Air traffic complexity and weather

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Outline

- Motivation
- Decision support
- Air traffic complexity
- Conclusions

Motivation

- Weather is a major reason for air traffic delays

LOWW* Arrival Delays

Delay reason	Jan-Dec 2018		Jan-Dec 2019	
	minutes	share	minutes	share
Aerodrome Capacity	2 776	3%	5 981	4%
ATC Capacity	0	0%	239	0%
ATC Equipment	1 157	1%	230	0%
ATC Staff	0	0%	24 477	18%
Weather	77 973	95%	102 391	77%
Other	21	0%	0	0%
Total	**81 927**	**100%**	**133 318**	**100%**

LOWW* Weather Delays

Delay reason	Jan-Dec 2017		Jan-Dec 2018		Jan-Dec 2019	
	minutes	share	minutes	share	minutes	share
Low visibility procedures	43 548	38%	22 814	29%	34 265	33%
CB / TS	52 867	46%	50 276	64%	45 153	44%
Strong winds	15 827	14%	3 705	5%	21 783	21%
Snow	2 718	2%	795	1%	1 190	1%
Other	0	0%	383	0%	0	0%
Total	**114 960**	**100%**	**77 973**	**100%**	**102 391**	**100%**

In 2013: 34,826 minutes because of snow

* Vienna International Airport

Took off to…

… minimize weather delays*

Solution:

Trivial: do not issue ATFCM regulations because of weather

- Zero delay minutes due to weather
- Many diversion and holdings -> high cost for airlines (+ bad for the environment)
- Sector/airport capacity is exceeded -> high workload for ATCOs (+ bad for safety)

* Performance tarket set by the European Commission - ANSPs have to keep ATFCM delay/flight in given limits

Reasonable objective…

… minimize weather impact* (includes optimizing weather delays)

Solution:

Challenging!

- Establish the concept of unavoidable / achievable delay
- Decision support -> to optimize usage of weather information and its uncertainty
- Air traffic complexity for given weather -> as a prerequisite to determine unavoidable / achievable delay

* Maximize provided capacity while keeping workload on acceptable levels

What is …

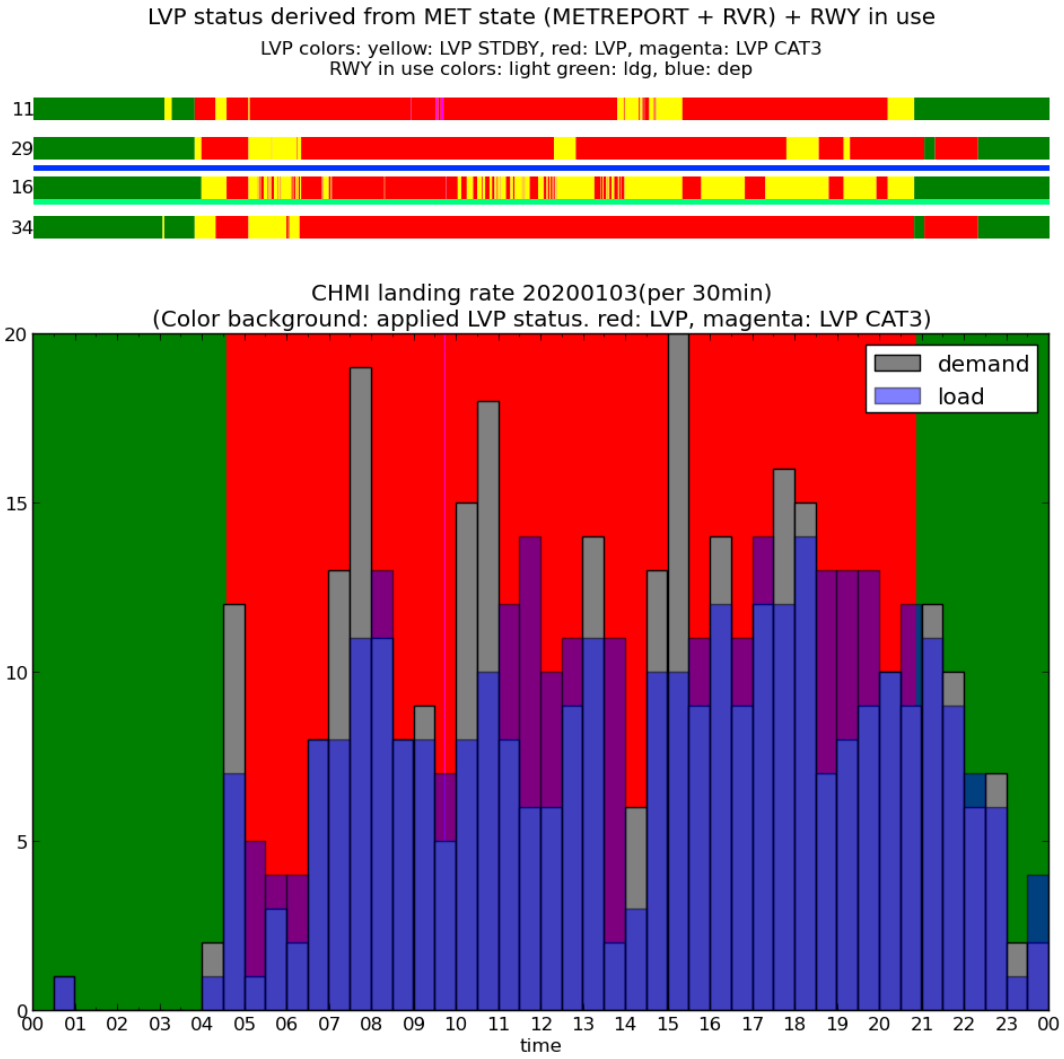
Unavoidable delay (UAD):

- Delay which cannot be avoided even if the disrupting weather event is known exactly before and mitigation measures can be taken without limit.
- Is not achievable in reality (weather forecast uncertainty, …).

Achievable delay (AD):

- Minimum delay which can be achieved if available information (weather forecasts, uncertainty information, …) is optimally used in established process.

Unavoidable delay in practice …



Low Visibility Procedures (LVP):

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

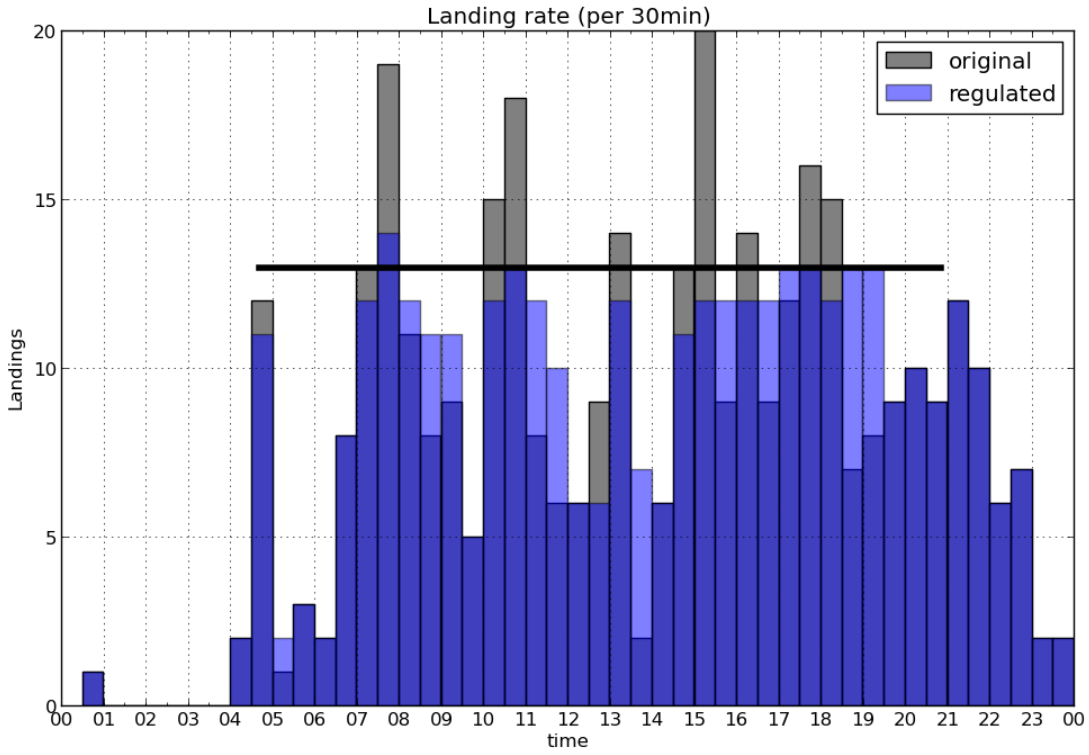
LVP reduces available capacity by 37.5% - 55% without a possibility for mitigation.

Unavoidable delay in practice …

If LVP situation would have been known in advance …

Unavoidable delays = 2812min

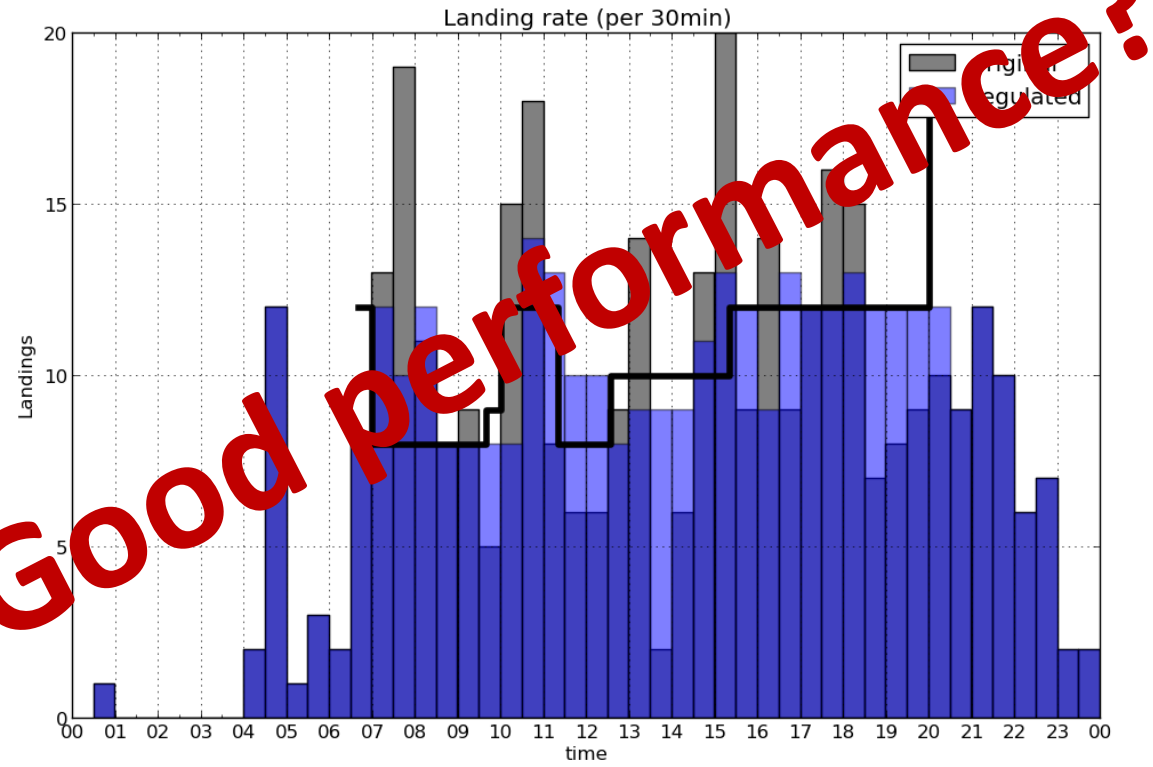
Regulation issued at 00:00 for exact duration of LVP (i.e. perfect forecast)



That's what happened …

Delays for actual regulation = 6594min

(Regulations issued as actually done)



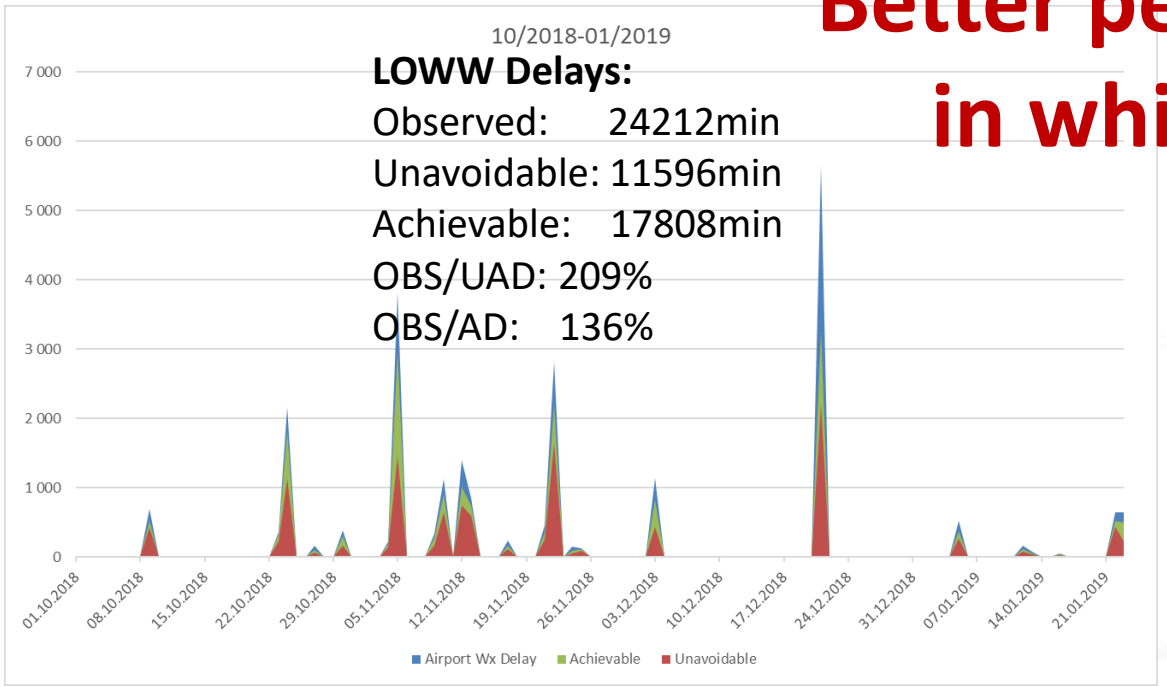
Good performance?

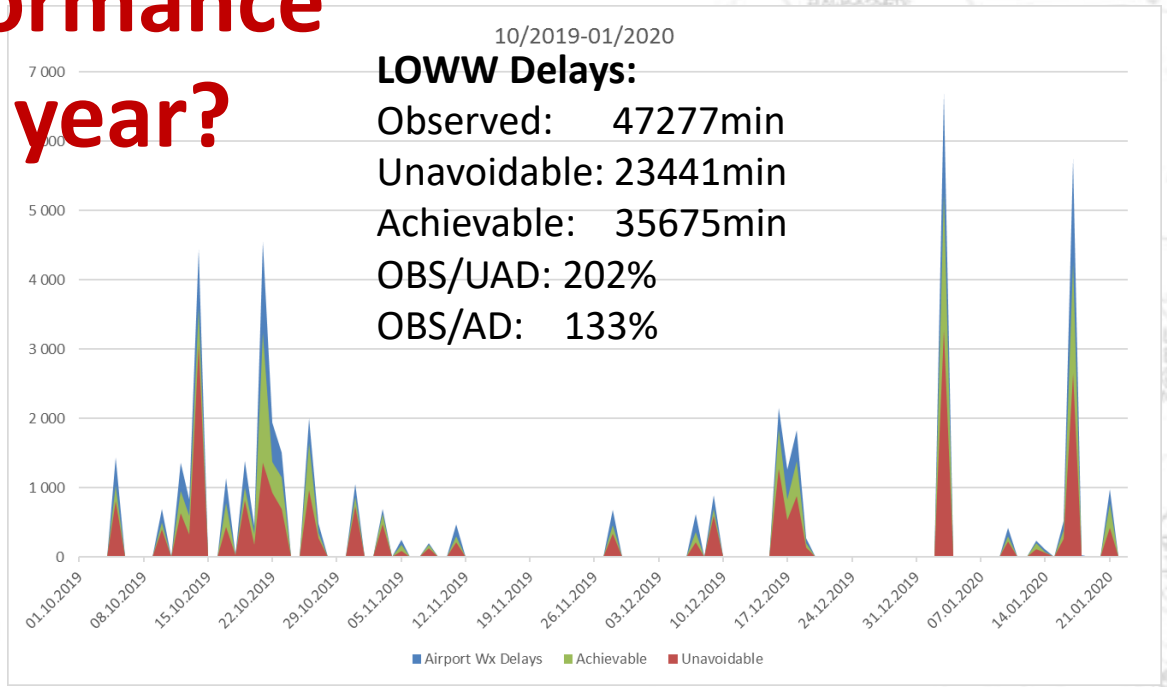
Unavoidable / achievable delay on longer timescales

Absolute number depends on:

- Frequency of disruptive weather events
- How disruptive weather coincides with traffic peaks

Better performance in which year?





NOTE: Unavoidable/achievable delays shown are randomly generated and for illustration only!

Application of unavoidable / achievable delay

Proposal KPIs:

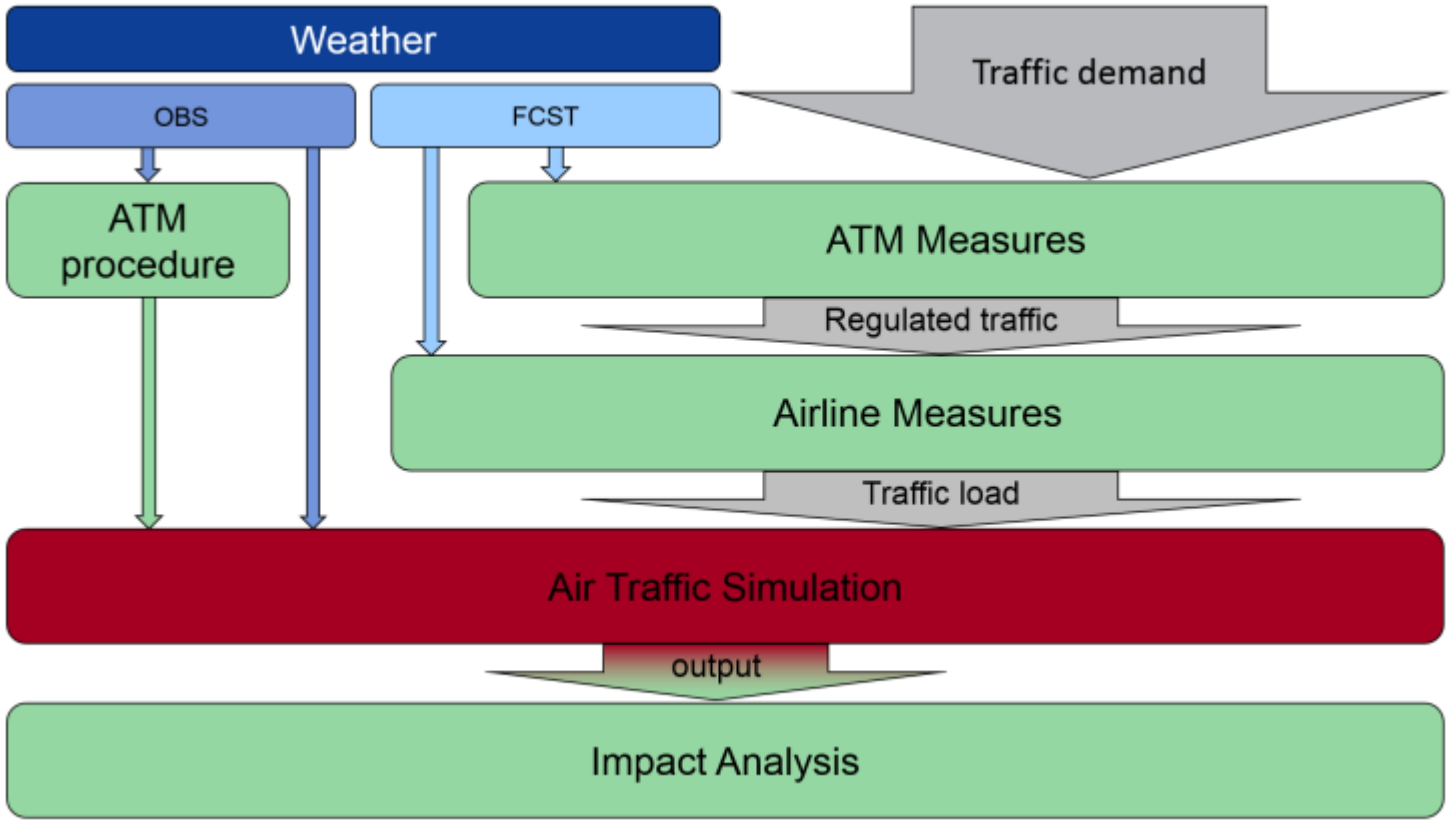
- OBS/UAD and OBS/AD to measure how well existing processes are applied
- AD/UAD to measure improvement of processes

Research questions:

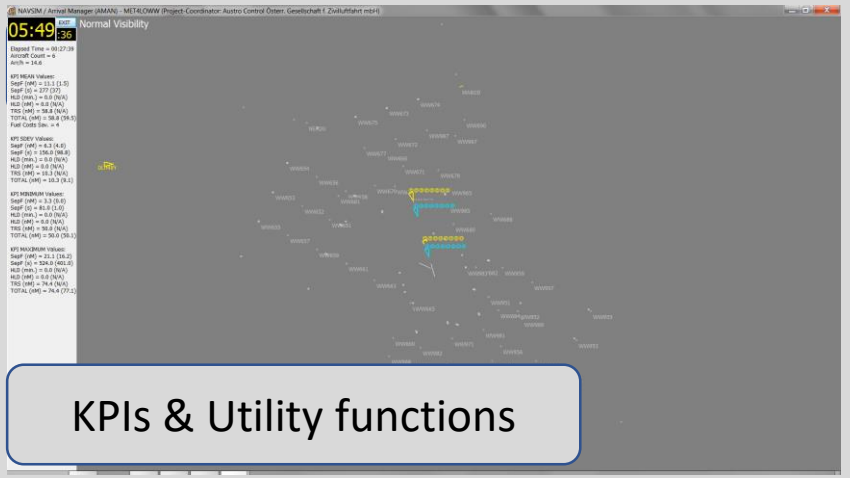
- Available capacity for weather events with high impact on workload
- Decision support to make optimal use of weather forecasts and related uncertainty information
- Suitable utility function for use in decision support (linked to traffic complexity / workload)
- Derivation of achievable delay from relevant factors (forecast quality, decision support, …)

Decision Support

“LOWW Arrival - Laboratory”



Traffic regulation



KPIs & Utility functions

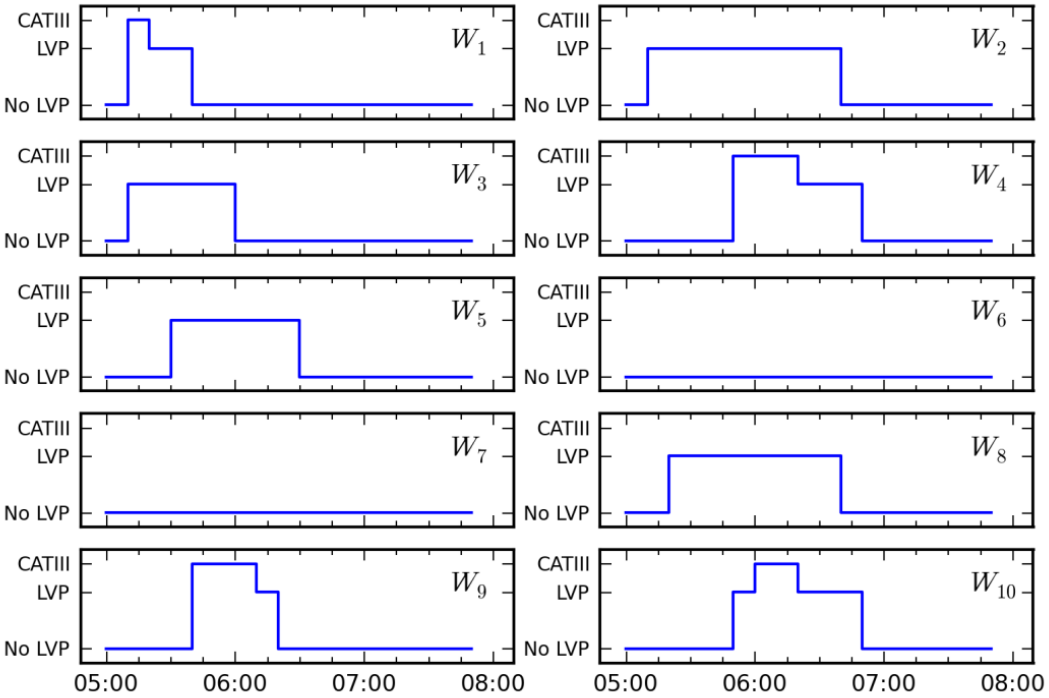
NAVSIM

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

What if …

… but many possibilities

Multiple possible Weather Outcomes



Multiple possible Actions

- Time of issuing regulation
- Duration of regulation

…

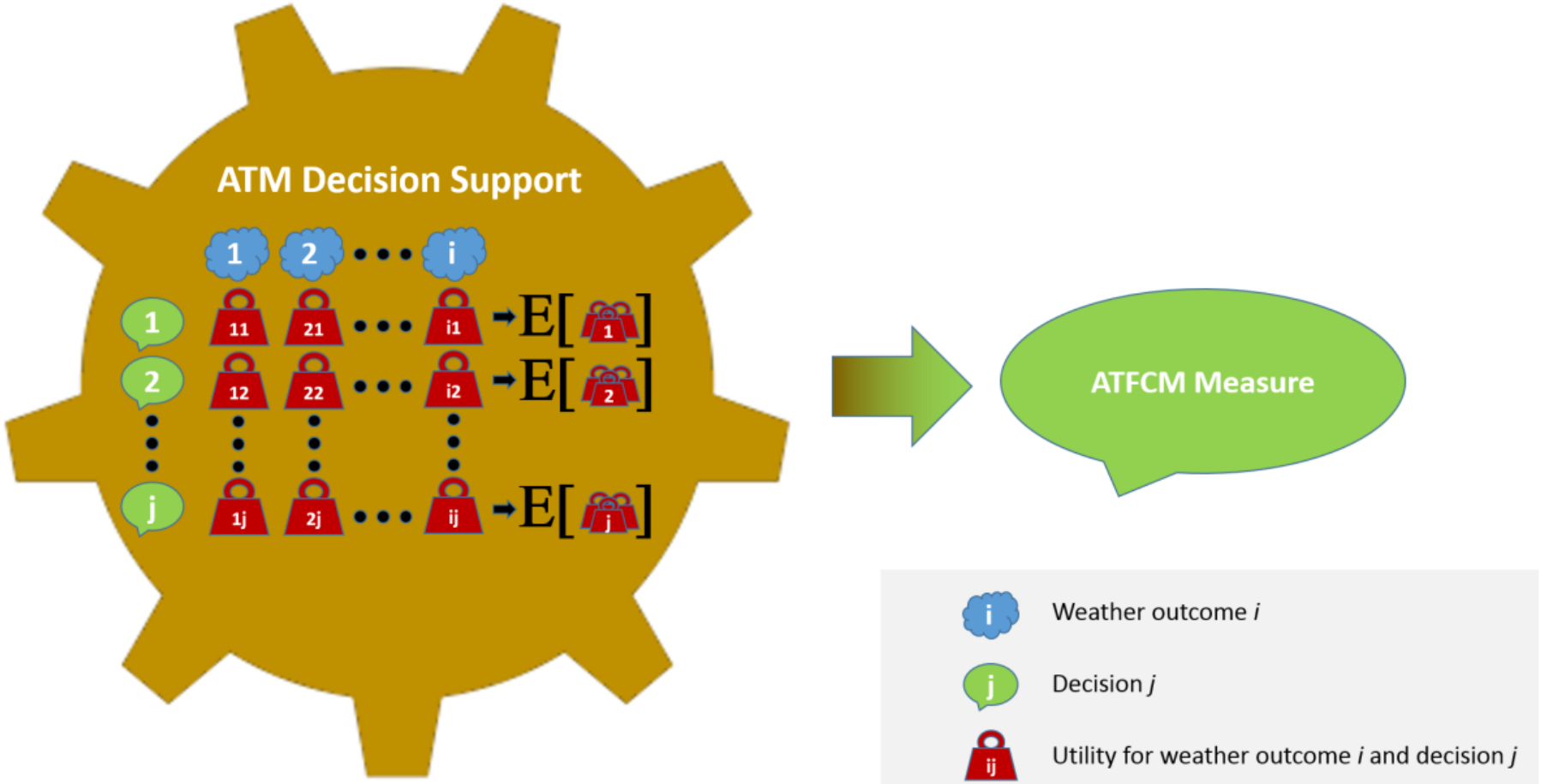
- Rate 18
- Rate 19

…

- Rate 30
- Rate 31

…

Decision support - integrated



Utility functions

Airline Cost

Cost of Delay

Disregards ATCO workload

Very sensitive to small input perturbations

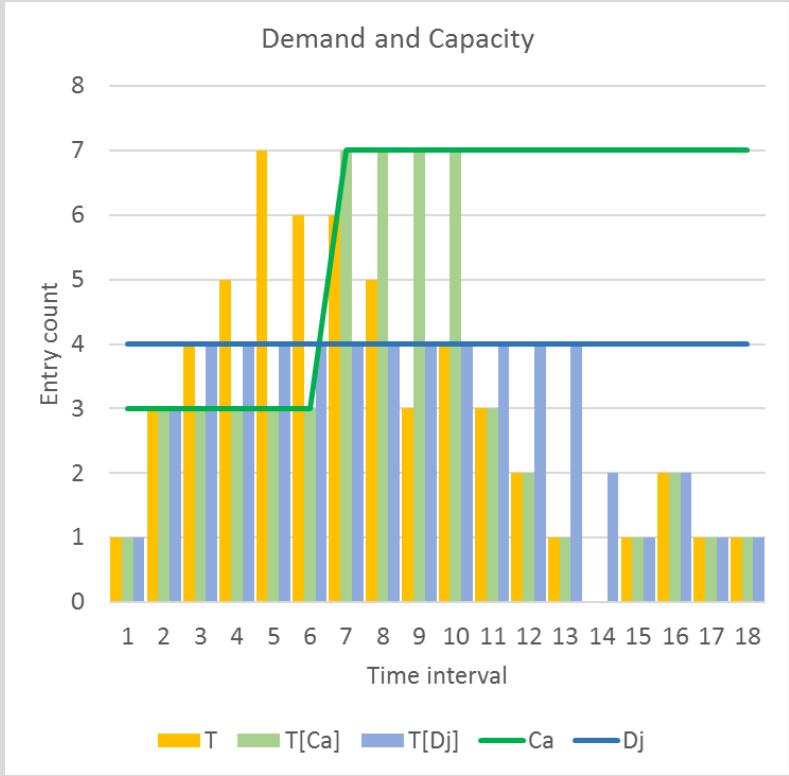
Based on: A. Cook and G. Tanner, "European airline delay cost reference values, updated and extended values," Version 4.1, 24 December 2015.

Cost of Diversion

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

Based on: EUROCONTROL, "Standard Inputs for EUROCONTROL Cost-Benefit Analyses," Edition Number 8.0, January 2018.

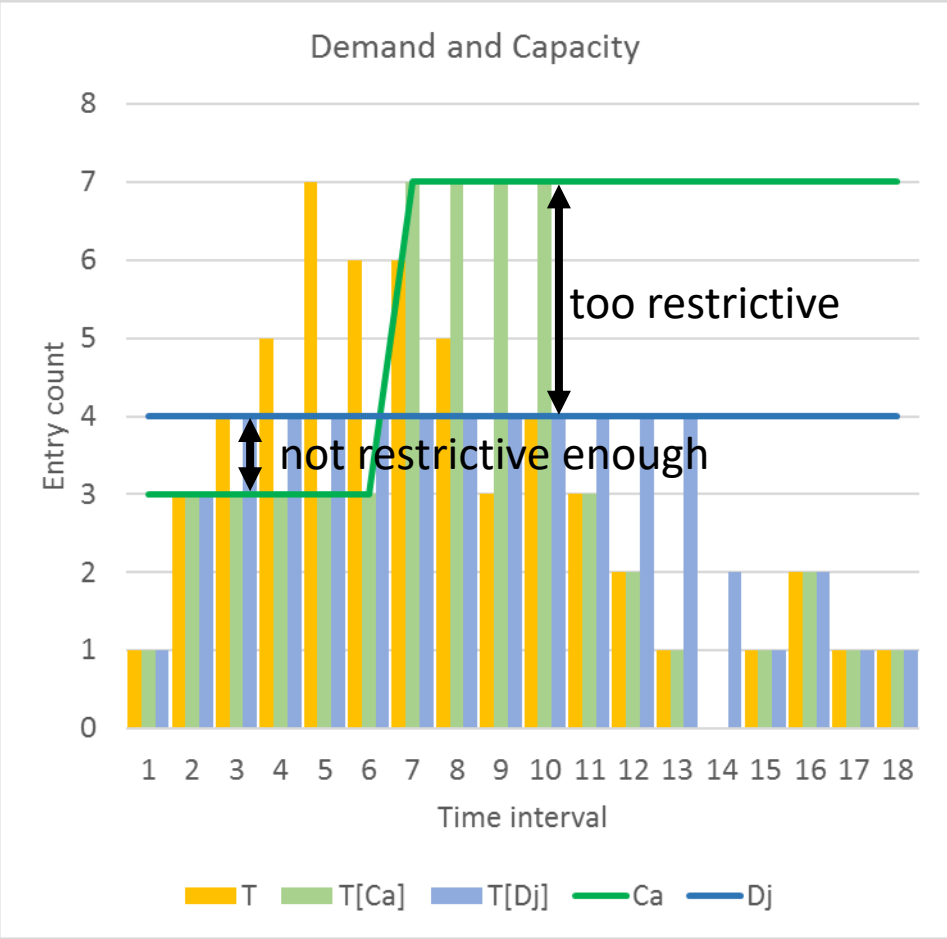
"Traffic - Capacity Balance"



T: Traffic demand
T[Ca]: Traffic matching available capacity
T[Dj]: Traffic for decision j

Ca: available capacity
Dj: rate for decision j

Traffic - Capacity Balance



Traffic Demand

Available Capacity for given weather situation

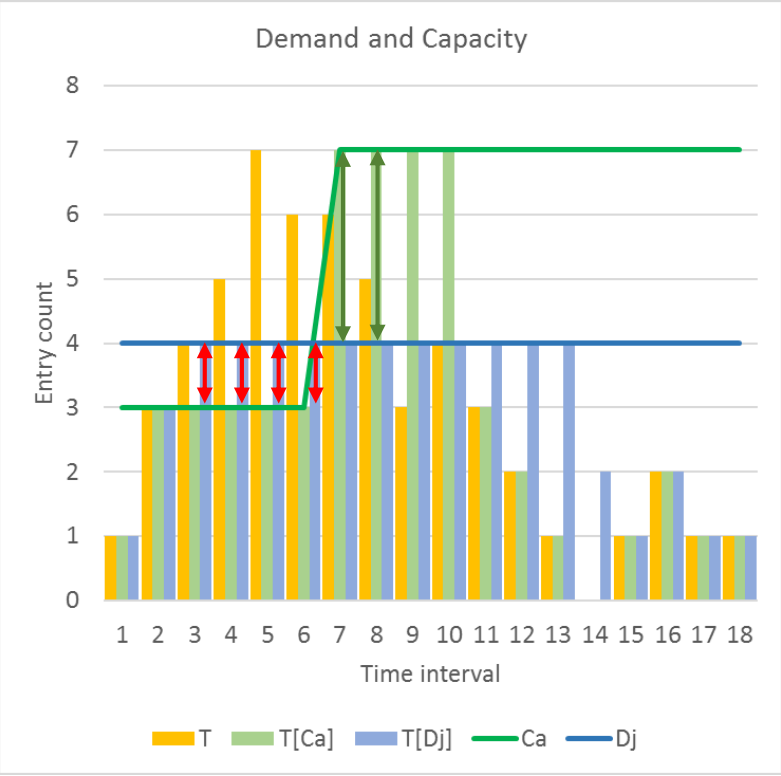
Traffic Load matching available capacity

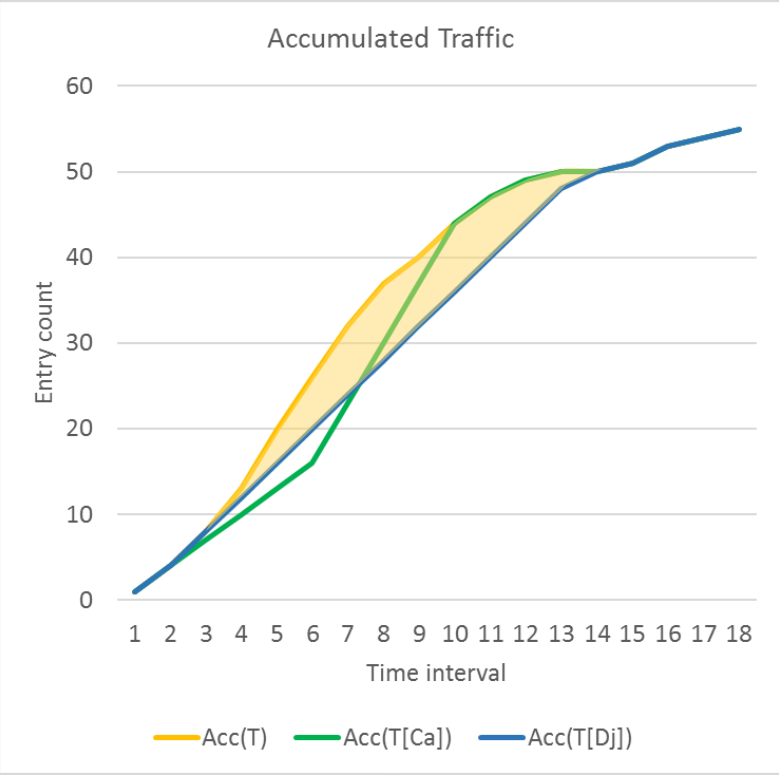
Regulation in case of decision Dj

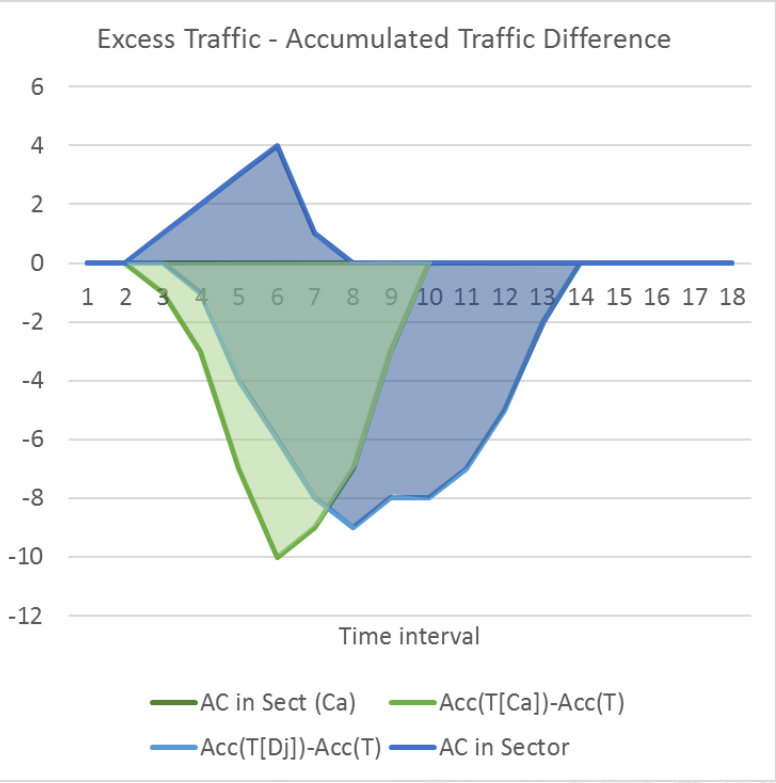
Traffic Load in case of decision Dj

“Traffic - Capacity Balance”

$$U[D_j, W_i] = \alpha \underbrace{\left(\sum_{\kappa} A[D_j, W_i]_{\kappa} \right)}_{\text{airborne delay \& workload}} - \underbrace{\sum_{\kappa} \left(\mathrm{ACC}(T[D_j]) - \mathrm{ACC}(T_d) \right)_{\kappa}}_{\text{ground delay}}$$





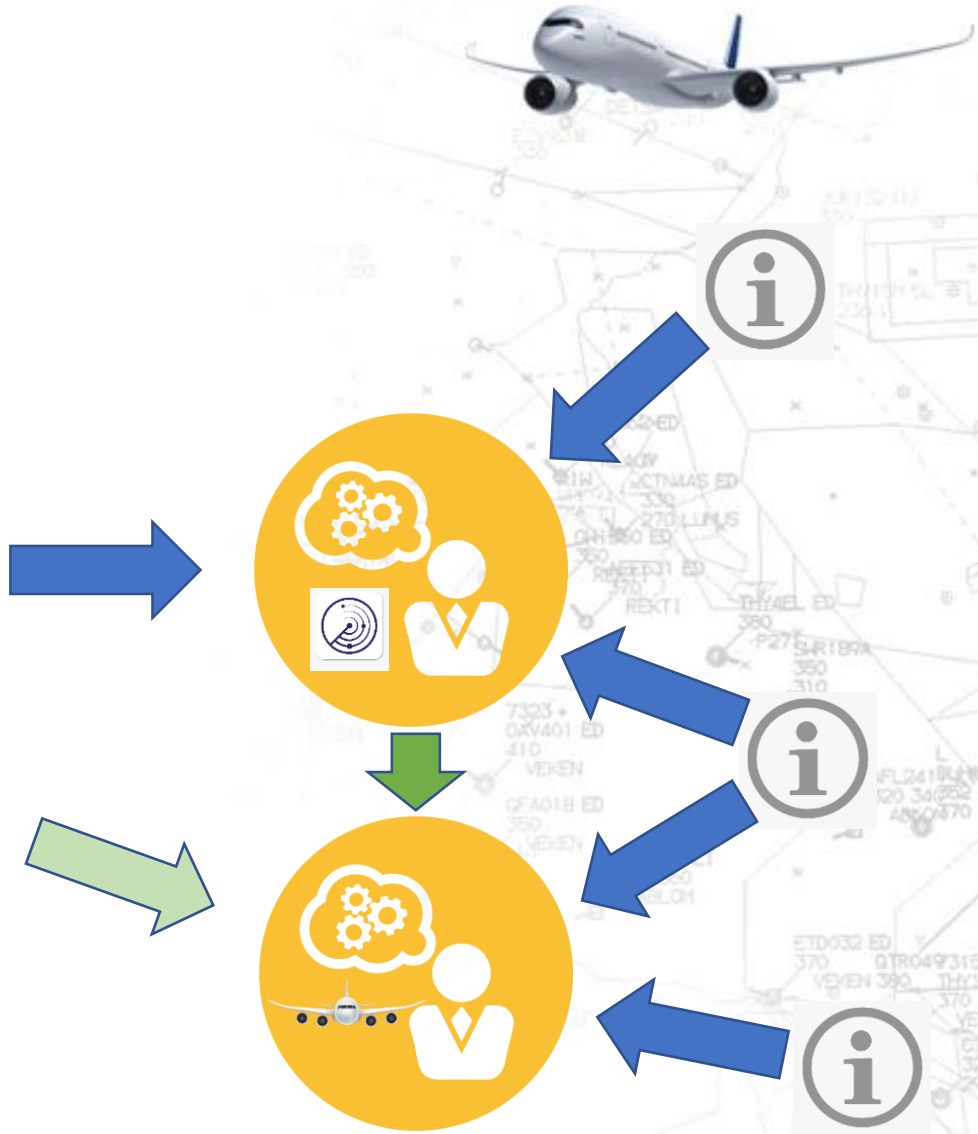


$$A[D_j, W_i]_{\kappa} = \begin{cases} \max\left(0;\quad T[D_j]_{\kappa} - C_a[W_i]_{\kappa}\right) & : \kappa = 1 \\ \max\left(0;\quad A[D_j, W_i]_{\kappa-1} + T[D_j]_{\kappa} - C_a[W_i]_{\kappa}\right) & : \kappa > 1 \end{cases}$$

$$\mathrm{ACC}(T[D_j])_k = \sum_{\kappa=1}^{k} T[D_j]_{\kappa}$$

Concept: Weather based decision support

	W_1	W_2	W_3	W_4	W_5	W_6	W_7	W_8	W_9	W_{10}	$\mathbb{E}[U]$
Rate 18	264	264	264	256	254	254	254	264	254	256	258.4
Rate 19	217	217	217	215	207	207	207	217	207	215	212.6
Rate 20	167	167	167	187	157	157	157	167	167	175	166.8
Rate 21	153	153	153	173	143	143	143	153	153	161	152.8
Rate 22	143	143	143	163	133	133	133	143	143	151	142.8
Rate 23	128	128	128	148	118	118	118	128	128	136	127.8
Rate 24	124	124	124	144	114	114	114	124	124	132	123.8
Rate 25	91	97	91	129	83	81	81	97	91	115	95.6
Rate 26	72	88	72	128	70	62	62	88	78	112	83.2
Rate 27	66	82	66	122	64	56	56	82	72	106	77.2
Rate 28	60	76	60	120	58	50	50	76	66	102	71.8
Rate 29	55	71	55	115	53	45	45	71	61	97	66.8
Rate 30	47	71	47	121	51	37	37	71	57	103	64.2
Rate 31	31	75	31	137	45	21	21	75	49	117	60.2
			22	146	50	12	12	84	52	126	61.0
						12	12	84	52	126	



Air traffic complexity

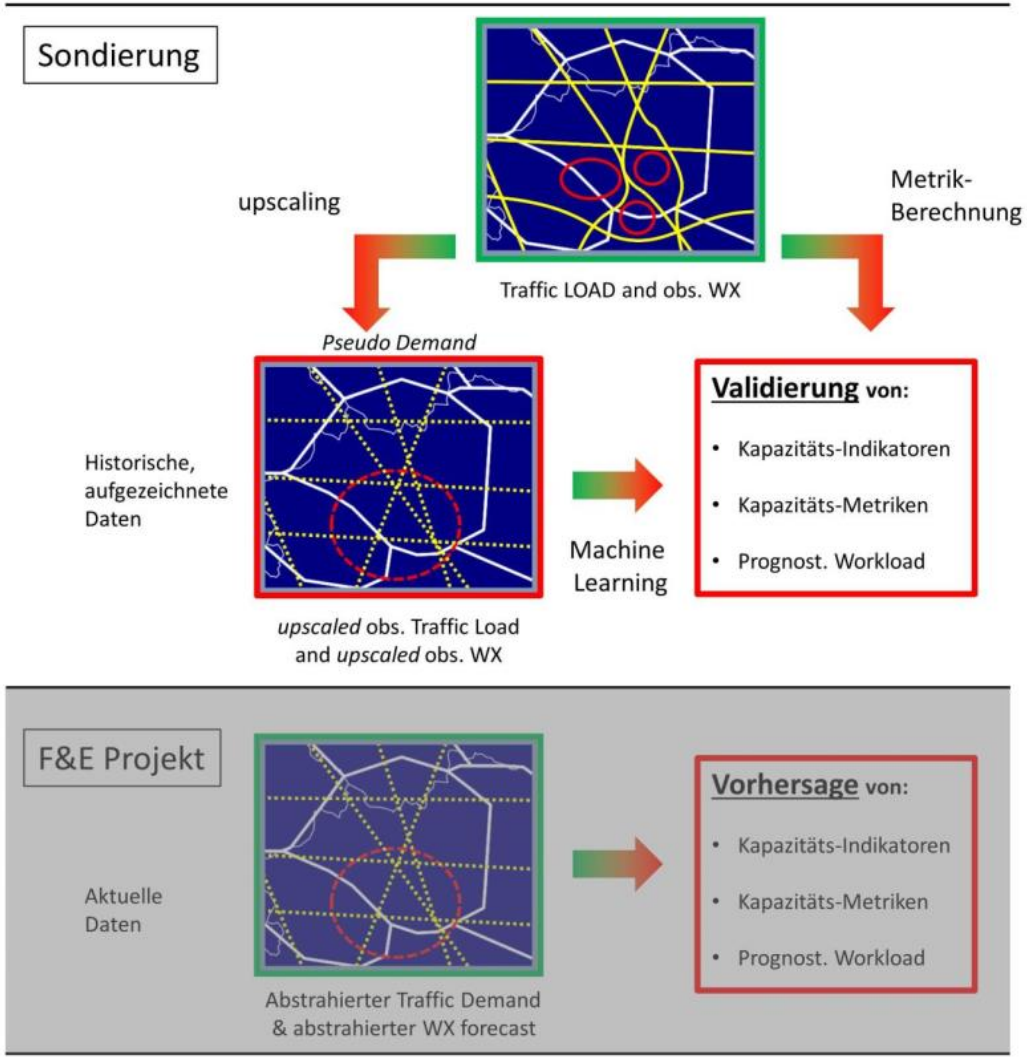
as proxy for ATCO workload

WeCaP

A project by
Robimo & Austro Control

austro CONTROL

Weather Dependent Capacity Analysis and Planning



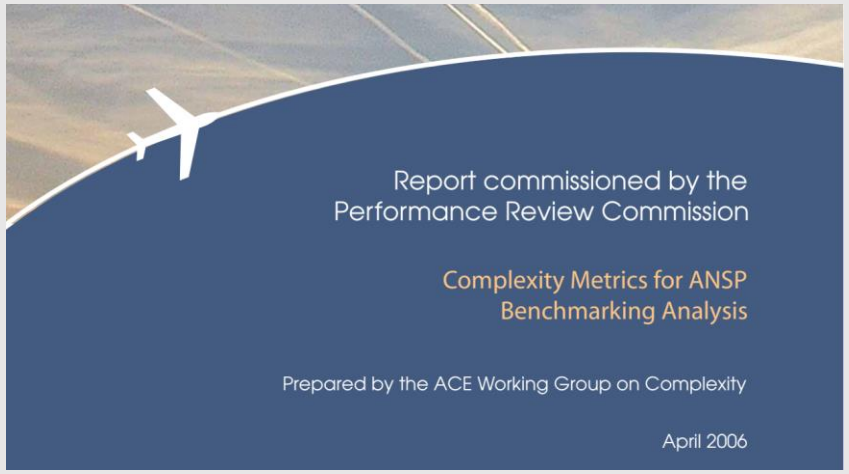
- Estimate expected complexity from flight plan data and weather forecasts using machine learning
- Train the model using:
  - complexity derived from full resolution data (CPR-tracks and weather radar) as observation
  - flight plan data and coarse-grained weather radar as input variables

WeCap receives funding from Take Off programme. Take Off is a Research, Technology and Innovation Funding Programme of the Austrian Federal Ministry for Climate Action, Environment, Energy, Mobility, Innovation and Technology (BMK). The Austrian Research Promotion Agency (FFG) has been authorized for the Programme Management.

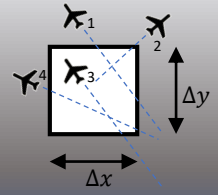
But first we need a reliable…

traffic complexity analysis

Complexity metrics



- Time flown in cell / sector
- Expected duration of potential interaction
- Potential horizontal interactions (HDIF)
- Potential vertical interactions (VDIF)
- Potential speed interactions (SDIF)
- Complexity Score (HDIF + VDIF + SDIF)

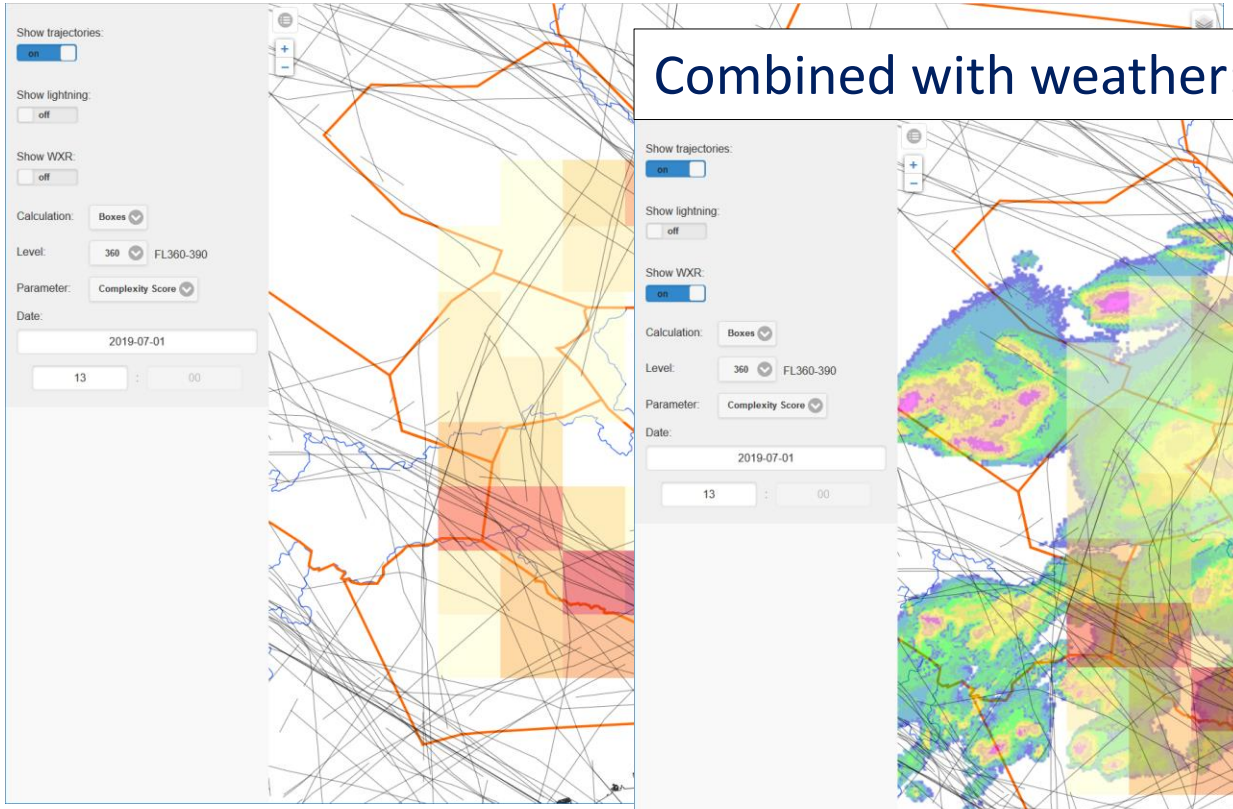


Additional metrics:

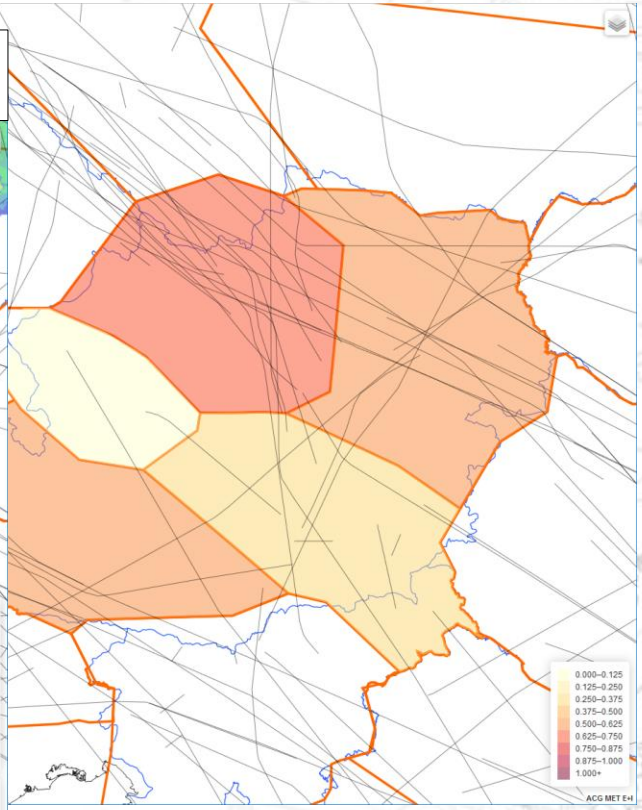
- Hourly traffic count
- Maximum occupancy
- Heading-change count
- Potential heading-change interactions
- „Piece of cake“
- Wang et al. + TS extension

Traffic Complexity Monitor

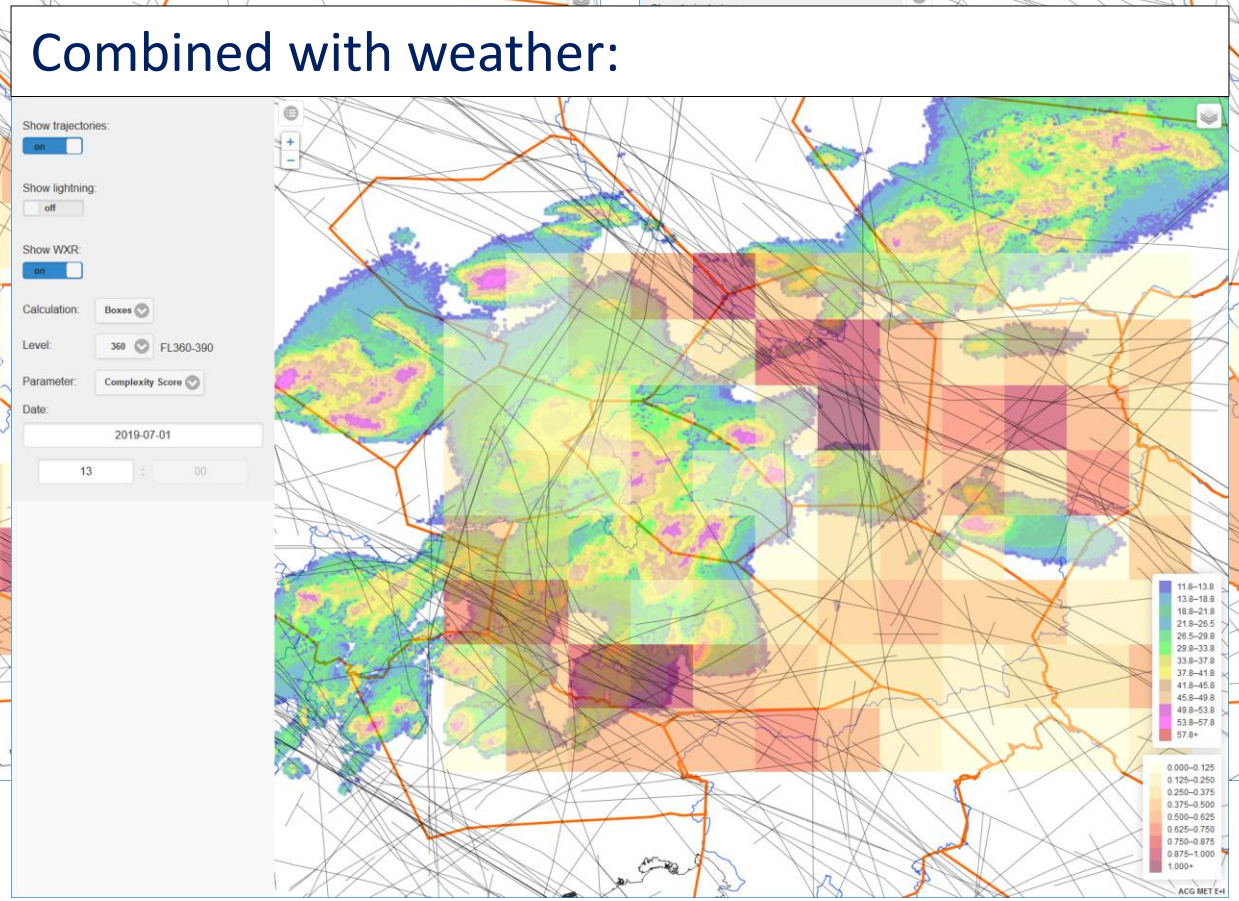
For Boxes (20 nm x 20 nm x 3000 ft x 1h):



For sectors:



Combined with weather:



Live Demo…

Conclusions

Conclusions

Weather is a limiting factor for air traffic capacity

- Directly by impacting capacity, e.g. runway throughput in case of LVP
- Indirectly by impacting air traffic complexity / workload, e.g. in case of CB/TS

Knowledge about available capacity in a given weather situation, considering direct and indirect impact, is important as input for

- performance evaluation (unavoidable / achievable delays)
- objective decision making

A reliable measure for acceptable workload is an important prerequisite to optimize weather management in the ATM-system.

Questions & Comments ?

Acknowledgment

The work presented here was carried out in the framework of the MET4LOWW, PROB4LOWW and ongoing WeCaP projects which were/are funded by Take Off. Take Off is a Research, Technology and Innovation Funding Programme of the Austrian Federal Ministry for Climate Action, Environment, Energy, Mobility, Innovation and Technology (BMK). The Austrian Research Promotion Agency (FFG) has been authorized for the Programme Management.

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