Identification of Complexity Factors for Remote Towers

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Introduction: Remote Tower Center, Interest in Workload Measure

Data

Identification of Critical Factors

Summary

Outlook
• Remotely operated towers enable control of multiple aerodromes from a single Remote Tower Module (RTM) in a Remote Tower Center.
• In Sweden: two remotely controlled airports in operation, five more studied.
• Splits the cost of Air Traffic Services (ATS) provision and staff management between several airports
  • Labour accounts for up to 85% of ATS cost
  ➡ Significant cost savings possible
• To ensure safety: no ATCO is confronted with traffic-inherent, non-manageable situations
• RTC: we need to create reasonable rosters for the ATCOs
• We used #IFR flights as a measure
• LFV: IFR accounts only for about 40% of the workload at smaller airports
• Other important aspects:
  - Ground traffic movements
  - Bad weather conditions
  - VFR
  - Extra traffic movements….

➡ We need to be able to quantify controller workload, in particular, for multiple remote control: not two airports together that constitute non-manageable workload!
• How do we decide when extra staff is needed?
• During a potentially risky period we assign two ATCOs for two airports that are otherwise assigned to a single ATCO
  ➡ We want to split if the workload becomes too high for a single ATCO to handle
  ➡ Need hard/soft thresholds
  ➡ Need quantitative statements
  ➡ First: identify factors that potentially drive the complexity of the traffic situation the ATCO has to handle
  ➡ Here: a first attempt at identifying such factors
  ❅ Interesting to quantify workload for various other applications
Responsibilities of the RTC ATCO:

- Runway control
- Ground control
- Ground support
- Sometimes even apron control

In particular, interested in complex situations that derive from interaction of the different tasks

- Will be what distinguishes workload description from traditional tower controller from that of an RTC ATCO
Data

- Six teams of ATCO pairs
- Introduction, two training runs, final simulation
- Airports: Erfurt and Braunschweig
- Study was designed to compare:
  - (a) One controller responsible for a single airport
  - (b) Two controllers responsible for both airports (controller and coordinator)
  - (c) One controller responsible for both airports

- All simulations with “high” traffic volume
  - Achieve parallel movements
- Two setups:
  - UJ: Switching between airports
  - UN: Both airports visible at all time
Data collection:
- Adapted Cooper-Harper Scale:

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

Critical (in terms of safety)

- One ATCO controlled the traffic, the other observed the situation and assessed any multiple specific situation with the adapted scale.
• Relevant or critical situations in a multiple remote tower center were derived during preparation phase of the simulation through discussions of human factors and operational experts.
• Mainly of interest: situations where the visual attention of the controller is affected
• Believed: monitoring is crucial for a tower controller, thus visual attention is the limiting factor.
• We cannot look at two things at the same time
  ➡ Situations evolved quite “naturally”
  ➡ Varied simultaneous traffic types like “departure – landing”; “landing – landing”, “taxi – landing”.
  ➡ Set of predefined situations (like two landings)
+ ATCO should rate any situation which could only occur because of multiple working conditions
**Data Set:**

- 222 ratings for 222 situations  
- Produced by 12 ATCOs  
- ATCO rated an average of 19 situations (sd=8)  
- Each rating:  
  - Team number  
  - Experimental condition: training or not  
  - Workplace design: Switching (UJ) or not (UN)  
  - Predefined situation number (out of nine, e.g., landing airport A, taxiing airport B)  
  - Evaluation according to adapted Cooper-Harper Scale  
  - Brief description of the problem/situation  
- All situations part of 20 minute simulation scenario
Data preparation:
- Coding of the ratings based on predefined situations and problem description
  - Coding variables to capture all ratings
    - Typical flight phases and connected ATCO clearances (initial call, landing, ....)
    - Conflicts
    - Emergencies
    - Performance problems of the ATCO (mix-up of airports)
  - Coding scheme of 23 variables = initial events
Identification of Critical Factors
Goal:
Identify critical complexity factors that drive the workload for a remote tower ATCO
  - Identify situations at the two controlled airports that induce risk

Approach:
- Aggregate information w.r.t. combination of events
- Combination of events = situation
- Identify all controllers that evaluated this
- We used:
  - Pairs of events
  - Triples of events
- Also: filtered out consequences of events at two airports
  ➔ Which events resulted in problematic consequences?
Event Pairs
Two criteria

- **Mean Controller Rating**:  
  - Whether Situation un-/manageable depends on experience, age, ….  
  - We want a generic measure  
    - Assume an “average” controller  
    - Which factors problematic to this average controller?

- **Maximum Controller Rating**:  
  - More conservative  
  - Possibly only single ATCO rated as critically  
  - We want to identify all critical factors for the remote tower environment  
  - We want to ensure safe operation, so, we should exclude what is unmanageable for any ATCO
Pairs of Events

switching (UJ)

18 critical event pairs

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

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

17 critical event pairs

no switching (UN)

green: mean
red: median

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Event Pairs

Comparison UJ/UN:
- Both pairs with a conflict at a single airport
- Pairs with an emergency problematic for UJ, not for average controller in UN setup

<table>
<thead>
<tr>
<th>Situation</th>
<th>UN</th>
<th>UJ</th>
</tr>
</thead>
<tbody>
<tr>
<td>Approach/Conflict</td>
<td>9.5</td>
<td>9.0</td>
</tr>
<tr>
<td>Clearance/Approach</td>
<td>9.5</td>
<td>7.5</td>
</tr>
<tr>
<td>Start/Conflict</td>
<td>9.0</td>
<td>9.0</td>
</tr>
<tr>
<td>Start/Approach</td>
<td>9.0</td>
<td>9.0</td>
</tr>
<tr>
<td>Landing/Go around</td>
<td>9.0</td>
<td>-</td>
</tr>
<tr>
<td>Clearance/Go around</td>
<td>9.0</td>
<td>-</td>
</tr>
<tr>
<td>Go around/Conflict</td>
<td>9.0</td>
<td>-</td>
</tr>
<tr>
<td>Landing/Conflict</td>
<td>8.33</td>
<td>7.2</td>
</tr>
<tr>
<td>Approach/Approach</td>
<td>8.0</td>
<td>-</td>
</tr>
<tr>
<td>High traffic/Conflict</td>
<td>8.0</td>
<td>-</td>
</tr>
<tr>
<td>Clearance/Conflict</td>
<td>7.57</td>
<td>-</td>
</tr>
<tr>
<td>Departure/High traffic</td>
<td>7.5</td>
<td>-</td>
</tr>
<tr>
<td>Clearance/Start</td>
<td>7.0</td>
<td>9.67</td>
</tr>
<tr>
<td>Departure/Conflict</td>
<td>7.0</td>
<td>9.0</td>
</tr>
<tr>
<td>Landing/High traffic</td>
<td>7.0</td>
<td>7.0</td>
</tr>
<tr>
<td>Departure/Technical problem</td>
<td>7.0</td>
<td>-</td>
</tr>
<tr>
<td>Taxi/Conflict</td>
<td>7.0</td>
<td>-</td>
</tr>
<tr>
<td>Start/Emergency</td>
<td>-</td>
<td>10.0</td>
</tr>
<tr>
<td>Start/Problem</td>
<td>-</td>
<td>10.0</td>
</tr>
<tr>
<td>Landing/Outbound traffic</td>
<td>-</td>
<td>9.0</td>
</tr>
<tr>
<td>Departure/Emergency</td>
<td>-</td>
<td>8.33</td>
</tr>
<tr>
<td>Taxi/Start</td>
<td>-</td>
<td>8.0</td>
</tr>
<tr>
<td>Release/High traffic</td>
<td>-</td>
<td>8.0</td>
</tr>
<tr>
<td>Clearance/Departure</td>
<td>-</td>
<td>8.0</td>
</tr>
<tr>
<td>Taxi/Emergency</td>
<td>-</td>
<td>7.5</td>
</tr>
<tr>
<td>Start/Start</td>
<td>-</td>
<td>7.2</td>
</tr>
<tr>
<td>Conflict/Conflict</td>
<td>-</td>
<td>7.0</td>
</tr>
</tbody>
</table>
More event pairs have maximum controller rating ≥ 7 than event pairs that have mean controller rating ≥ 7.

- 38 critical event pairs out of 55 event pairs
- 22 with maximum rating of 10
Comparison UJ/UN:
• Again: Pairs with an emergency problem for UJ, not for average controller in UN setup

UJ: 38 critical event pairs out of 55 event pairs
22 with maximum rating of 10

31 critical event pairs out of 65 event pairs
5 with maximum rating of 10
Comparison UJ/UN:

- UJ setup higher ratio of all event pairs leads to a critical rating
- Why?
- Workplace design:
  ATCO prevented to have all relevant information available at the same time
  - Focus on UN setup now (UJ for scientific purpose, UN planned for RTCs in Sweden)
Triples of Events
Triples of Events

- Event pairs often receive higher rating when part of a situation with more events
  - Triples of events
- Only UN setup
- Which triples?
  - Triples of events for which rating dominates at least the rating of one sub-pair
  - Triple (A,B,C), sub-pairs: (A,B), (B,C), (A,C)
  - Complicating triple:
    - (A,B,C) dominates at least one pair, e.g., (A,B)
    - Either w.r.t. mean or w.r.t. maximum rating
  - Example: (A,B,C) mean rating of 6, maximum rating of 9
    - (a) (A,B) mean rating of 5, maximum rating of 10
    - (b) (A,B) mean rating of 7, maximum rating of 8
- Idea: adding an event here increases complexity for ATCO
  \[\rightarrow\] For triple that does not dominate any sub-pair, complexity stems already from a combination of two factors
- Dominance interesting for triples with rating of 7 or higher (w.r.t at least one criterion)
  \[\Rightarrow\text{ Critical triples}\]
### Triples of Events

<table>
<thead>
<tr>
<th>Situation</th>
<th>mean</th>
<th>min</th>
<th>max</th>
<th>Situation</th>
<th>mean</th>
<th>min</th>
<th>max</th>
</tr>
</thead>
<tbody>
<tr>
<td>Clearance/Start/Callsign</td>
<td>3</td>
<td>3</td>
<td>3</td>
<td>Taxi/Release</td>
<td>5,333333333</td>
<td>7</td>
<td>7</td>
</tr>
<tr>
<td>Start/Callsign mixup</td>
<td>2.5</td>
<td>2</td>
<td>3</td>
<td>Taxi/Landing/High traffic</td>
<td>6,666666667</td>
<td>5</td>
<td>8</td>
</tr>
<tr>
<td>Taxi/Start</td>
<td>3.5</td>
<td>2</td>
<td>5</td>
<td>Taxi/Landing</td>
<td>5.888888889</td>
<td>9</td>
<td>9</td>
</tr>
<tr>
<td>Start</td>
<td>3.454545455</td>
<td>5</td>
<td>6</td>
<td>Clearance/Clearance</td>
<td>6,666666667</td>
<td>3</td>
<td>9</td>
</tr>
<tr>
<td>Taxi/Departure/Landing</td>
<td>2.825</td>
<td>1</td>
<td>9</td>
<td>Clearance/Clearance</td>
<td>5.181818182</td>
<td>1</td>
<td>10</td>
</tr>
<tr>
<td>Start</td>
<td>3.454545455</td>
<td>1</td>
<td>9</td>
<td>Taxi/Clearance/Clearance/Start/Parking</td>
<td>6,666666667</td>
<td>4</td>
<td>10</td>
</tr>
<tr>
<td>Taxi/Callsign</td>
<td>4</td>
<td>4</td>
<td>4</td>
<td>Taxi/Start/Go around</td>
<td>4,590909091</td>
<td>1</td>
<td>9</td>
</tr>
<tr>
<td>Start</td>
<td>3.454545455</td>
<td>1</td>
<td>9</td>
<td>Taxi/Landing/High traffic</td>
<td>5.181818182</td>
<td>1</td>
<td>10</td>
</tr>
<tr>
<td>Start/Start/Communications</td>
<td>4</td>
<td>4</td>
<td>4</td>
<td>Landing/High traffic</td>
<td>7</td>
<td>5</td>
<td>9</td>
</tr>
<tr>
<td>Release/Start/Start</td>
<td>4</td>
<td>4</td>
<td>4</td>
<td>Landing/High traffic</td>
<td>4,090909091</td>
<td>1</td>
<td>9</td>
</tr>
</tbody>
</table>

- **Critical triples**
  - All critical event triples
  - Only dominated sub-pairs

- **Critical triples**
  - Increased complexity
  - Added event significantly increases complexity
  - Adding a third to one sub-event increases the complexity: landing/high-traffic already so much intrinsic complexity

- **Most critical pairs dominate at most one sub-pair**
- **Some triples dominate all sub-pairs**
- **No critical triple:**
  - Emergency
  - Call sign mix-up
  - Communication

- **All critical event triples that dominate w.r.t. mean, dominate one sub-pair clearly**

- **Added event significantly increases complexity**

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- **Added event significantly increases complexity**

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**Added event significantly increases complexity**
Consequences of Events and Their Causing Factors
Consequences of Events and Their Causing Factors

- Rationale: problematic consequence can be indicator of risky, non-manageable situation
- Data from UN and UJ setup
- Coding variables that are consequences:
  - Monitoring problem
  - Small delay
  - Mix-up of airports
  - Switching airports
  - Communication problem
- 40% of communication led to communication problem
- 100% of VFR traffic (when mentioned!!) led to communication problem (VFR not part of predefined scenario events)
  ➡ 100% of mentions of VFR traffic coincided with communication problem
- Several never caused a problematic consequence (e.g., go-arounds)

<table>
<thead>
<tr>
<th></th>
<th>Taxi</th>
<th>Clearance</th>
<th>Departure</th>
<th>Landing</th>
<th>Release</th>
<th>Start</th>
<th>Approach</th>
<th>Go around</th>
<th>Problem</th>
<th>Initial call</th>
<th>Technical problem</th>
<th>Callsign mixup</th>
<th>High traffic</th>
<th>Conflict</th>
<th>Communication</th>
<th>Outbound traffic</th>
<th>VFR</th>
<th>Emergency</th>
</tr>
</thead>
<tbody>
<tr>
<td>Monitoring problem</td>
<td>11.1%</td>
<td>0.0%</td>
<td>14.3%</td>
<td>13.6%</td>
<td>0.0%</td>
<td>0.0%</td>
<td>20.0%</td>
<td>0.0%</td>
<td>0.0%</td>
<td>0.0%</td>
<td>0.0%</td>
<td>0.0%</td>
<td>28.6%</td>
<td>0.0%</td>
<td>0.0%</td>
<td>0.0%</td>
<td>0.0%</td>
<td>0.0%</td>
</tr>
<tr>
<td>Small delay</td>
<td>0.0%</td>
<td>0.0%</td>
<td>0.0%</td>
<td>0.0%</td>
<td>0.0%</td>
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<td>20.0%</td>
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<td>0.0%</td>
<td>0.0%</td>
</tr>
<tr>
<td>Mix-up of airports</td>
<td>3.7%</td>
<td>0.0%</td>
<td>0.0%</td>
<td>0.0%</td>
<td>0.0%</td>
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<td>0.0%</td>
<td>0.0%</td>
<td>10.0%</td>
<td>0.0%</td>
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<td>0.0%</td>
<td>0.0%</td>
<td>0.0%</td>
<td>0.0%</td>
</tr>
<tr>
<td>Switching airports</td>
<td>3.7%</td>
<td>0.0%</td>
<td>0.0%</td>
<td>2.3%</td>
<td>0.0%</td>
<td>0.0%</td>
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</tr>
<tr>
<td>Communication problem</td>
<td>3.7%</td>
<td>40.9%</td>
<td>4.8%</td>
<td>6.8%</td>
<td>25.0%</td>
<td>4.5%</td>
<td>20.0%</td>
<td>0.0%</td>
<td>0.0%</td>
<td>0.0%</td>
<td>0.0%</td>
<td>0.0%</td>
<td>14.3%</td>
<td>12.5%</td>
<td>40.0%</td>
<td>0.0%</td>
<td>100.0%</td>
<td>0.0%</td>
</tr>
</tbody>
</table>
Summary
Summary

Three sets of critical complexity factors:

• Pairs which are impossible to manage or manageable only with limited situational awareness for at least one controller or an average controller.

‣ Availability of relevant information
  ‣ Switching:
    - Emergencies at one airport reduce handling qualities
    - Ratio of situations with critical handling qualities increased

‣ For both conditions:
  - Complexity increased when ATCOs have to solve a traffic conflict at one airport and manage routine traffic at the second airport (UN+: 9 out of 17 critical pairs have conflict at a single airport)

‣ Complexity is influenced when ATCOs need to prioritise tasks at two airports w/o proper rules
  - Conflict high priority
  - Single airport: rules for prioritising
  - Rules needed for multiple operations (design, training)
  - OR: scheduling must avoid these
• Triples: adding a third event to two landings significantly increases the complexity (also for pairs of two departures, and departure/landing)
  ‣ ATCO already has to manage a/c movements simultaneously, possibly at the two different airports, any additional event induces critical handling qualities
• Factors that are likely to cause problematic consequences:
  - VFR traffic
  - Higher traffic numbers
  - Approaching traffic
  ‣ Complexity influenced by unforeseen events
  ‣ In many countries VFR traffic does not require a flight plan
  ‣ VFR traffic is unforeseen event for ATCO’s preplanned actions
• Pairs/Triples: Not a single factor that drives complexity
  ‣ Known from safety research—concept of human performance envelope:
    - Single factor cannot explain performance breakdowns or critical events
Outlook
Here: First set of complexity factors

Future work:
- Analyse situations that received rating below 7
- Analyse larger data sets
- Identify further factors
- Goal: quantitative measure
Thanks

SAVE THE DATE: February 11-12, 2019
Workshop on Digital Air Traffic Services: Workload and Safety Assessment
Norrköping, Sweden
http://webstaff.itn.liu.se/~chrsc91/DATS-workshop-norrkoping/