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

Tobias Andersson Granberg, Peter Axelsson,
Jonas Petersson, Tatiana Polishchuk,
Valentin Polishchuk, Christiane Schmidt

ITN, Linköping University, Sweden

***Abstract*— Today, many small aerodromes struggle with financial difficulties, and a large cost is air traffic control. Remote tower centers, which remotely provide air traffic services to aerodromes, can help reduce this cost. Each center may contain a number of remote tower modules, where each module is manned by a controller that can handle one or more aerodromes. In this paper we present the remote tower center concept and develop a model that optimizes the assignment of airports to the remote tower modules. Computational results for a possible scenario based on real data for Swedish airports are presented.**

Keywords – remote tower control center, aerodromes, optimization of air traffic, assignment problem, air traffic management.

I. Introduction

Small airports are important for ensuring an equal connectivity and accessibility to fast transportation in a country. This is especially true for Sweden, which contains large sparsely populated areas. However, since population density is directly related to demand for aviation services, it is also hard to make these small airports profitable. One large cost is that of air traffic control service. To be able to keep small airports running, the industry needs to find a more cost-effective solution.

Today, most aerodromes with air traffic services (ATS) are controlled from a tower situated at the aerodrome. The air traffic controller(s) (ATCO(s)) in the tower is responsible for the traffic on the maneuvering area (runways and taxiways) and the traffic in the vicinity of the aerodrome [1]. The main means of surveillance used by an ATCO is looking out of the windows. In some towers, primary or secondary surveillance radar (PSR/SSR) and surface movement radar (SMR) are also used as means of surveillance. The remote tower concept aims to replace the local tower with cameras and sensors, while still providing the same service.

The Single European Sky ATM Research (SESAR) program is a project for research and development launched by the European Union to meet the future need of capacity and safety within aviation [2]. Saab AB is in charge of projects within SESAR that concern the conduct of remote air traffic service (ATS) for one or more airports simultaneously, i.e. the Remotely Operated Tower (ROT) [3]. By implementing the ROT concept, the cost of having air traffic controllers on duty could be split between several airports [4].

Researchers study ROT concept from different angles. The authors of [5] evaluate the influence of replacing the outside view on the point in time when controllers detect safety-relevant aspects of traffic. The work [6] focuses on the controllers' capability to detect changes in the velocity of aircraft from the control tower. Usability aspects within the novel work environment were considered in [7], [8]. These papers also introduce the issue of controller assistance tools for remote tower. Wittbrodt et al. [9] stress the role of radio communication in the context of a remote airport traffic control center. In a safety assessment of the ROT concept, Meyer et al. [10] suggest functional hazard analyses and pinpoint the issue of getting reliable probability values for the models. Oehme and Schulz-Rueckert [11] propose a sensor-based solution for aerodrome control to become independent of visibility condition and the tower location.

In [12] Moehlenbrink et al. consider various aspects of work organization in a remote center. They propose several variants of work to control two airports from one center. If the remote control center reliably offers all information and communication facilities for ATC, there is a wide range of how roles and tasks can be assigned to the controllers in the control center.

The ROT concept is currently operational at Sundsvall Timrå Airport where a Remote Tower Center (RTC) is located, and where Örnsköldsvik Airport is controlled from one Remote Tower Module (RTM). According to the plan, both Sundsvall Timrå Airport and Linköping City Airport will be remotely controlled from the RTC in Sundsvall, starting in 2016.

Following the evaluations in Sundsvall Timrå Airport, Saab will enter a phase of development where they need to test the system on a larger scale. Simulations including several modules and maybe even several RTCs must be performed in order to fully understand the effects and impact of a large scale implementation. Simulations with more than three aerodromes at the same time have not yet been performed, nor has any specific research been done on how a simulation like that would be executed [13].

The contributions of this paper include:

- introduction and description of the RTC design,
- optimization and modeling of aerodromes-to-RTM assignment problem,
- evaluation of the model based on the real data from Swedish airports.

The notation we use is summarized in TABLE I.

The remainder of the paper is organized as follows. Section II describes how the air traffic at most airports is controlled. The Remote Tower Concept is introduced in Section III. We describe the model and formulate the optimization problem in connection to RTC in Section IV. Section V contains experimental evaluation and Section VI concludes the paper.

TABLE I. NOTATION

Notation	***Description***
AD	aerodrome
APP	approach control service
ATC	air traffic control service
ATCO	air traffic control officer
ATM	air traffic management
ATS	air traffic services
CWP	controller working position
HMI	human machine interface
OTW	out-of-the window view
ROT	remotely operated tower
RTC	remote tower centre
RTM	remote tower module
SMR	surface movement radar
SSR	secondary surveillance radar
TWR	aerodrome control service
WS	watch supervisor

II. CURRENT ATM SYSTEM

The essentials of the current system are the physical tower located at the aerodrome and one or more ATCO(s) situated in the tower. From the tower ATCO can see and monitor the maneuvering area to assure safe and orderly flow of traffic on and in the vicinity of the aerodrome. The ATCO is also responsible for clearance delivery, ground control, managing traffic to and from the aerodrome, and flight data processing. In some cases, the TWR also provides Approach Control, from a separate working position with separate radar.

According to [14], the aerodrome tower has to fulfil some requirements in order to properly control aircraft operating on and in the vicinity of the aerodrome:

1. The tower must permit the controller to visually survey those portions of the aerodrome and its vicinity over which he/she exercises control.

2. The tower must be equipped to provide the controller with rapid and reliable communication with aircraft. Moreover, the requirements state that the controller must be able to distinguish between aircraft and vehicles operating on the same or different runways and/or taxiways. The tower needs to be high enough to allow the controller to abide by previously mentioned requirements.

The ATCO uses many means and systems to provide ATS. Some of them are optional, such as Surface Movement Radar (SMR), but the most important and most distinguishing means for a local TWR, is the out-the-window (OTW) view.

Other examples of systems and tools used for the provision of ATS include air-ground communications (e.g. radio), flight plan and ATS message handling systems, light controls (e.g., for runway/taxiway lights), binoculars, signal light gun, etc.

III. REMOTE TOWER CONCEPT

The objective of remote provision for single or multiple aerodromes is to provide the ATS defined in [15], [16], [17] for more than one aerodrome, by a single ATCO, from a remote location. The concept is expected to be applied to low density and medium density aerodromes. However, the concept might also be implemented as a contingency system for larger airports [17].

The RTC contains controller working positions (CWPs) and remote tower modules (RTM). The module is the room in which the visual reproduction display is located. Within the room, there can be one or more CWPs. For example, another CWP can be fitted in the module if a certain aerodrome or event requires the attention of two ATCOs. However, the most common setup is one CWP in the module [17].

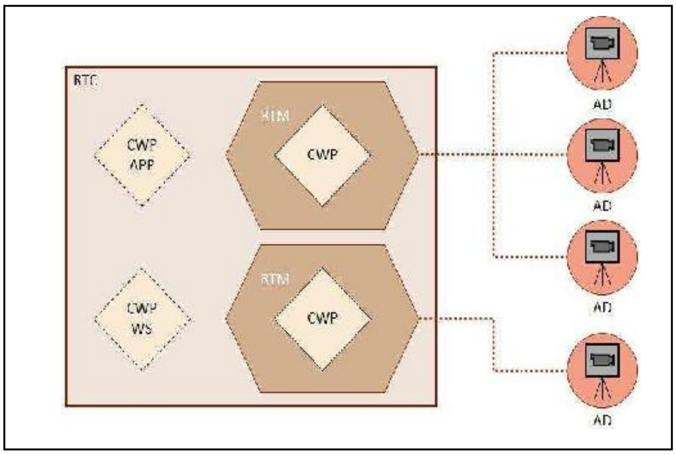

Figure 1. Schematic overview of an RTC.

Outside the module, but inside the RTC, separate CWPs can be installed. In the RTC shown in Figure 1 there are two additional CWPs: a watch supervisor (WS) position that is responsible for the operations, and an approach control position (APP). These positions are however optional and APP could instead be provided by the module. In larger RTCs, it is reasonable to assume that separate WS and APP positions would be installed.

To allow transition between aerodromes to be as fast and efficient as possible, the module will be required to have a unified layout. Today the layout, or Human-Machine Interface (HMI), varies between different towers. The unified HMI in a module will eliminate the need to either change the HMI of the working position or require the controller to be licensed for a specific HMI at a specific aerodrome.

Technically, one module could present visual reproductions of an infinite number of aerodromes simultaneously. However, thus far Saab is working from the hypothesis that one remote tower module can handle at most three aerodromes simultaneously [13].

The OTW view provided to the controller in a module is a reproduction of the actual view, using the means of cameras and sensors. Depending on how far away from the aerodrome the module is located (or rather the length of the cable linking the two), there is some delay, i.e. what is shown is not actually real-time. However, this delay usually does not exceed one second [15].

The reproduced OTW view is solely based on the cameras mounted on a camera-tower at every aerodrome, and if one or more of these cameras show a false picture or no picture at all, the OTW surveillance would cease to exist. If no other surveillance equipment is available at the aerodrome (e.g. SMR), the service would be heavily reduced or even terminated. However, this is not different from other types of equipment failures at regular airports, or when visual flight rules cannot be used, e.g. during fog. Contingency plans will be used until the problem is solved.

The main benefit of an RTC implementation is cost effectiveness. Remote ATS facilities will be cheaper to maintain, able to operate for longer periods and enable lower staffing and training/re-training costs (through centralized resource pools), by large scale effects. RTC implementation will also significantly reduce the requirement to operate and maintain actual control tower buildings and infrastructure, leading to further cost savings, as well as eliminating the need to build replacement towers.

IV. RTM ASSIGNMENT PROBLEM

The RTM assignment problem is to assign aerodromes to remote tower modules in the way which minimizes the amount of modules needed to provide remote ATS. The problem needs to consider operating hours as well as movements at the aerodromes, while finding the best combination according to the given constraints.

A. *Assumptions and limitations*

For the purpose of this paper, the concept of ROT and all its components are considered available and ready to be implemented wherever suitable. No emphasis is placed on the technical aspect of the system, whether it functions correctly or not. The system is also considered reliable and no safety margin, i.e. for unusual events, is added.

We decide which aerodromes are suitable to be remotely controlled solely based on the traffic intensity; in general, a more comprehensive evaluation of suitability can be performed. The aspect of staffing the RTC, i.e. who works where, and when in the RTC, the need of separate positions for approach control, as well as where to locate the RTC, are out of the scope of this paper.

B. *Data collection*

Information about Swedish aerodromes that could be eligible for remote tower services was retrieved from the Aeronautical Information Publication (AIP) online [16]. This list (publically available) includes all airports in Sweden with scheduled traffic, as well as a number of additional ones.

Statistics for the traffic at the specific aerodromes was received from Transportstyrelsen, the Swedish Transport Agency. The major input to the model is movements at each aerodrome, which was received from the Demand Data Repository (DDR) hosted by EUROCONTROL. The flight data from DDR is split into segments, making it possible to isolate the arrival and departure information for each flight. This was extracted and used as input data in the model.

C. Input

We summarize the extracted input data in TABLE II. We are given a number of aerodromes, n, that are to be remotely controlled from the RTC, by one of r available RTMs, where all RTMs do not have to be used. Time is discretized into p periods, and the number of movements at each airport in each period is used as a base for making the assignment.

TABLE II. INPUT DATA

Notation	***Description***
n	number of aerodromes
p	number of periods
r	number of RTMs
$maxMov$	maximum number of movements per RTM per period
$maxAD$	maximum number of aerodromes per RTM
$ADmov_{jk}$	number of movements at aerodrome j during period k
op_{jk}	indicator if aerodrome j is active during period k

D. Output

The output is an assignment of aerodromes to RTMs.

E. Integer program

$$\min \quad \sum_{i=1}^{r} \mathsf{RTM}_i \qquad (1)$$

$$\text{s.t.} \quad \sum_{j=1}^{n} \mathsf{mov}_{ijk} \le \mathsf{maxMov} \qquad \forall i,k \qquad (2)$$

$$\sum_{j=1}^{n} \mathsf{AD}_{ij} \le \mathsf{maxAD} \qquad \forall i \qquad (3)$$

$$\sum_{i=1}^{r} \mathsf{AD}_{ij} \le 1 \qquad \forall j \qquad (4)$$

$$\sum_{i=1}^{r} \mathsf{period}_{ijk} \le 1 \qquad \forall j,k \qquad (5)$$

$$\mathsf{mov}_{ijk} \le \mathsf{period}_{ijk} \times \mathsf{maxMov} \qquad \forall i,j,k \qquad (6)$$

$$\sum_{i=1}^{r} \mathsf{mov}_{ijk} = \mathsf{ADmov}_{jk} \qquad \forall j,k \qquad (7)$$

$$\sum_{i=1}^{r} \mathsf{period}_{ijk} \ge \mathsf{op}_{jk} \qquad \forall j,k \qquad (8)$$

$$\sum_{k=1}^{p} \mathsf{period}_{ijk} \le \mathsf{AD}_{ij} \times p \qquad \forall i,j \qquad (9)$$

$$\sum_{j=1}^{n} \mathsf{AD}_{ij} \le \mathsf{RTM}_i \times \mathsf{n} \qquad \forall i \qquad (10)$$

$$\mathsf{period}_{ijk}, \mathsf{AD}_{ij}, \mathsf{RTM}_i \in \{0,1\} \qquad \forall i,j,k \qquad (11)$$

We formulate our problem as an integer program (IP) with the following variables:

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

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

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

mov_{ijk} – the number of movements handled by RTM i at aerodrome j during period k.

The constraints (2) and (3) restrict the maximum number of movements and aerodromes assigned to one RTM respectively. The constraints (4) and (5) assure that each aerodrome is assigned to only one RTM at a time and during all periods. The constraints (6) and (7) guarantee that all movements are handled during all periods. All ATS hours are to be covered, which is ensured by constraint (8). We use constraints (9) and (10) to connect the variables.

The considered problem is related to the family of Knapsack problems, i.e. it is type of Bin-Packing problem [18], which are NP-hard [19]. Smaller instances of the problem can however be solved using commercial off-the-shelf optimization software.

V. EVALUATION

We use the AMPL modelling language and the CPLEX solver [20] to model and solve the IP. The data covers Swedish airport operations during one week in 2013 (14th to 20th of October).

In the experiments, the size of the period is set to 1 hour. The maximum number of movements per module per period was set to $maxMov$ = 6, which is within a clear safety margin from a workload perspective. Some implications of this assumption are discussed later. As stated before, the number of aerodromes per module is restricted to $maxAD$ = 3.

Of the aerodromes in the AIP [16], 35 had traffic during the considered period. However, only 29 were deemed as “ROT-compatible”, since large aerodromes, such as Stockholm Arlanda, were not relevant to consider for remote operations. Furthermore, they violated the $maxMov$ constraint (2) in the model.

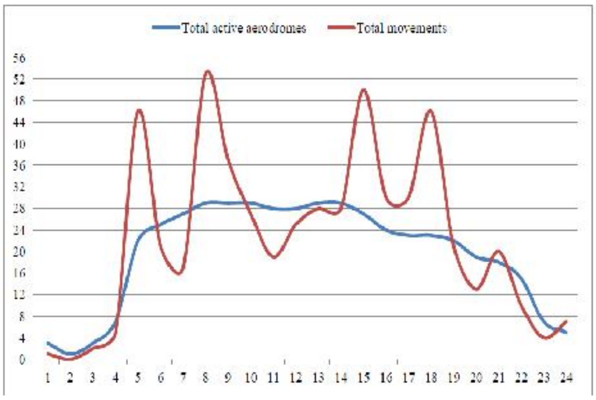

Figure 2. The number of movements and the number of active aerodromes.

Figure 2 illustrates the relationship between the number of movements and the number of active aerodromes for every hour during the day October 14. There are four obvious peaks in the traffic, while the number of aerodromes is somewhat more stable. On average, the number of movements is larger than the number of active aerodromes, which in practice means that there is more than one movement per aerodrome per period.

A. Lower bounds

Lower bounds for the number of modules are easy to obtain. Our first lower bound (LB1) is based on the number of active aerodromes: we divide the maximum number of active aerodromes in a given period by the maximum amount of aerodromes a single module can handle simultaneously. During October 14, a maximum of 29 aerodromes are active (periods 8, 9, 10, 13 and 14). This results in a lower bound of 10 modules (*ceil* [29/3] = 10).

The second lower bound (LB2) is based on the number of movements: we divide the maximum number of movements during a given period by the maximum number of movements a module can handle. For example, during period 8 on the day of October 14, 53 movements were observed. This results in a lower bound of 9 modules (*ceil* [53/6]), since not more than 6 movements are allowed per module.

B. Experimental results

For October 14, we obtained the module assignment as shown in TABLE III. TABLE VI illustrates the number of RTMs for each weekday, which is almost the same amount during the week. The results are in line with the estimates of the lower bounds discussed above.

TABLE III. OPTIMAL ASSIGNMENT OF AERODROMES ON OCT 14

MODULE	*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

TABLE V shows the number of movements during each period handled by one module (RTM9). As specified by the constraints, three airports are assigned to the module and the number of movements in each period does not exceed six.

TABLE IV. NUMBER OF RTMS FOR ALL WEEKDAYS

DATE	*NUMBER OF 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

TABLE V. THE NUMBER OF MOVEMENTS AT AERODROMES IN RTM9

Period	**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

C. Discussion

As clearly seen from TABLE V there are inactive periods in the module, when no movements are present. The unused periods would only be profitable if it were possible to find a user who needs them. This could either be an airline with a new flight, or another aerodrome (preferably in another time zone to fit the "idle" hours).

It is easy to adjust the model to accommodate various aspects of RTC implementation. For example, we could possibly achieve a better solution by omitting the constraint (4) that every aerodrome must be assigned to only one RTM. This way aerodromes would be allowed to be controlled by different RTMs in different time periods. When movements at different aerodromes occur in different time periods, less modules would be needed to control them. Of course, this modification requires changing the system functionality for switching between the modules. The overheads of such a solution should be taken into consideration.

It is important to notice that there is a possibility that movements at different aerodromes are not distributed uniformly during a period but may occur at the same time. For modelling purposes an ATCO is supposed to be able to handle simultaneous movements, but this aspect of the problem needs to be carefully studied and is left for future work. One possibility is to use a shorter period than one hour (e.g. 10 minutes), and decrease the maximum number of movements during the period (e.g. $maxMov = 1$).

In the analysis, the maximum amount of movements a single module can handle per period is set to six. In theory, this means that six movements could be split amongst three different aerodromes. In reality, one ATCO's total workload when controlling three aerodromes simultaneously would probably be higher than for one aerodrome and the same amount of traffic. With the previous statement in mind, the capacity for one module would depend on how many aerodromes are controlled simultaneously. However, this is not considered in the model.

VI. CONCLUSIONS AND FUTURE WORK

We presented the concept of remote tower control centers, which are designed to provide cost-saving opportunities for small airports. Although one center is already used operationally, many practical questions still exist in connection to large scale implementation.

In this paper we studied how to assign airports to the remote tower modules in an optimal way. For that purpose we formulated the problem as an IP and evaluated the optimization model on data for Sweden during a week in October 2013. We estimated the lower bounds and compared them with the output from the model and found that these estimates agree with the actual RTM demand.

The proposed model is quite general and can be used for planning the number of RTMs for future air traffic. If we input forecasted data, such as provided by EUROCONTROL, the model will help to find how many modules are needed in total and propose their operational schedule for each day of the following year.

Our model does not consider fair distribution of the workload across all modules, when one module would not have much more traffic than another module, thus creating a more balanced workload for all modules.

After the number of RTMs is decided, a lot of work is still to be done regarding staffing. Working hours, local agreements, and so on need to be fulfilled. A major question is how to combine the aerodromes to make the ATCOs as efficient as possible. There might be a need to cluster the aerodromes in a specific way to make it easier for the ATCOs to handle the traffic. This can be done in several ways and since it has not been analysed properly, it would be interesting to solve the problem of optimal clustering. The examples of possible clustering criteria include geographical position, runway configurations, and amount of traffic.

The location of the RTC is also an important aspect that has to be investigated. There could be advantages in placing an RTC in close proximity to an aerodrome which is not subject to remote control. This way the RTC will be co-located with an air traffic control centre, where technicians, infrastructure, and facilities are already available.

In addition, it may be interesting to consider combinations of conventional and remote operations, e.g. utilizing ATCOs at the airport during peak times, and letting the aerodrome be remotely controlled otherwise.

Before making the decision about abandoning the actual tower and controlling the aerodrome from a remote location, both operating hours and traffic must be considered thoroughly. Furthermore, formal risk assessments or a RAMS analysis (Reliability, Availability, Maintainability, Safety) should be performed before eventually deciding key parameters that may affect safety issues such as workload and situational awareness. The model presented in this paper could be used as a tool in such an analysis, and provide a good base for decision-making.

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