Configuration and Planning of the Remote Tower Modules in a Remote Tower Center
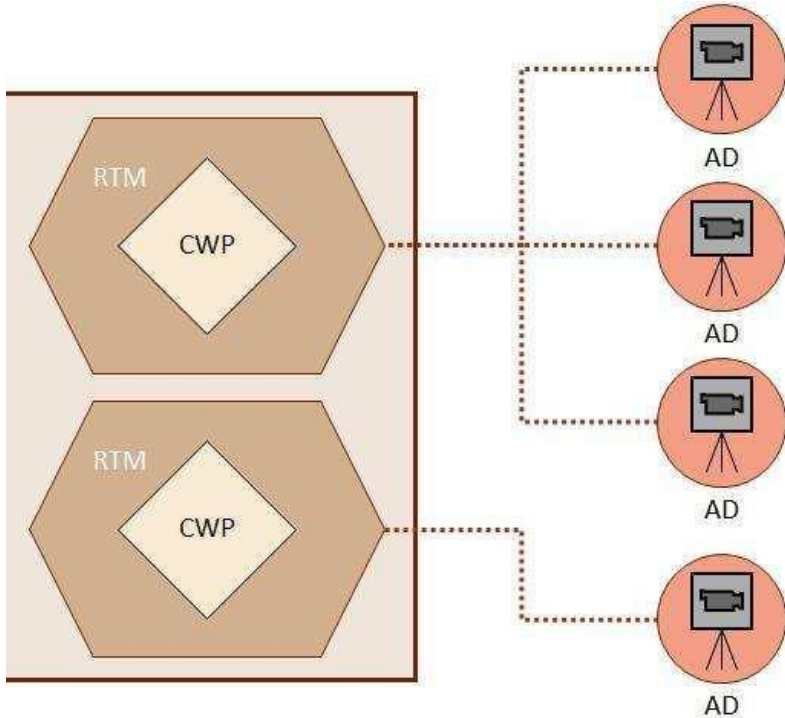
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ATS today

- Local tower situated at the aerodrome

    → *maintenance cost*

- ATCO(s) responsible for maneuvering and taxying

    → *staffing, (re)training costs*

- Out-of-the-window views + radars (PRS/SSR/SMR)

Remotely Operated Towers (ROT)

- replace local tower with cameras and sensors
- save on staff and building maintenance
- provide ATS remotely to small aerodromes

Remote Tower Center
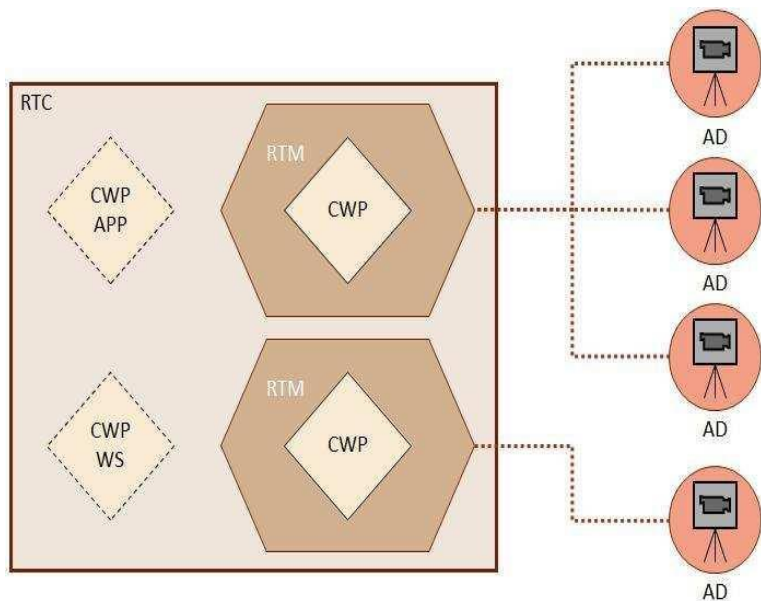
- contains Remote Tower Modules (RTMs)
- RTM contains several CWPs + optional WS and APP

- unified HMI

ROT

- within SESAR

- in Sweden
    - run by SAAB and LFV
    - RTC in Sundsvall is currently evaluated

- similar programs in Germany et al.

- Next: large-scale tests (3 aerodromes per module?)

Prior work: Safety, perception, usability

- Möhlenbrink, C., Rudolph M., Schmidt M. Fürstenau N., Wahrnehmungsexperimente im RApTOr DemonstratorRTO-Workshop, Braunschweig, 2007
- Ellis, S.R., Liston, D., Visual Features Involving Motion Seen from Airport Control Towers. IFAC 2007
- Papenfuß, A., Friedrich, M., Möhlenbrink, C., Rudolph, M., Schier, S., Schmidt, M., Fürstenau, N.. High-fidelity Tower Simulation for operational validity of Remote Tower Control. IFAC 2010
- Möhlenbrink, C., Friedrich, M., Papenfuß, A., Rudolph, M., Schmidt, M., Morlang, F., & Fürstenau, N. High-fidelity human-in-the-loop simulations as one step towards remote control of regional airports: A preliminary study. ICRAT 2010
- Wittbrodt, N., Gross, A., Thüring, M. Challenges for the Communication Environment and Communication Concept for Remote Airport Control Centres. IFAC 2010
- Meyer, L., Vogel, M., Fricke, H. Functional Hazard Analysis of Virtual Towers. IFAC 2010
- Oehme, A., & Schulz-Rueckert, D. Distant Air Traffic Control for Regional Airports. IFAC 2010
- Moehlenbrink, C., Papenfuss, A., and Jakobi, J., The Role of Workload for Work Organisation in a Remote Tower Control Center. ATM-Seminar 2011

This paper

Optimization:
    minimize # of modules
    while serving ATC demand
    and
    not overloading ATCOs

RTM assignment problem (1)

Assumptions and limitations:

- ROT components are implemented and available

- No emphasis on technical aspects

- Safe and reliable system

- Aerodromes are suitable for RTC operation

- Precise controllers schedule is out of the scope

RTM assignment problem (2)

Input:

- Aerodromes
    - Periods of operation per aerodrome (open hrs)
        - which aerodromes are active in each period
    - Number of movements per aerodrome per period
- RTC modules (RTMs)
    - Max number of movements per RTM per period
    - Max number of aerodromes per RTM

Output: aerodromes-to-RTMs assignment

RTM assignment problem (3)

Objective: minimizing the number of modules

Constraints:

- number of aerodromes per module ≤ 3
- number of movements per module per period ≤ 6
- each aerodrome assigned to only 1 module
- all movements are handled
- all operating hours are covered

RTM assignment problem (4)

- Bin Packing problem

- NP-hard

- Solve small instances using optimization software (AMPL, CPLEX)

Integer programming (IP) formulation: variables

mov_{ijk} = # of movements handled by RTM i
at aerodrome j during period k

$$period_{ijk} = \begin{cases} 1 & \text{if AD } j \text{ assigned to RTM } i \text{ during period } k \\ 0 & \text{otherwise} \end{cases}$$

$$AD_{ij} = \begin{cases} 1 & \text{if AD } j \text{ assigned to RTM } i \\ 0 & \text{otherwise} \end{cases}$$

$$RTM_i = \begin{cases} 1 & \text{if RTM } i \text{ is used} \\ 0 & \text{otherwise} \end{cases}$$

Objective function and constraints

$$\min \quad \sum_{i=1}^{r} RTM_i$$

$$\text{s.t.} \quad \sum_{j=1}^{n} mov_{ijk} \leq maxMov \qquad \forall i, k$$

$$\sum_{j=1}^{n} AD_{ij} \leq maxAD \qquad \forall i$$

$$\sum_{i=1}^{r} AD_{ij} \leq 1 \qquad \forall j$$

$$\sum_{i=1}^{r} period_{ijk} \leq 1 \qquad \forall j, k$$

$$mov_{ijk} \leq period_{ijk} \times maxMov \qquad \forall i, j, k$$

$$\sum_{i=1}^{r} mov_{ijk} = ADmov_{jk} \qquad \forall j, k$$

$$\sum_{i=1}^{r} period_{ijk} > op_{jk} \qquad \forall j, k$$

$$\sum_{k=1}^{p} period_{ijk} \leq AD_{ij} \times p \qquad \forall i, j$$

$$\sum_{j=1}^{n} AD_{ij} < RTM_i \times \mathbf{n} \qquad \forall i$$

$$period_{ijk}, AD_{ij}, RTM_i \in \{0, 1\} \qquad \forall i, j, k$$

mov_{ijk} = # of movements handled by RTM i at aerodrome j during period k

$$period_{ijk} = \begin{cases} 1 & \text{if AD } j \text{ assigned to RTM } i \text{ during period } k \\ 0 & \text{otherwise} \end{cases}$$

$$AD_{ij} = \begin{cases} 1 & \text{if AD } j \text{ assigned to RTM } i \\ 0 & \text{otherwise} \end{cases}$$

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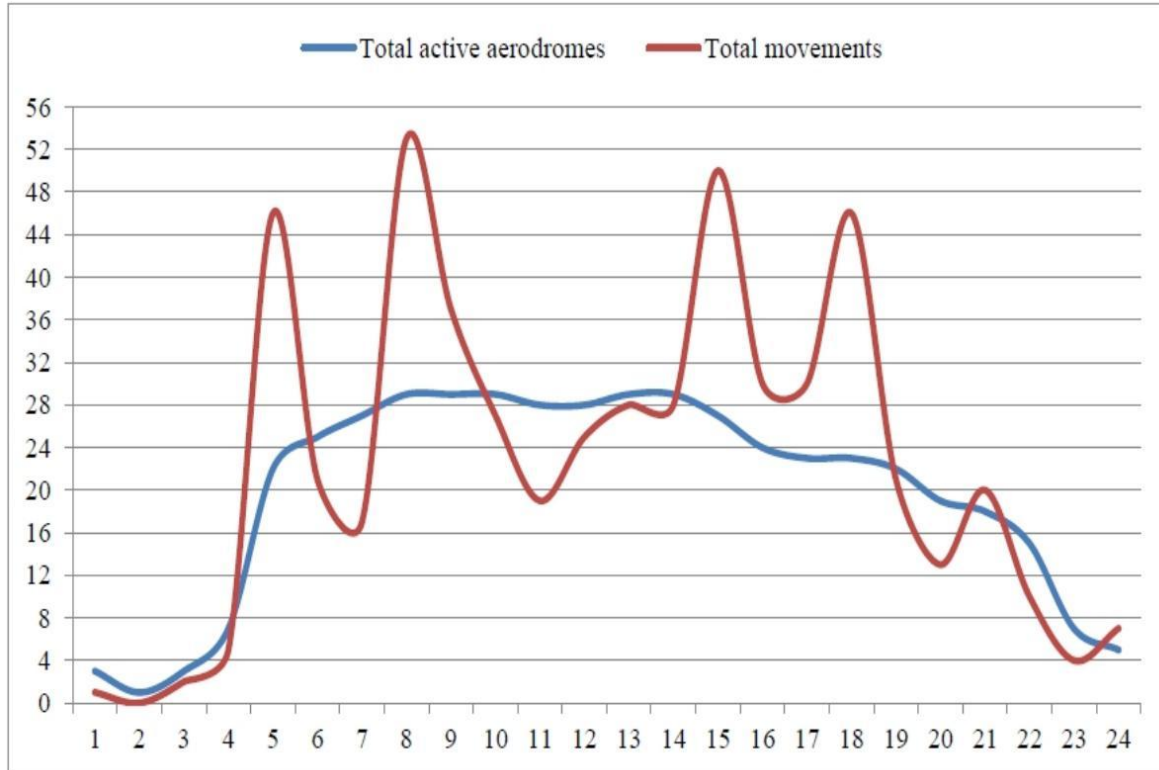
Data collection (1)

29 "ROT-compatible" swedish airports
(# movements per period ≤ 6)
operating during a week in October 2013

from:

- LFV (AIP)

- Transportstyrelsen

- EUROCONTROL (DDR2)

Data collection (2)

Lower bounds

LB1

= max # active aerodromes / max # aerodromes per RTM

= ceil [29/3] = **10** modules

LB2

= max # movements per period / max # movements per RTM

= ceil [53/6] = **9** modules

Evaluation (1)

Module	Assigned aerodromes
RTM1	ESMT, ESNO, ESSD
RTM2	ESDF, ESMQ, ESSL
RTM3	ESCF, ESKN, ESMK
RTM4	ESGJ, ESOK, ESSP
RTM5	ESIB, ESNQ, ESNZ
RTM6	ESNS, ESNX, ESPA
RTM7	ESGP, ESPE, ESTL
RTM8	ESCM, ESNN
RTM9	ESGT, ESOW, ESTA
RTM10	ESIA, ESMX, ESOE

Optimal assignment of aerodromes to modules for October 14, 2013

Evaluation (2)

Date	RTMs
2013-10-14	10
2013-10-15	10
2013-10-16	10
2013-10-17	10
2013-10-18	9
2013-10-19	9
2013-10-20	9

The number of RTMs for all weekdays in October 2013

Evaluation (3)

```
movements[9,j,k]

:      0  1  2  3  4  5  6  7  8  9 10 11 12 13 14 15 16 17 18 19 20 21 22 23  :=

ESGT  0  0  0  0  1  0  2  0  1  0  0  0  0  0  1  0  1  0  0  0  0  0  0  0

ESOW  0  0  0  0  2  1  1  0  2  4  2  0  5  4  3  3  1  3  5  2  1  0  0  0

ESTA  0  0  0  0  2  2  1  6  1  0  1  2  1  1  2  1  1  3  1  0  1  0  0  0
```
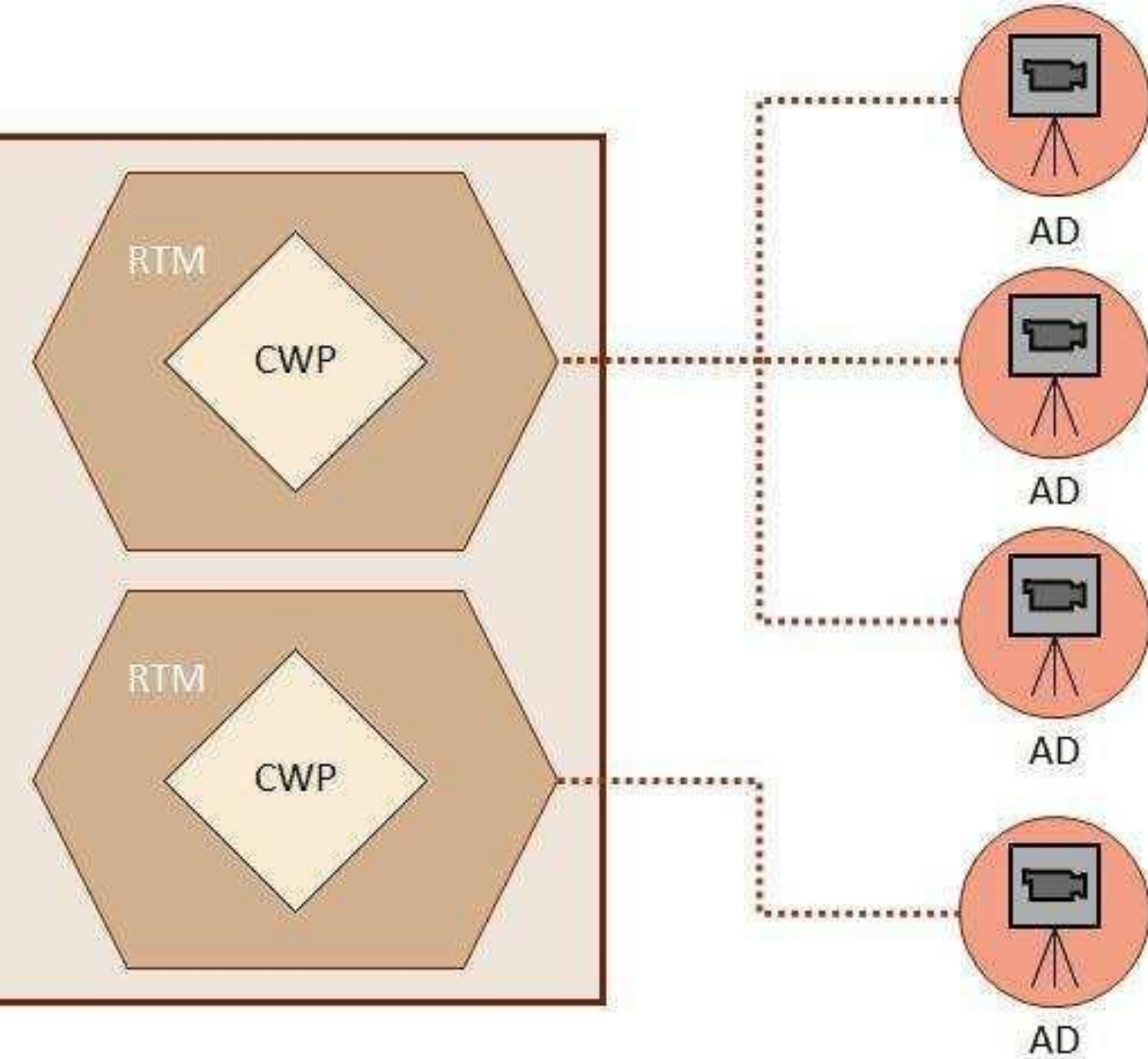
The number of movements at aerodromes in the module RTM9.

Conclusions

- ROT concept - cost-saving opportunities for small aerodromes

- Many challenging practical questions

- Modeling can solve some of them

- Results agree with lower bounds estimation

Future Work

- optimize workload across modules
- handle simultaneous movements inside the module
- staffing (schedule)
- clustering aerodromes
- RTC positioning
- simulations
- risk assessment
- …

RTM

CWP

RTM

CWP

AD

AD

AD

AD

Thank

you!