Identification of Complexity Factors for Remote Towers

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- 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

Responsibilites 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

Data

Data from DLR [C. Möhlenbrink, A. Papenfuss, and J. Jakobi. The role of workload for work organization in a remote tower control center. Air Traffic Control Quarterly, 20(1):5, 2012]

- 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:

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	

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.

Data

- 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

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

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

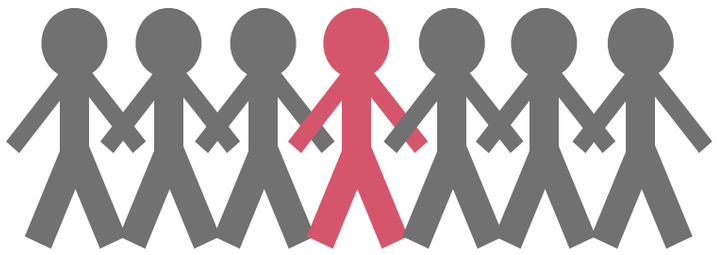
Pairs of Events

Two criteria

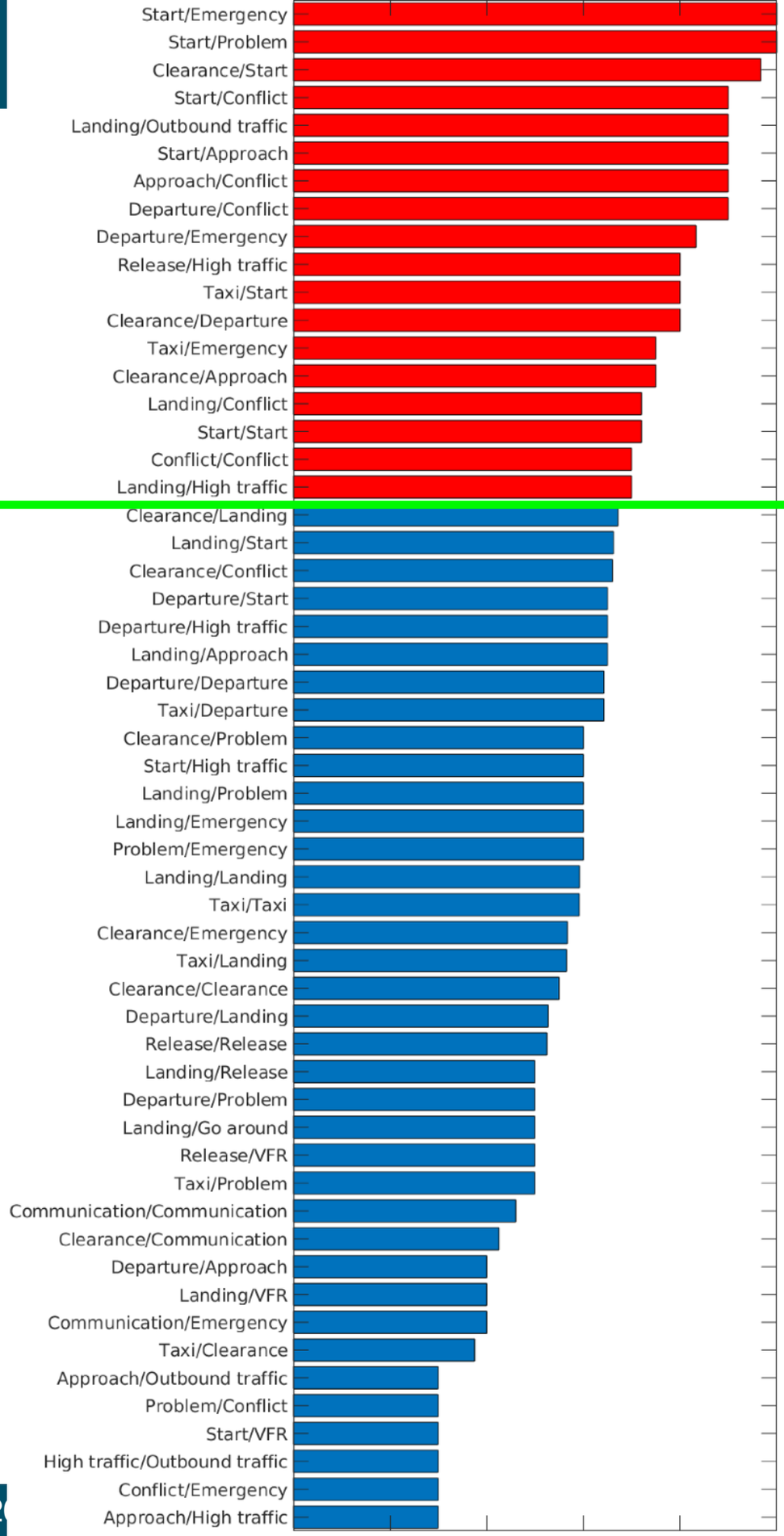
- **Mean Controller Rating**:
  - Whether Situation un-/manageable depends on experience, age, ….
  - We want a generic measure
  - Assume an “average” controller
  - Which factors problematic to this average controller?

- **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



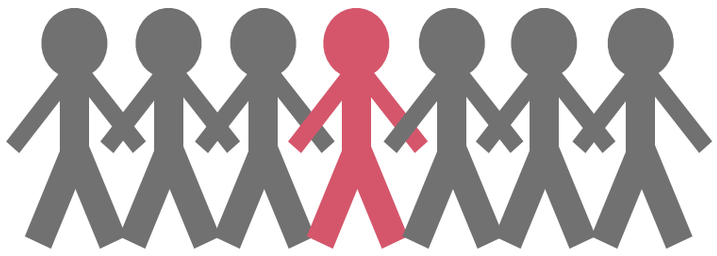
switching (UJ)



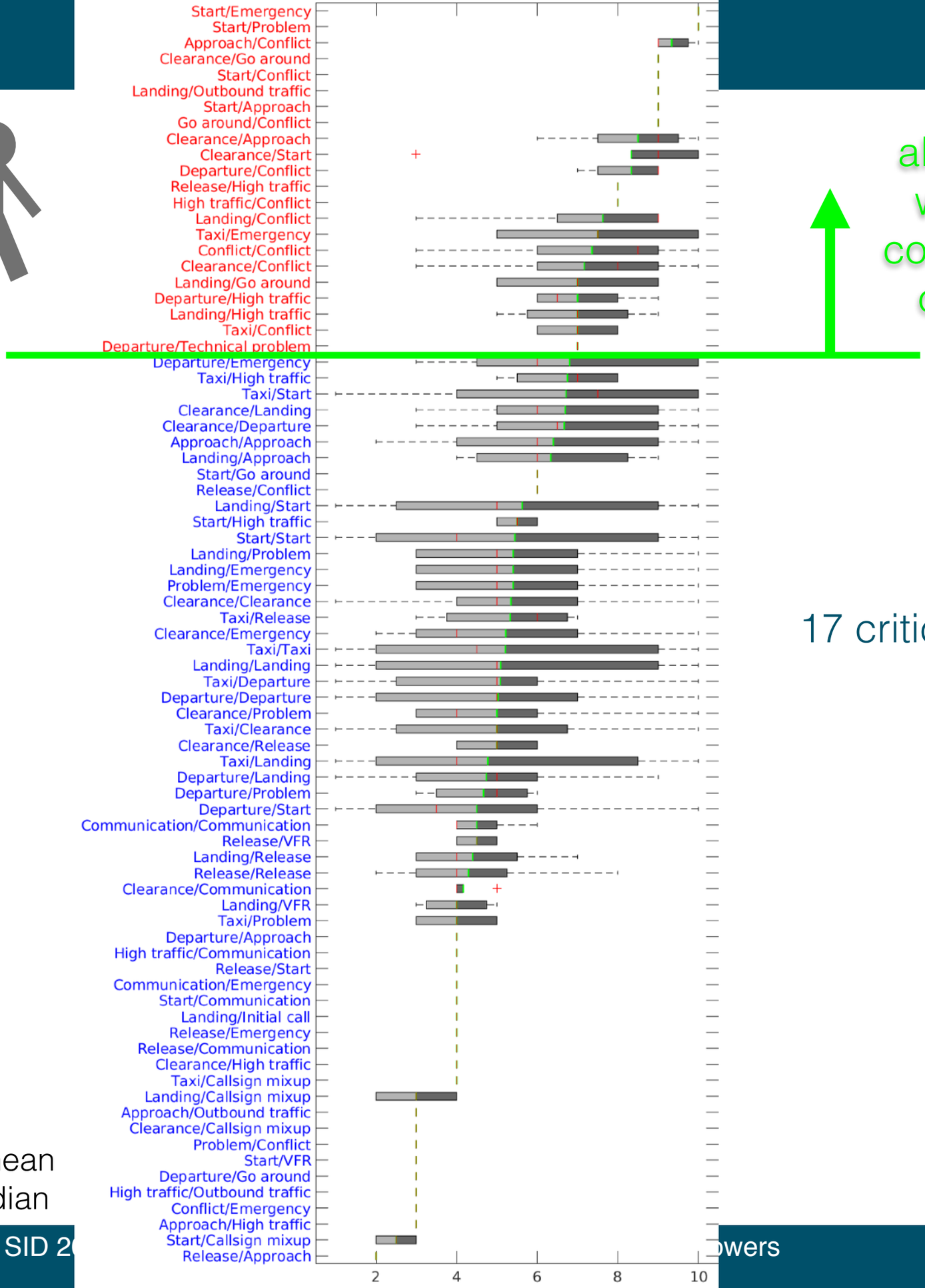
all event pairs with a mean controller rating of at least 7

18 critical event pairs

Pairs of Events



no switching (UN)



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

17 critical event pairs

green: mean
red: median

Event Pairs

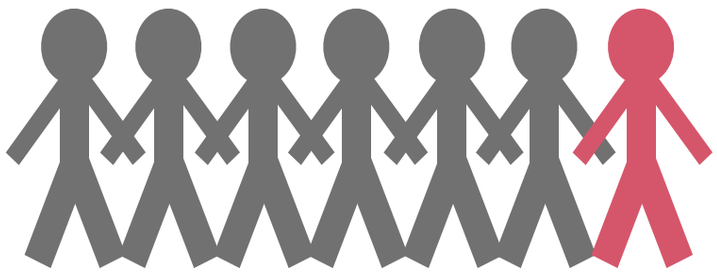
Comparison UJ/UN:

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

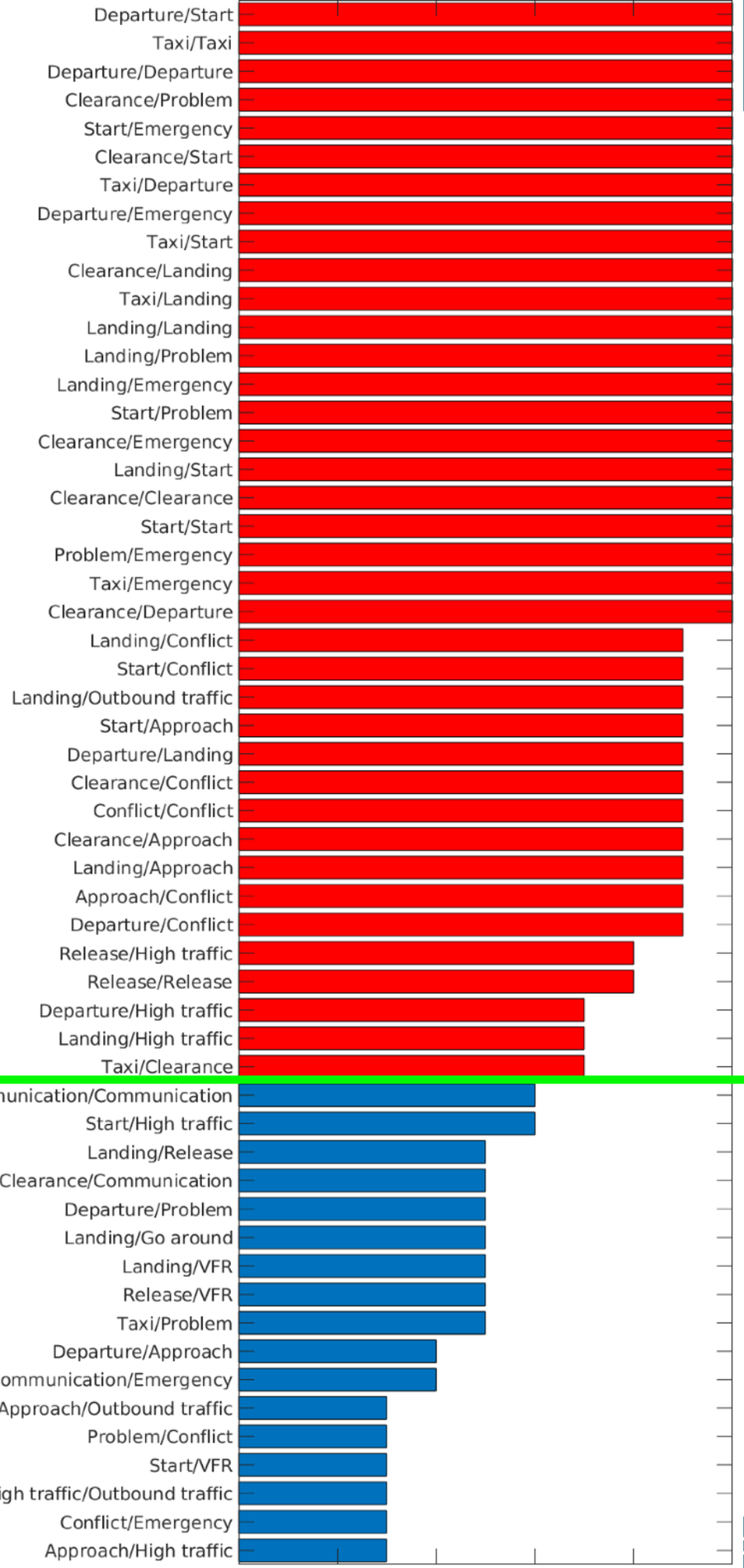
EVENT PAIRS THAT WERE CRITICAL FOR THE MEAN CONTROLLER RATING FOR EITHER THE UN OR THE UJ SETUP. EVENT PAIRS THAT WERE NOT CRITICAL FOR A SETUP ARE DENOTED BY AN ''-", THE OTHER EVENT PAIRS ARE SHOWN WITH THEIR MEAN CONTROLLER RATING

Situation	UN	UJ
Approach/Conflict	9.5	9.0
Clearance/Approach	9.5	7.5
Start/Conflict	9.0	9.0
Start/Approach	9.0	9.0
Landing/Go around	9.0	-
Clearance/Go around	9.0	-
Go around/Conflict	9.0	-
Landing/Conflict	8.33	7.2
Approach/Approach	8.0	-
High traffic/Conflict	8.0	-
Clearance/Conflict	7.57	-
Departure/High traffic	7.5	-
Clearance/Start	7.0	9.67
Departure/Conflict	7.0	9.0
Landing/High traffic	7.0	7.0
Departure/Technical problem	7.0	-
Taxi/Conflict	7.0	-
Start/Emergency	-	10.0
Start/Problem	-	10.0
Landing/Outbound traffic	-	9.0
Departure/Emergency	-	8.33
Taxi/Start	-	8.0
Release/High traffic	-	8.0
Clearance/Departure	-	8.0
Taxi/Emergency	-	7.5
Start/Start	-	7.2
Conflict/Conflict	-	7.0

Pairs of Events



switching (UJ)



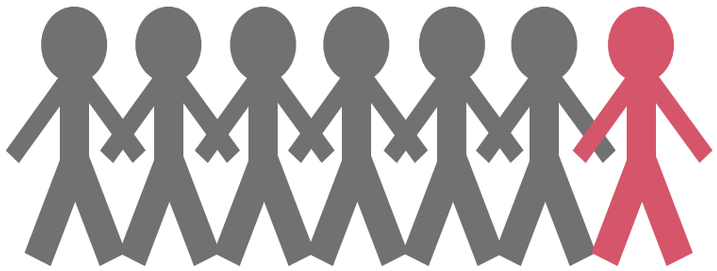
More event pairs have maximum controller rating ≥ 7 than event pairs that have mean controller rating ≥ 7

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

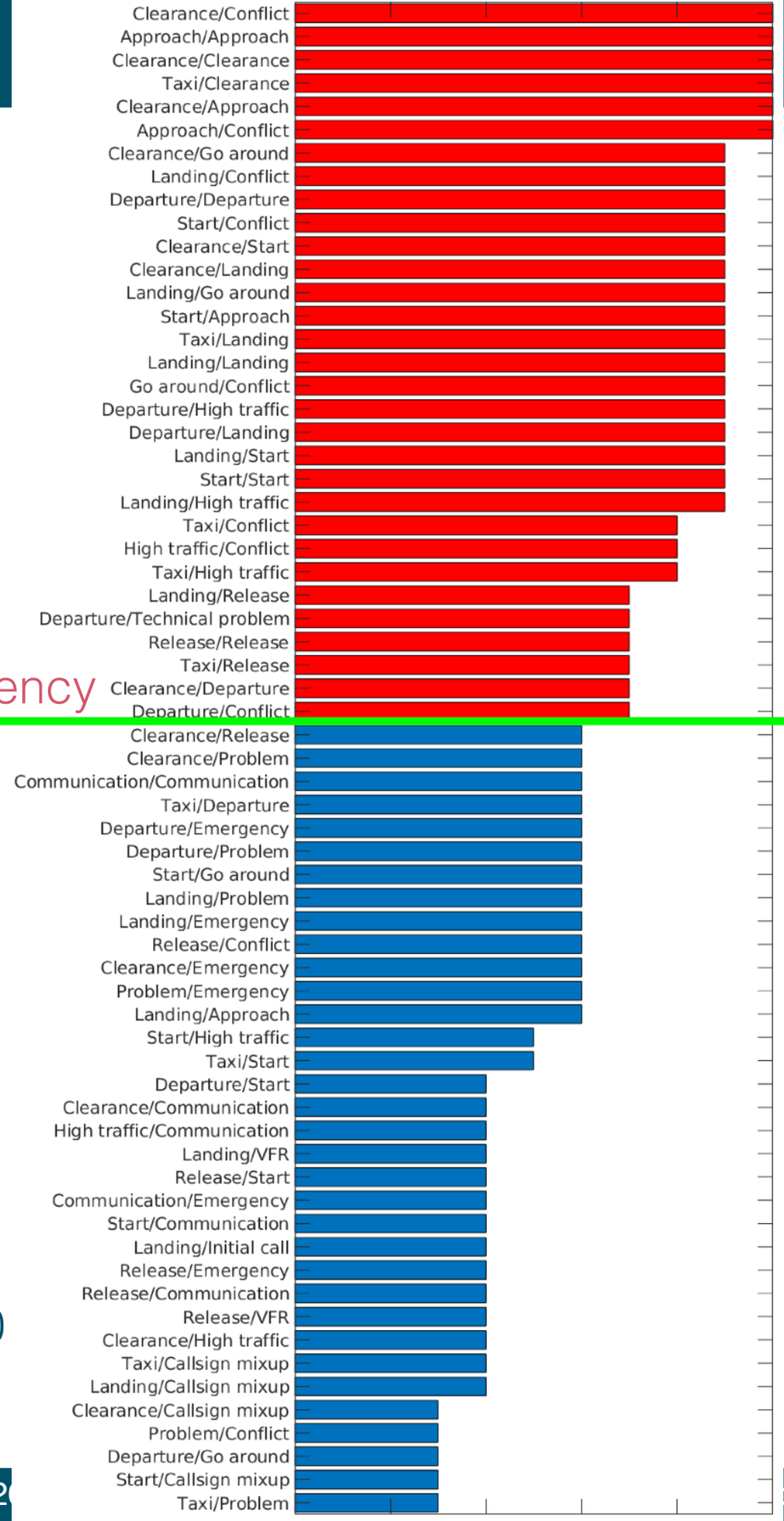
38 critical event pairs out of 55 event pairs

22 with maximum rating of 10

Pairs of Events



no switching (UN)



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

Comparison UJ/UN:

- Again: Pairs with an emergency problematic 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

Event Pairs

TOTAL NUMBER OF EVENT PAIRS, AND SHARE OF CRITICAL EVENT PAIRS

	UN	UJ
# identified event pairs	65	55
# event pairs with mean rating$\geq$ 7	17	18
share of event pairs with mean rating $\geq$ 7	26%	33%
# event pairs with max rating $\geq$ 7	31	38
share of event pairs with max rating $\geq$ 7	48%	69%

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

<=> 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)

= **Critical triples**

Triples of Events

only dominated sub-pairs
Critical triples

Most triples dominate at most one 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

Situation	mean	min	max
Clearance/Start/Callsign	**3**	**3**	**3**
Start/Callsign mixup	*2,5*	*2*	*3*
Taxi/Start/Start	**3,5**	**2**	**5**
Start/Start	*3,454545455*	*1*	*9*
Taxi/Departure/Landing	**3,5**	**1**	**6**
Taxi/Departure	*3,2*	*1*	*6*
Landing/Start/Start	**3,625**	**1**	**9**
Start/Start	*3,454545455*	*1*	*9*
Taxi/Landing/Callsign	**4**	**4**	**4**
Landing/Callsign mixup	*3*	*2*	*4*
Taxi/Landing	*3,588235294*	*1*	*9*
Start/Start/Communicati	**4**	**4**	**4**
Start/Start	*3,454545455*	*1*	*9*
Release/Start/Start	**4**	**4**	**4**
Start/Start	*3,454545455*	*1*	*9*
Landing/Release/Release	**4,25**	**3**	**7**
Release/Release	*4,166666667*	*2*	*7*
Departure/Landing/Land	**4,25**	**1**	**9**
Landing/Landing	*4,090909091*	*1*	*9*
Departure/Departure/La	**4,25**	**1**	**9**
Departure/Departure	*3,619047619*	*1*	*9*
Landing/Landing/Release	**4,25**	**3**	**7**
Landing/Landing	*4,090909091*	*1*	*9*
Landing/Landing/Emerge	**4,5**	**3**	**6**
Landing/Landing	*4,090909091*	*1*	*9*
Departure/Departure/Em	**4,5**	**3**	**6**
Departure/Departure	*3,619047619*	*1*	*9*
Departure/Departure/Pro	**4,5**	**3**	**6**
Departure/Departure	*3,619047619*	*1*	*9*
Departure/Landing/Emer	**4,5**	**3**	**6**
Departure/Landing	*4,25*	*1*	*9*
Clearance/Departure/Pro	**4,5**	**3**	**6**
Clearance/Problem	*4*	*3*	*6*
Landing/Landing/Proble	**4,5**	**3**	**6**
Landing/Landing	*4,090909091*	*1*	*9*
Departure/Landing/Probl	**4,5**	**3**	**6**
Departure/Landing	*4,25*	*1*	*9*
Clearance/Problem/Emer	**4,5**	**3**	**6**
Clearance/Problem	*4*	*3*	*6*
Clearance/Emergency	*4,333333333*	*3*	*6*
Clearance/Landing/Probl	**4,5**	**3**	**6**
Clearance/Problem	*4*	*3*	*6*
Clearance/Landing/Emer	**4,5**	**3**	**6**
Clearance/Emergency	*4,333333333*	*3*	*6*
Clearance/Departure/Em	**4,5**	**3**	**6**
Clearance/Emergency	*4,333333333*	*3*	*6*
Clearance/Release/Releas	**5**	**4**	**6**
Release/Release	*4,166666667*	*2*	*7*
Start/Start/High traffic	**5**	**5**	**5**
Start/Start	*3,454545455*	*1*	*9*
Taxi/Start/High traffic	**5**	**5**	**5**
Taxi/Start	*3,5*	*2*	*5*
Landing/Start/High	**5**	**5**	**5**
Landing/Start	*3,625*	*1*	*9*
Clearance/Departure/Lan	**5,333333333**	**3**	**7**
Departure/Landing	*4,25*	*1*	*9*
Taxi/Release/Release	**5,333333333**	**3**	**7**
Release/Release	*4,166666667*	*2*	*7*
Clearance/Departure/Dep	**5,333333333**	**3**	**7**
Departure/Departure	*3,619047619*	*1*	*9*
Clearance/Clearance/Dep	**5,333333333**	**3**	**7**
Clearance/Clearance	*5,181818182*	*1*	*10*
Release/Release/Conflict	**6**	**6**	**6**
Release/Release	*4,166666667*	*2*	*7*
Landing/Landing/Approa	**6**	**6**	**6**
Landing/Landing	*4,090909091*	*1*	*9*
Start/Start/Go around	**6**	**6**	**6**
Start/Start	*3,454545455*	*1*	*9*
Taxi/Release/Conflict	**6**	**6**	**6**
Taxi/Release	*5,333333333*	*3*	*7*
Taxi/Departure/High	**6**	**6**	**6**
Taxi/Departure	*3,2*	*1*	*6*
Clearance/Release/Confli	**6**	**6**	**6**
Clearance/Release	*5*	*4*	*6*
Taxi/Clearance/Release	**6**	**6**	**6**
Clearance/Release	*5*	*4*	*6*

Situation	mean	min	max
Taxi/Release	*5,333333333*	*3*	*7*
Taxi/Landing/High traffic	**6,333333333**	**5**	**8**
Taxi/Landing	*3,588235294*	*1*	*9*
Clearance/Clearance/Landing	**6,666666667**	**3**	**9**
Clearance/Clearance	*5,181818182*	*1*	*10*
Clearance/Landing/Landing	**6,666666667**	**3**	**9**
Landing/Landing	*4,090909091*	*1*	*9*
Taxi/Clearance/Clearance	**6,666666667**	**4**	**10**
Clearance/Clearance	*5,181818182*	*1*	*10*
Departure/Departure/Conflict	**7**	**7**	**7**
Departure/Departure	*3,619047619*	*1*	*9*
Landing/Landing/High traffic	**7**	**5**	**9**
Landing/Landing	*4,090909091*	*1*	*9*
Clearance/Clearance/Start	**7**	**3**	**9**
Clearance/Clearance	*5,181818182*	*1*	*10*
Departure/Departure/Technical	**7**	**7**	**7**
Departure/Departure	*3,619047619*	*1*	*9*
Departure/Landing/Conflict	**7**	**7**	**7**
Departure/Landing	*4,25*	*1*	*9*
Clearance/Start/Start	**7**	**3**	**9**
Start/Start	*3,454545455*	*1*	*9*
Clearance/Departure/Conflict	**7**	**7**	**7**
Clearance/Departure	*5,333333333*	*3*	*7*
Departure/Departure/High traffic	**7,5**	**6**	**9**
Departure/Departure	*3,619047619*	*1*	*9*
Departure/Landing/High traffic	**7,5**	**6**	**9**
Departure/Landing	*4,25*	*1*	*9*
Landing/High traffic	*7*	*5*	*9*
Clearance/Clearance/Conflict	**7,571428571**	**3**	**10**
Clearance/Clearance	*5,181818182*	*1*	*10*
Taxi/High traffic/Conflict	**8**	**8**	**8**
Taxi/High traffic	*6,75*	*5*	*8*
Taxi/Conflict	*7*	*6*	*8*
Landing/Landing/Conflict	**8,333333333**	**7**	**9**
Landing/Landing	*4,090909091*	*1*	*9*
Clearance/Landing/Conflict	**8,333333333**	**7**	**9**
Clearance/Landing	*6,666666667*	*3*	*9*
Clearance/Conflict	*7,571428571*	*3*	*10*
Clearance/Start/Approach	**9**	**9**	**9**
Clearance/Start	*7*	*3*	*9*
Start/Start/Approach	**9**	**9**	**9**
Start/Start	*3,454545455*	*1*	*9*
Clearance/Go around/Conflict	**9**	**9**	**9**
Clearance/Conflict	*7,571428571*	*3*	*10*
Start/Start/Conflict	**9**	**9**	**9**
Start/Start	*3,454545455*	*1*	*9*
Clearance/Clearance/Go around	**9**	**9**	**9**
Clearance/Clearance	*5,181818182*	*1*	*10*
Landing/Go around/Conflict	**9**	**9**	**9**
Landing/Conflict	*8,333333333*	*7*	*9*
Clearance/Start/Conflict	**9**	**9**	**9**
Clearance/Start	*7*	*3*	*9*
Clearance/Conflict	*7,571428571*	*3*	*10*
Clearance/Landing/Start	**9**	**9**	**9**
Landing/Start	*3,625*	*1*	*9*
Clearance/Landing	*6,666666667*	*3*	*9*
Clearance/Start	*7*	*3*	*9*
Clearance/Landing/Go around	**9**	**9**	**9**
Clearance/Landing	*6,666666667*	*3*	*9*
Landing/Landing/Go around	**9**	**9**	**9**
Landing/Landing	*4,090909091*	*1*	*9*
Start/Approach/Approach	**9**	**9**	**9**
Approach/Approach	*8*	*6*	*10*
Landing/Start/Conflict	**9**	**9**	**9**
Landing/Start	*3,625*	*1*	*9*
Landing/Conflict	*8,333333333*	*7*	*9*
Clearance/Approach/Approach	**9,5**	**9**	**10**
Approach/Approach	*8*	*6*	*10*
Approach/Approach/Conflict	**9,5**	**9**	**10**
Approach/Approach	*8*	*6*	*10*
Clearance/Clearance/Approach	**9,5**	**9**	**10**
Clearance/Clearance	*5,181818182*	*1*	*10*
Clearance/Approach/Conflict	**9,5**	**9**	**10**
Clearance/Conflict	*7,571428571*	*3*	*10*

adding a third to one sub-event increases the complexity: landing/high-traffic already so much intrinsic complexity—adding a landing cannot increase the rating

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)

	Taxi	Clearance	Departure	Landing	Release	Start	Approach	Go around	Problem	Initial call	Technical problem	Callsign mixup	High traffic	Conflict	Commu-nication	Outbound traffic	VFR	Emergency
Monitoring problem	11.1%	0.0%	14.3%	13.6%	0.0%	0.0%	20.0%	0.0%	0.0%	0.0%	0.0%	0.0%	28.6%	0.0%	0.0%	0%	0.0%	0.0%
Small delay	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	20.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0%	0.0%	0.0%
Mix-up of airports	3.7%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	10.0%	0.0%	0.0%	0.0%	0%	0.0%	0.0%
Switching airports	3.7%	0.0%	0.0%	2.3%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0%	0.0%	0.0%
Communication problem	3.7%	40.9%	4.8%	6.8%	25.0%	4.5%	20.0%	0.0%	0.0%	0.0%	0.0%	10.0%	14.3%	12.5%	40.0%	0%	**100.0%**	0.0%

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

Summary

- 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

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/