasts on the ATM system
- An integrated holistic view involving all stakeholders is key to identify improvement potentials
- Improved awareness and mutual understanding between ATM and MET
  - ATM processes, needs and scope of action
  - Capabilities and limits of weather predictability
- Insight into airline and airport impacts important for further understanding and quantification

The way forward
How to use the results…

- Results evaluation
  - Improved weather products targeting the potentials
  - Review ATM decision making based on results / weather products
  - Discuss impact and ATM-measures with stakeholders based on project results

- A follow up project proposal was submitted
  - Includes flight planning expertise to refine cost estimates
  - Focus on how probability forecasts can be integrated in ATM decision making
  - Evaluate what ATM decisions can be improved by probability forecasts
  - Evaluate available probabilistic weather forecast systems
  - Holistic view on the ATM-System (Airlines + Airport + ATC)

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