DATS

Capacity Modeling for Controller Workload Evaluation and Optimization of Staff Planning at RTC

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Based on joint work with: J. Jakobi, A. Lemetti, L. Meyer, A. Papenfuss, M. Peukert, L. Sedov

LINKÖPING UNIVERSITY

LFV

The First Remote Tower Center in Sweden

Photo from the visit in November 2016

✔ Research visit to Sundsvall RTC

Research questions

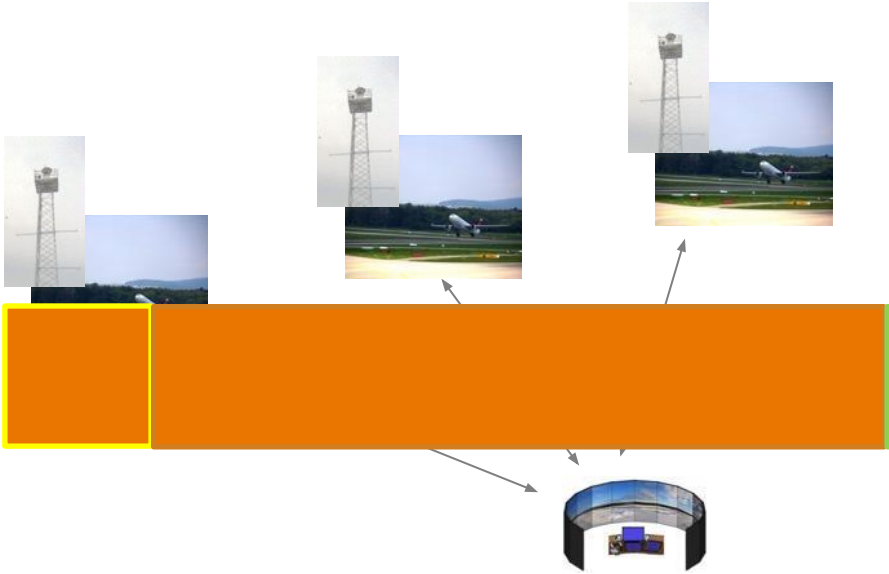
- ✔ How are human resources (HR) **organized** at RTC?
- ✔ How is the **total taskload** from a number of airports **distributed** over several controller working positions? (**KODIC I, II projects 2016-2017**)
- ✔ How does the **workload** at the Remote Tower environment **differ** from the one at the conventional tower? (**CAPMOD project 2018-2021**)

1

Problem 1: Assigning airports to RTMs

Main CONSTRAINTS

- ✔ Number of airports assigned to one module bounded (1, 2, 3, ?)
- ✔ Total number of moves within a module is bounded



2

ATCO rostering at RTC

How are remote ATCOs ***shifts*** organized?

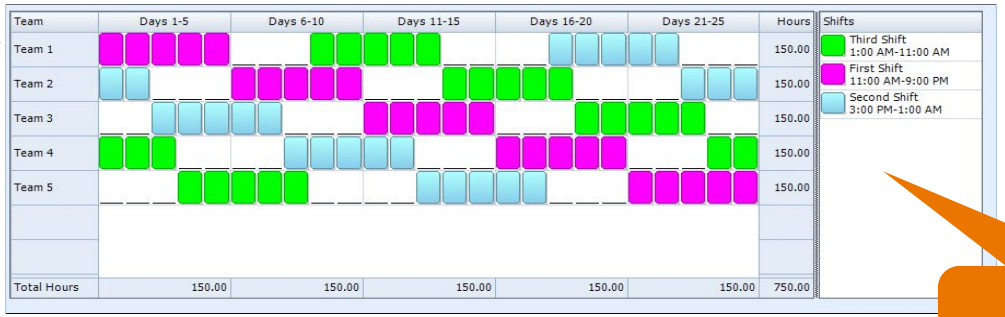
Workload from several airports

Endorsements and trainings

24/7 operation

Scheduled breaks

Time ”in position”



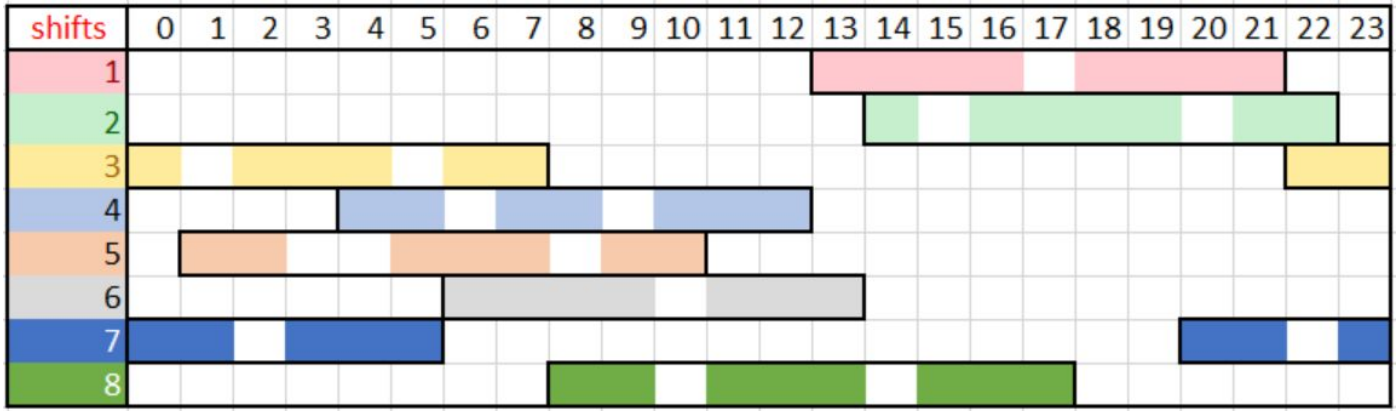
AUTOMATION REQUIRED!

KODIC II

OBJECTIVE 2: Min average # controllers per airport

High traffic

19-Oct-16	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
AP1	0	0	0	0	2	0	0	2	1	0	0	2	0	0	0	0	0	0	0	0	1	0	0	0
AP2	1	1	2	3	4	9	10	7	5	3	2	5	7	4	5	10	8	7	6	8	8	2	0	2
AP3	1	0	2	1	6	5	2	6	4	3	5	4	2	5	6	4	6	8	6	4	3	1	2	2
AP4	0	0	0	0	2	3	3	3	2	1	2	3	2	2	2	4	3	3	0	2	0	0	0	0
AP5	0	0	0	0	3	2	0	4	3	1	2	1	0	2	4	3	2	2	1	2	0	1	0	0



Total #. of ATCOs	Av. # of ATCOs per airport	Av. # endorsements per ATCO	Av. time in position	Av. time at work	COP
8	3.4	2.13	7.5	9.38	0.8

Minimum 8 ATCOs are needed to cover 5 airports

2-weeks rosters

ATCO	Mon 03.10		Tue 04.10		Wed 05.10		Thur 06.10		Fri 07.10		Sat 08.10		Sun 09.10	
1	14:00	18:00	6:00	10:00			23:00	0:00	0:00-8:00	23:00-0:00	0:00-6:00	22:00-0:00	0:00-9:00	23:00-8:00
2			20:00	23:00	0:00-8:00	23:00-0:00	0:00-9:00	20:00-0:00	0:00-6:00	14:00-17:00				
3			8:00	12:00			9:00	17:00	15:00	23:00	16:00	22:00	6:00	16:00
4	19:00	0:00	0:00-2:00	22:00-0:00	0:00-6:00	19:00-0:00	0:00	6:00	19:00	0:00	11:00	16:00		
5			9:00	14:00	7:00	19:00	8:00	20:00	7:00	11:00				
6	0:00-8:00	16:00-21:00	6:00	12:00	13:00	21:00	8:00	17:00						
7	8:00	14:00	6:00	18:00			19:00	23:00	7:00	16:00				
8			15:00	22:00	8:00	12:00	16:00	23:00	9:00	14:00			11:00	23:00
9			20:00	0:00	0:00-7:00		14:00	18:00	10:00	14:00				
10	19:00	0:00	0:00	6:00					19:00	0:00	0:00-7:00	20:00-0:00	0:00-6:00	21:00-0:00
11	8:00	22:00	6:00	18:00	7:00	15:00			11:00	15:00				
12	0:00	9:00			10:00	21:00	6:00	10:00	6:00	18:00				
13	19:00	0:00	0:00	6:00			6:00	18:00						
14	11:00	18:00			20:00	0:00	0:00-8:00	20:00-0:00	17:00	21:00	6:00	15:00		
15	11:00	15:00	10:00	14:00	10:00	14:00					7:00	19:00	9:00	21:00
16					8:00	20:00	6:00	18:00						
17			9:00	20:00	17:00	0:00	0:00-1:00	9:00-13:00						

ATCO	Mon 10.10		Tue 11.10		Wed 12.10		Thur 13.10		Fri 14.10		Sat 15.10		Sun 16.10	
1				22:00-0:00	0:00-10:00									
2	9:00	15:00	7:00	14:00			18:00	21:00	10:00	16:00	10:00	19:00	6:00	10:00
3					6:00	12:00								
4	20:00	0:00	0:00-7:00	18:00-0:00	0:00	6:00								
5	14:00	23:00			10:00	20:00			14:00	19:00	19:00	0:00	0:00	7:00
6	8:00	15:00			13:00	19:00	7:00	19:00	8:00	15:00			20:00	0:00
7	19:00	0:00	0:00-3:00	20:00-0:00	0:00-1:00	21:00-0:00	0:00-6:00	16:00-20:00	11:00	17:00			19:00	23:00
8	18:00	0:00	9:00	22:00										
9					8:00	14:00			17:00	22:00	6:00	18:00	6:00	18:00
10	0:00-9:00	18:00-22:00	6:00	12:00										
11			14:00	19:00	10:00	21:00	6:00	16:00			7:00	16:00		
12	19:00	0:00	0:00	6:00			11:00	16:00	17:00	22:00	18:00	0:00	0:00-6:00	21:00-0:00
13					19:00	0:00	0:00-7:00	23:00-0:00	0:00	11:00			8:00	20:00
14	14:00	18:00	6:00	18:00										
15	8:00	19:00	19:00	0:00	0:00	6:00								
16			8:00	20:00					8:00	20:00				
17	9:00	13:00	7:00	11:00			20:00	0:00	0:00-8:00	22:00-0:00	0:00	7:00	12:00	19:00

Minimum 17 ATCOs are needed to cover 5 airports during 2 weeks

RTC efficiency evaluation

NUMBER OF CONTROLLERS	INDIVIDUAL 5 AIRPORTS	SAME 5 AIRPORTS AT RTC
Lower bound for the highest traffic day (October 19, 2016)	17	8
With the buffer of 33% – 45% for the highest traffic day (October 19, 2016)	26–34	12–15

After optimization, RTC provides 42–55% savings

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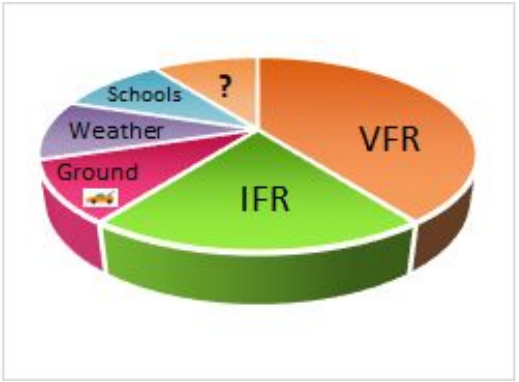
Capacity **Mod**eling for Controller Workload Evaluation at RTC Arlanda



Motivation

- ✔ ***Mental workload:*** limitation on number of tasks a human can perform during a certain period of time
- ✔ ***Complexity measures influencing workload:***
  the number of aircraft in a sector, voice messages, radar screen clicks, ground traffic movements, etc.
- ✔ ***A generic single metric for workload measurement is missing***

The *importance of quantitative assessment* of controller mental workload was reported in many of our projects

Research Questions

- ✔ Which ***factors*** contribute to controller's ***workload***?
- ✔ How does the ***workload at RTC*** differ from the workload at ***conventional towers***?
- ✔ How do different ***weather*** conditions influence controller's workload?

Methods

image source:
http://clipart-library.com/clipart/54081.html

- ✔ Data analysis from Simulations and Field studies
  - DLR simulation data
  - Sundsvall validation trials (May-June 2019)
- ✔ Observations and data collection in traditional towers + data analysis
  - Field study at Bromma airport (March 2019) video-recording, questionnaires
- ✔ Statistical learning: Objective vs. subjective assessment (workload rating vs. quantitative measures derived from eye tracking and video analysis)

= > **Mathematical analysis vs. Human Factor**

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Simulation Data Analysis: DLR Dataset

✔ **Identification of Complexity Factors Influencing Controller Workload in Remote Towers** (SID 2018):

Dataset provided by DLR:

- 12 ATCOs working in pairs
- 1 controller + 1 observer (assessing workload)
- Airports: Erfurt and Braunschweig
- **Multiple remote operation**
- All simulations with “high” traffic volume
- 20 min scenarios
- 222 situations

Adapted Cooper-Harper Scale:

critical
(in terms of safety)

Rating	Evaluation	Question for Evaluation
1	No problems, desirable	Is the situation solvable without major Disturbance?
2	Simple, desirable	
3	Adequate, desirable	
4	Small, but disruptive “delays”	Is the situation solvable by capacity-reducing measures?
5	Medium loss of capacity, which can be improved	
6	Very disruptive, but tolerable difficulties	
7	Problems to predict development of traffic situation	Is the situation solvable if the ATCO works with a reduced situational awareness?
8	Problems in information processing	
9 9	Problems in information reception	
10	Impossible	

Goals: Identify critical complexity factors that drive the workload for a remote tower ATCO
Identify situations at the two controlled airports that **induce risk**

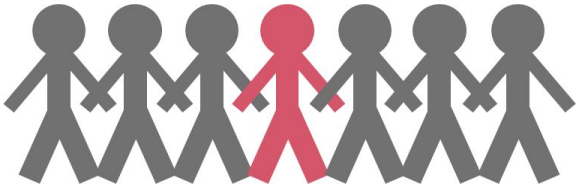
B. Josefsson, J. Jakobi, A. Papenfuss, T. Polishchuk, C. Schmidt, L. Sedov Identification of Complexity Factors for Remote Towers. In **SESAR Innovaon Days (SID 2018),** December 3-5, Salzburg.

Simulation Data Analysis: DLR Data

Approach: Aggregate information w.r.t. combination of events (We used: pairs and triples of events).

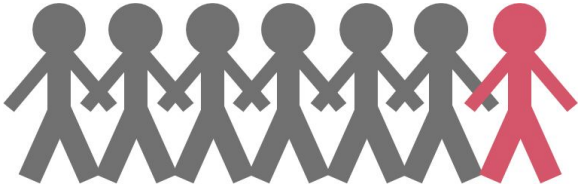
Mean Controller Rating:

- Assume an “average” controller
- Whether situation un-/manageable depends on experience, age, ….



Maximum Controller Rating:

- More conservative
- Possibly only single ATCO rated as critically
- This way we identify all critical factors for the remote tower environment
- Exclude what is unmanageable for any ATCO



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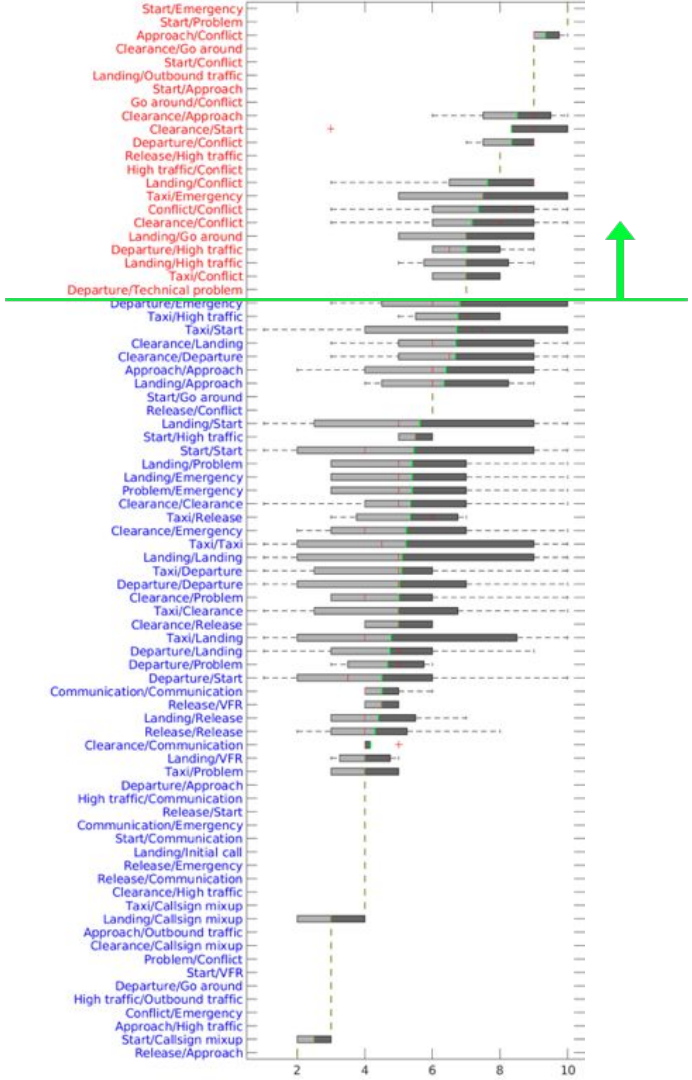
Mean Controller Rating

Complexity increased when ATCOs have to solve a traffic conflict at one airport and manage routine traffic at the second airport (9 out of 17 critical pairs have a conflict at a single airport)



all event pairs with a mean controller rating of at least 7

17 critical event pairs out of 65

green: mean
red: median

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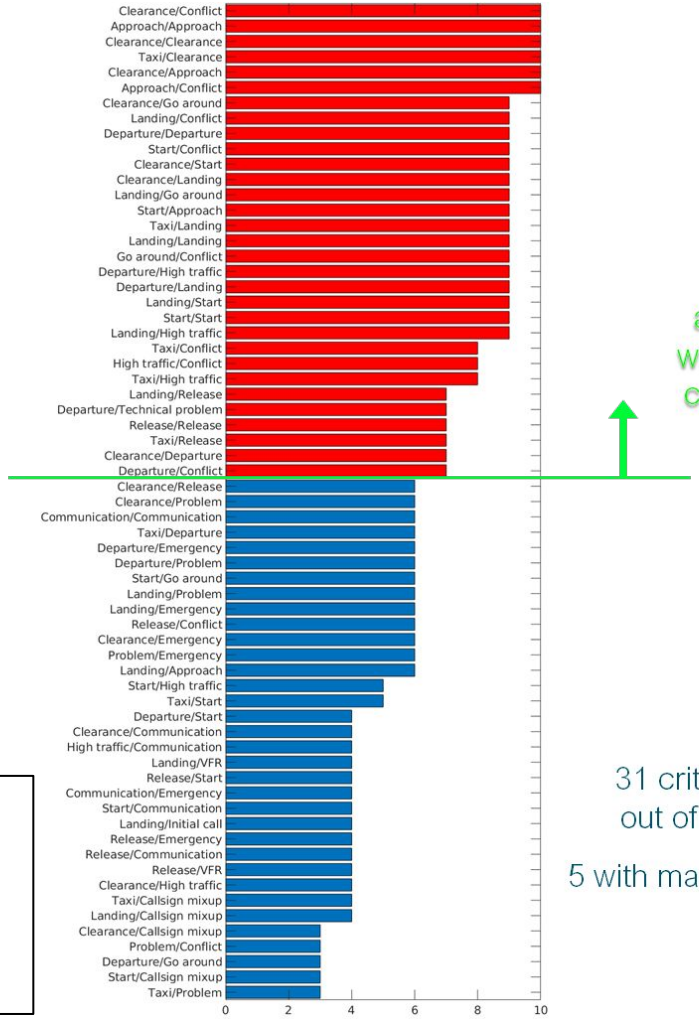
Maximum Controller Rating



all event pairs with a maximum controller rating of at least 7

31 critical event pairs out of 65 event pairs

5 with maximum rating of 10

B. Josefsson, J. Jakobi, A. Papenfuss, T. Polishchuk, C. Schmidt, L. Sedov Identification of Complexity Factors for Remote Towers. In **SESAR Innovaon Days (SID 2018),** December 3-5, Salzburg.

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Relation between:

- Subjective workload ratings
- Several quantitative measures:
  - # ATCO tasks (ATs)
  - Measures related to communication length

Validation of quantitative workload indicators on their power to predict workload in a conventional tower and Remote Tower (single and multiple mode)

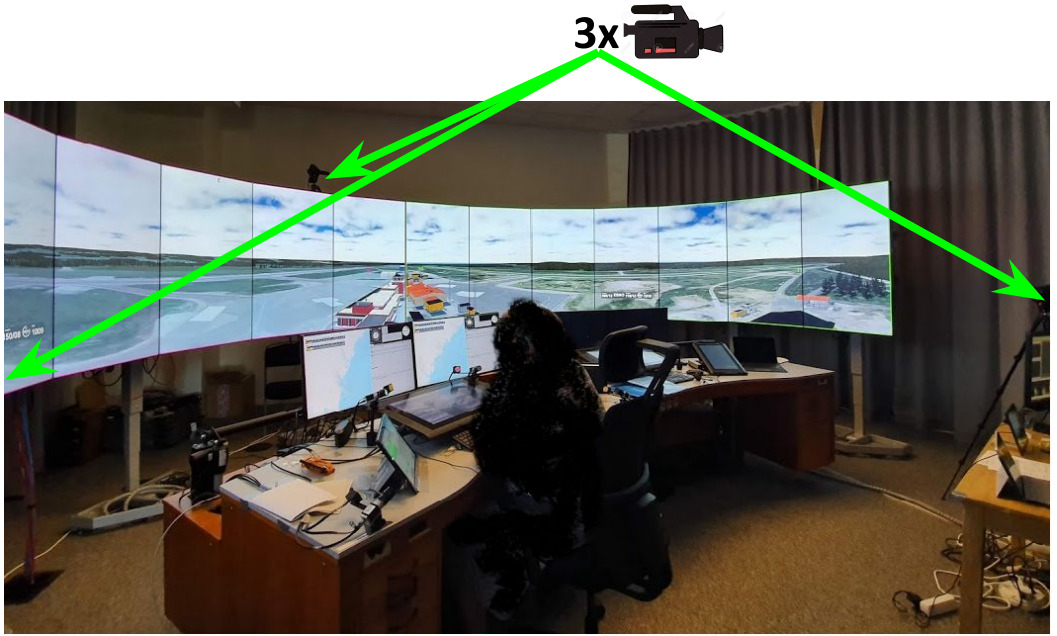
ATCO tasks:

- Arrival
- Clearance
- Communication
- Departure
- Secondary Task
- Taxi

B. Josefsson, L. Meyer, M. Peukert, T. Polishchuk, C. Schmidt Validation of Controller Workload Predictors at Conventional and Remote Towers In **ICRAT 2020**

Simulation Study: Sundsvall Validation Trials 2019

- Simulated Remote Tower
- Worload rating by ATCO every 3mins, ISA scale
- Three ATCOs
- **Multiple and single mode**
- Video data analysis:
  - ATCO tasks
  - Communication time
  - Reaction time SPAM queries



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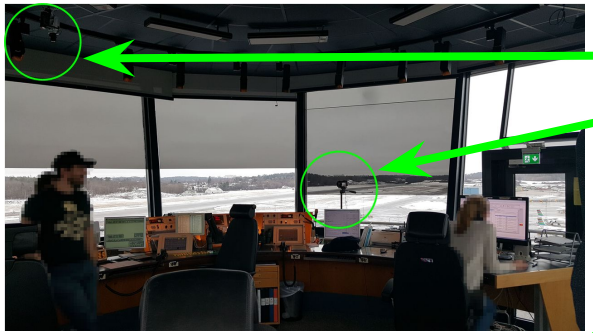
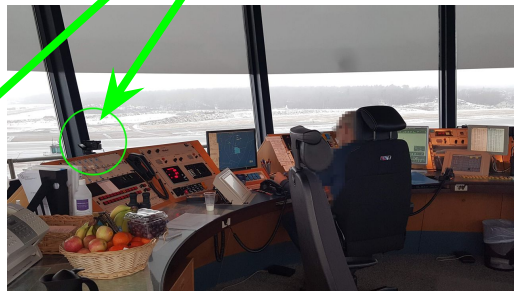
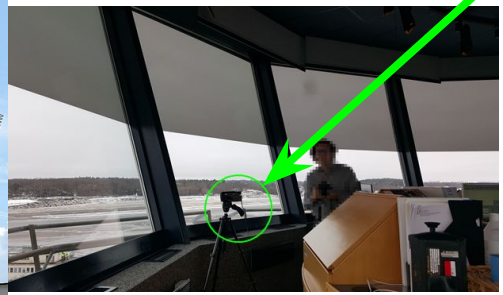
Bromma Airport: Field Study

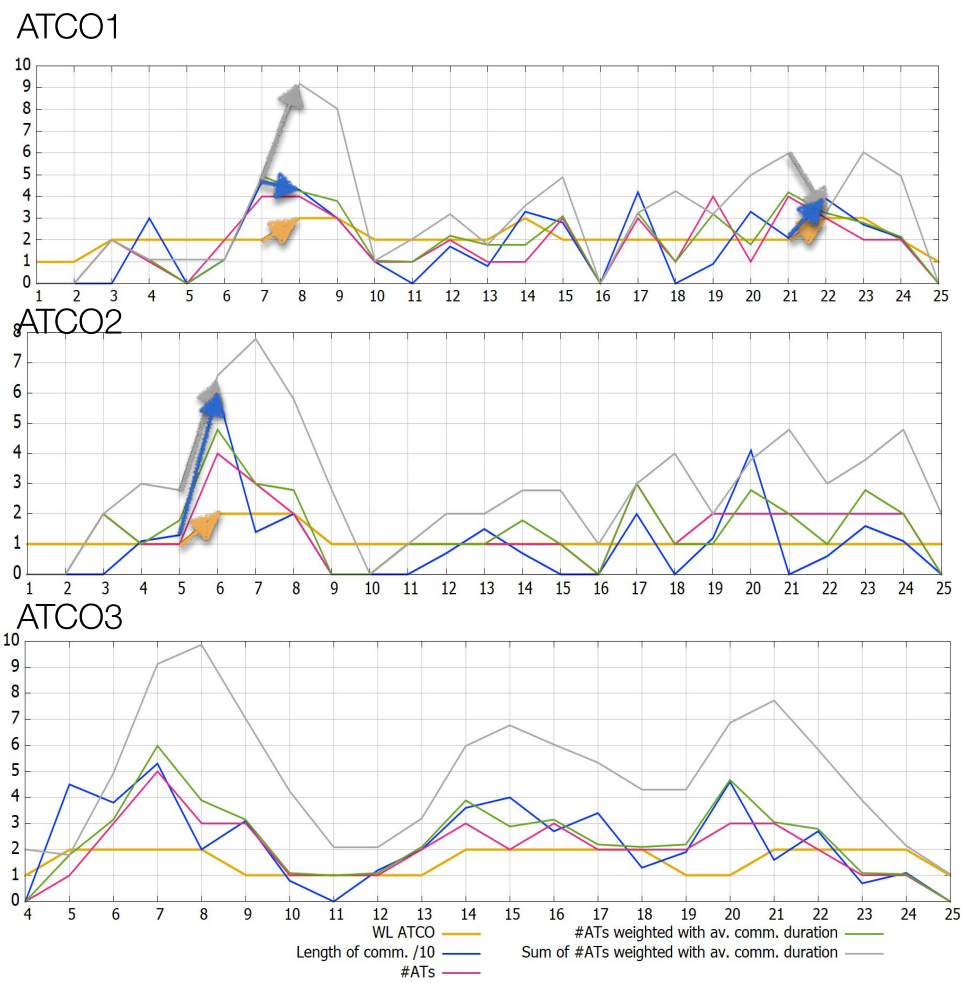
- During actual operations
- WL rating, Adapted Cooper-Harper Scale, every 5 mins
- 5 mounted video cameras
  - 3 facing ATCOs
  - 2 facing runway ends
- Video analysis: ATCO tasks
- 4-27 movs (increasing intensity)
- 3 ATCOs at work
- Audio recordings (communication)
- Weather (snow sweeping)







Simulation Study, Multiple Mode



We can observe a necessary condition:
Increase in **workload rating** always accompanied by an increase in at least one of:

- **Duration of communication during that time interval**
- Sum of the average-communication-duration weighted ATs for two consecutive time periods

- **Number of ATs not** a necessary condition for increase in **workload rating**

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Simulation and Field Studies

Each increase in the ATCO workload rating is accompanied by an increase in at least one of:

- ATs weighted with the percentage of the total communication time
- Average-communication-duration weighted ATs in the previous, current or following time period
- Sum of the average-communication-duration weighted ATs for two consecutive time periods
- Duration of communication during that time interval

The number of ATs is NOT a necessary condition for an increase in workload.

How exactly?

One of those or a combined measure?

Necessary ⟶ Insight in WL development

Goal: Sufficient criterion for WL increases AND decreases
⟶ Quantitative WL predictor

Slides, longer video:
http://webstaff.itn.liu.se/~chrsc91/icrat2020/

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AMPLIFY TEAMWORK WITH AUTOMATION

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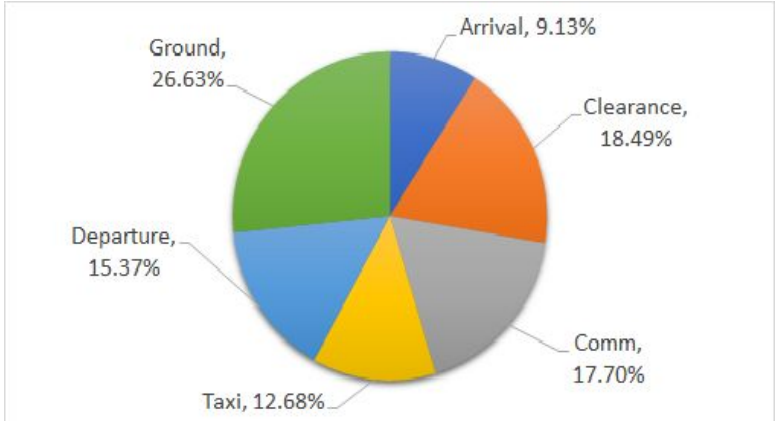
Bromma Airport: Field Studies

Weather Impact



Ground communication takes the largest share in total communication duration

Snow sweeping coordination is a major part in ground communication

Weather Impacts the ATCO Work

- Increased communication with ground services and pilots
- More frequent out-of-window observations
- Changes in Arrival and Departure routes and procedures

Image sources: Vectorstock.com

Staff Planning Challenges

- Conventional towers: staff adjustments are quite rare despite noticeable influence of weather
- Remote towers: weather impact to be integrated into automated rostering
- Multiple operation: ensure no controller is confronted unmanageable workload

Measuring Weather Impact

No good measures or classifications for weather impact on ATCOs exist

Research questions:

- How do different weather phenomena impact ATCO workload at different airports?
  - How to quantify the weather-induced capacity reductions?
    - How can we integrate this impact in RTC staff scheduling?

Contributes to: safety assessment of multiple operation (required by unions and regulation bodies)

Strategy Outline

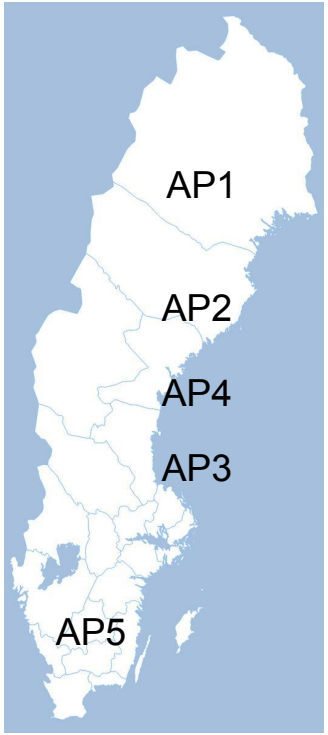
To integrate weather impact into RTC staff scheduling we propose the following steps:

1. Identify impactful weather phenomena for each considered airport
2. Define threshold values for these impactful weather phenomena
3. Choose exemplary historical dates at which all considered weather phenomena are present
4. Calculate probabilities for the weather phenomena exceeding the threshold values from (2)
5. Calculate probability for any impactful weather phenomenon occurrence for each hour
6. Obtain flight movements data for all airports for the chosen dates.
7. Calculate a distribution of the necessary number of ATCOs for RTC staffing

Airports

Five airports, operated remotely or planned for remote operation:

- **AP1**: Small AP w/ low traffic, few scheduled flights per hour. Inland location north of the Arctic Circle and other 4 airports
- **AP2**: Small regional AP with regular scheduled flights (usually open 24/7). Coastal location, north of AP3-5.
- **AP3**: Small regional AP with regular scheduled flights. Coastal location, north of AP5.
- **AP4**: Small regional AP with regular scheduled flights. Coastal location, north of AP3 and AP5.
- **AP5**: Low to medium-sized AP, multiple scheduled flights per hour (usually open 24/7). Coastal location in the South of Sweden, Marine West Coast Climate.



ATCOs


Image source: Clipart library

- Significant operational experience + some with experience in remote towers
- Familiar with operational procedures in different weather conditions
- Three ATCOs: two male, one female
- Average age: 46.7 years, experience as ATCO - 17.7 yrs, experience at these towers - 13 yrs
- Two of the three worked remotely

Structured Interview

Example additional tasks due to weather:

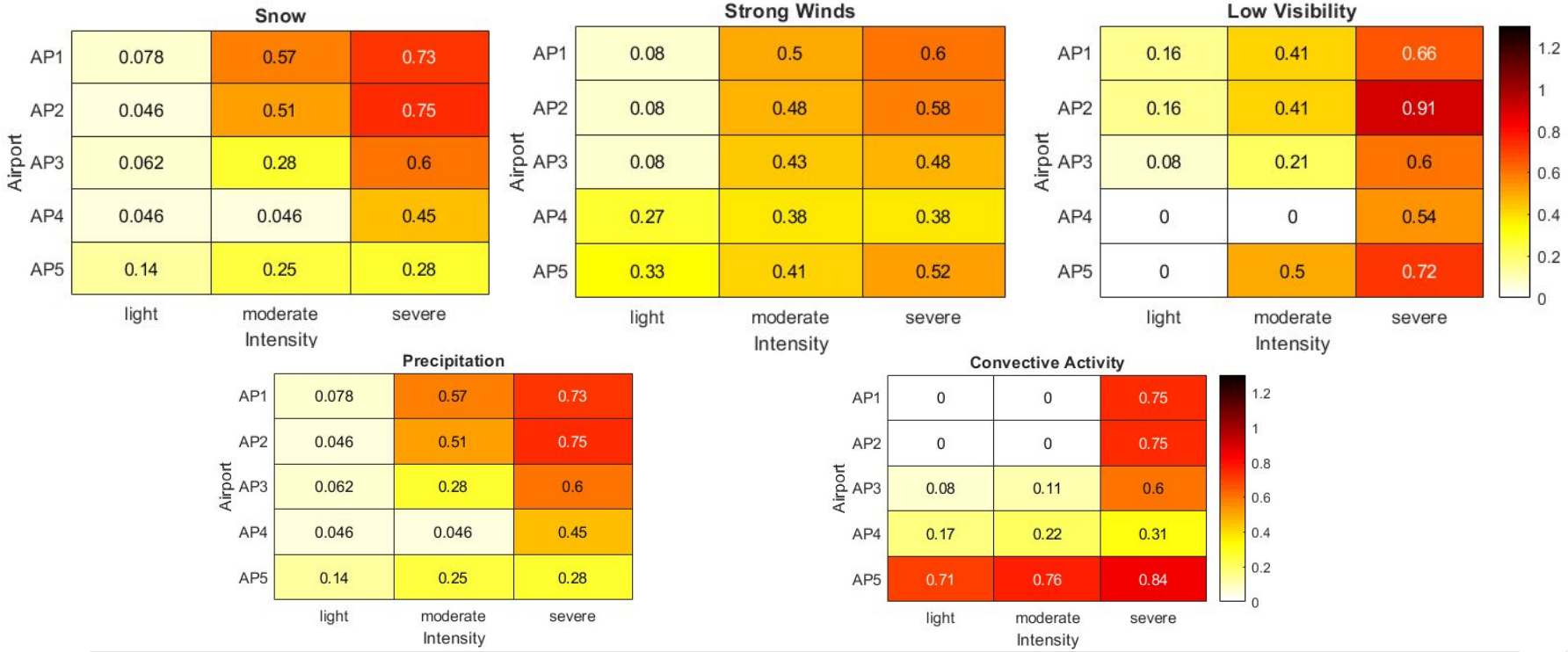
Anticipation and condition detection, Visual observation, RWY closing and re-opening for inspection change of departure/arrival RWY, Early warning to pilots, Clear arrivals to holding areas, Increased separation requirements, Increased coordination, Increased frequency occupancy time, frequent MET reports

Controllers' answers translated to numerical values:

Prose formulation	Numerical value
no	0
rarely, not too much	0.25
sometimes, maybe, can happen, several times	0.5
often, increased, more likely, higher	0.75
yes	1
much more; yes, significantly	1.25

Interview Results

We summed up the numerical values reflecting controller's answers and divided by the number of additional tasks



July 29: Probability of Impactful Weather Events

Jul 29	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
AP1	0.2	0.2	0.7	0.7	0.7	0.82	0.82	0.82	0.9571	0.9571	0.9571	1	1	1	1	1	1	1	1	1	1	1	1	0.7
AP2	0.4	0.4	0.8	0.8	0.8	0.51	0.51	0.51	0.36	0.36	0.36	0.88	0.88	0.88	1	1	1	1	1	1	1	1	1	1
AP3	1	1	1	1	1	0.915	0.915	0.915	0.325	0.325	0.325	0	0	0	0	0	0	0	0	0	0	0	0	0
AP4	0	0	0.5	0.5	0.5	0.1	0.1	0.1	0.5	0.5	0.5	0.15	0.15	0.15	0.5	0.5	0.5	0.1	0.1	0.1	0	0	0	0.5
AP5	0.15	0.15	0.25	0.25	0.25	0.52	0.52	0.52	0.6425	0.6425	0.6425	0.235	0.235	0.235	0.775	0.775	0.775	0.5	0.5	0.5	0	0	0	0

Flight data (FR24): #movements

Jul 29	8	9	10	11	12	13	14	15	16
AP1	0	0	0	0	0	0	1	1	0
AP2	0	0	1	2	1	1	1	0	3
AP3	0	0	0	0	1	1	0	1	1
AP4	0	1	1	0	0	0	0	0	0
AP5	3	0	0	0	1	1	3	4	0

Rosters enforcing single operation at the airports experiencing bad weather

Results: Distribution of the Optimal Number of Controllers

July 29, 2019 (8:00 - 16:00) with 4 out of 5 weather phenomena observed

No weather impact: **5** controllers needed

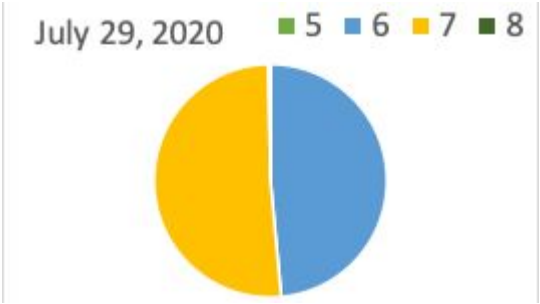
With weather impact taken into account:

5 controllers with probability 0,08 %

6 controllers -- 48,44 %

7 controllers -- 51,2 %

8 controllers -- 0,28 %



Conclusions

- Proposed a strategy based on experts opinions as a first step
- Modelled the probability of impactful weather events
- Incorporated into staff scheduling framework for RTC
- Obtained example distributions for optimal number of controllers
- Demonstrated that ignoring weather impact - can lead to understaffing

B. Josefsson, A. Lemetti, T. Polishchuk, V. Polishchuk, C. Schmidt. Integrating Weather Impact in RTC Staff Scheduling. SESAR Innovation Days (SID) 2020.

Future: Use our experience from KODIC/CAPMOD in other areas!

CAPMO-Train

Capacity Modeling and Shift Optimization for Train Dispatchers

Project funded by Trafikverket (within KAJT*, kajt.org), April 2021-March 2024.

Together with vti, the Swedish National Road and Transport Research Institute.

- Several train dispatchers direct and facilitate train movements
- Work of a train dispatcher results in workload
- During a train dispatcher shift the workload should be neither too high or too low
- Workload within “sweet spot”

Image source:
http://www.diplomacyandcommerce.rs/serbian-trains-will-be-even-safer-and-faster-thanks-to-russian-technology/

*Capacity in the Railway Traffic System - a research program for improved railway system performance

AMPLIFY TEAMWORK WITH AUTOMATION

CAPMO-Train

Capacity Modeling and Shift Optimization for Train Dispatchers

Project funded by Trafikverket (within KAJT*, kajt.org), April 2021-March 2024.

Together with vti, the Swedish National Road and Transport Research Institute.

- Several train dispatchers direct and facilitate train movements
- Work of a train dispatcher results in workload
- During a train dispatcher shift the workload should be neither too high or too low
- Workload within “sweet spot”

Image source:
http://www.diplomacyandcommerce.rs/serbian-trains-will-be-even-safer-and-faster-thanks-to-russian-technology/

In this project:

- Study upper and lower bounds for safe workload and influence of unforeseen events on workload
- Study operational requirements on and objectives for train dispatcher shifts
- Design optimization framework for the optimal planning of train dispatcher shifts
- Computation and analysis of train dispatcher shifts for Malmö dispatching center
- Extend optimization framework for ad-hoc replanning off train dispatcher shifts in case of unforeseen events
- Automated shift planning incl. workload

Open for new ideas and collaboration in other areas!

Status: Project start in April, hiring PhD student

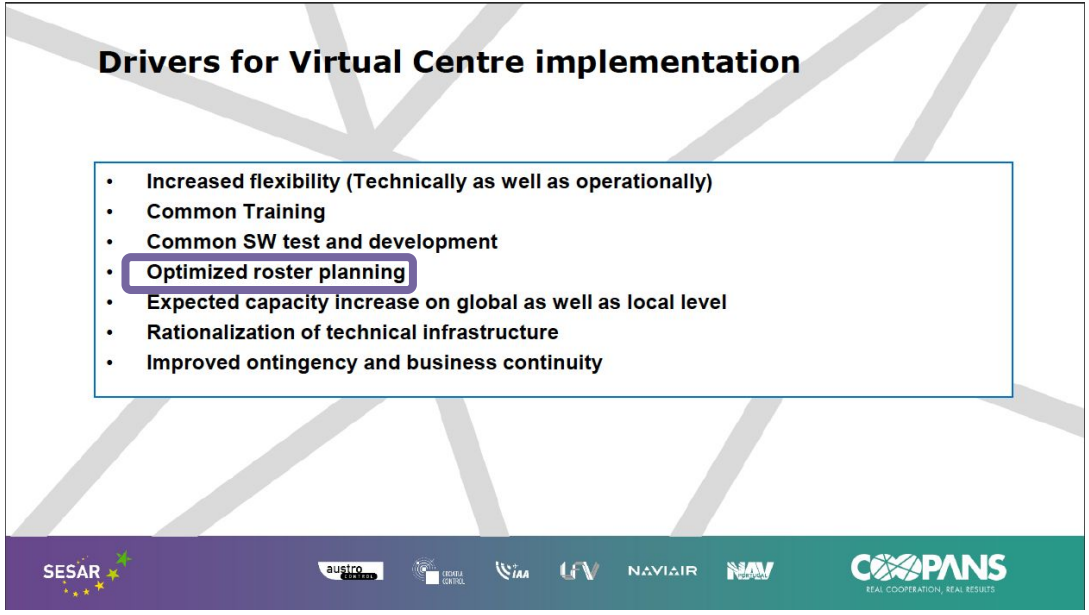
AMPLIFY TEAMWORK WITH AUTOMATION

Future Research Directions

We intend to use our framework for en-route traffic:

- ***Optimize rostering*** of ATCOs for traditional Area Control Centers (ACCs) - *application of our framework*
- ***Virtual centres***: cross-border delegation of ATS → split WL between ATCOs from different ANSPs - *innovations*

(COOPANS working thesis: We shall enable ATM provision anywhere from anywhere within COOPANS community)



Status: proposal preparation

Open for new ideas and collaboration!

Slide from ATSEP webinar,
COOPANS views on Virtual centre
November 4, 2020

THANK YOU!

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