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Designing Graceful Degradation into Complex Systems:

Identification of Causes of Degradation, Interactions, and Mitigation of Degradation in Air Traffic Control

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AIAA-2018-3510

Agenda

- Research motivation
- Aims
- Method
- Results
  - Causes of degradation
  - Relationships between causes
  - Prevention and mitigation of degradation – the ATCO role
  - Towards a theory of a system performance envelope
- Conclusions & Implications

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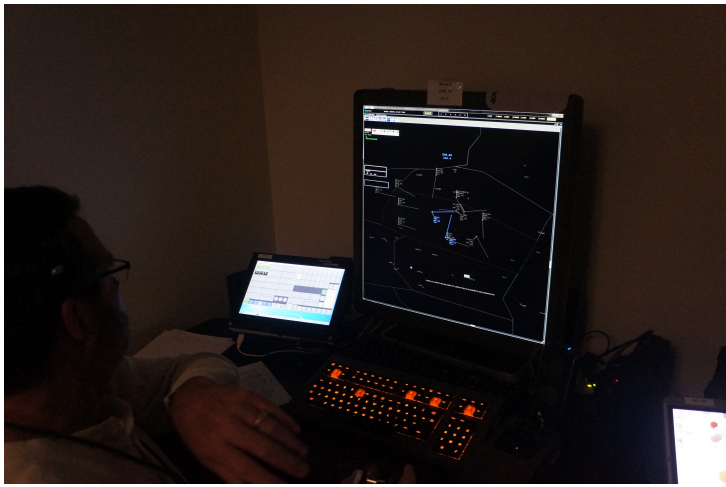
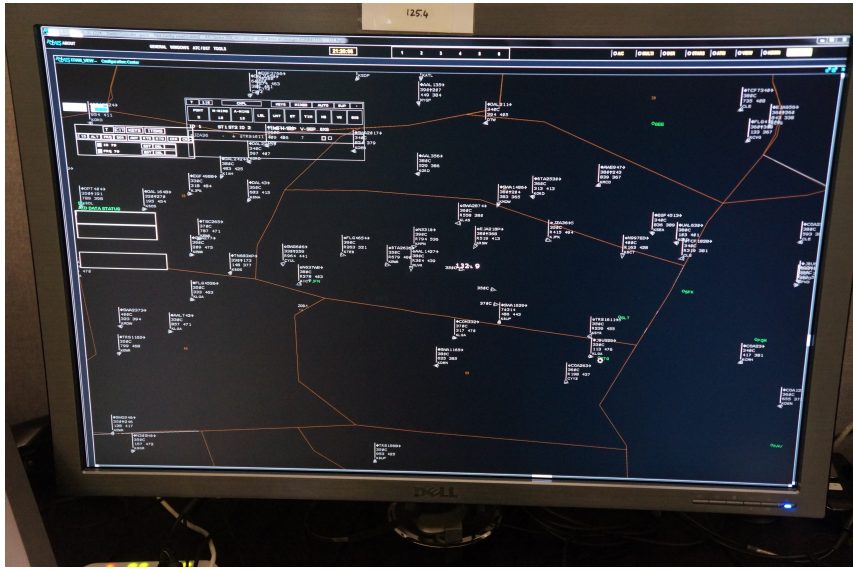
Research motivation

- Trajectory based operations (TBO) is an instrumental concept in the NextGen initiative
- In order for the TBO concept to be realized, there will be a “fundamental shift in ATM” (FAA, 2014):
  - Narrower tolerances (FAA, 2014)
  - More precise trajectories
  - Strategic vs tactical
- System resilience is critical
  - TBO system must be able to gracefully degrade to maintain safe operations
- Operationally-valid knowledge of the causes and mitigations of degradation must be specified for design of gracefully degrading systems

Aims

- Identify causes of degradation in ATC
- Investigate relationships between degradation causes
- Inform understanding of degradation prevention and mitigation strategies





Method

- One semi-structured interview (1 hour), one knowledge elicitation interview using scenarios (1 hour)
- Participants: 12 Retired controllers
  - TRACON and En-route experience, based in California
  - Age ranged 51 - 72 years, years of experience ranged 20-35 years
- Example questions:
  - “What has caused a ‘bad day’ in operations?”
  - “What are your control strategies for off-nominal situations?”
- Interviews transcribed orthographically and thematic analysis was used



Result 1a: Causes of degradation - Technology

- Technology
  - Failure – Radar, Communications

"Everything is working fine and then it doesn't work. Can you keep up with the phone and radio calls?"

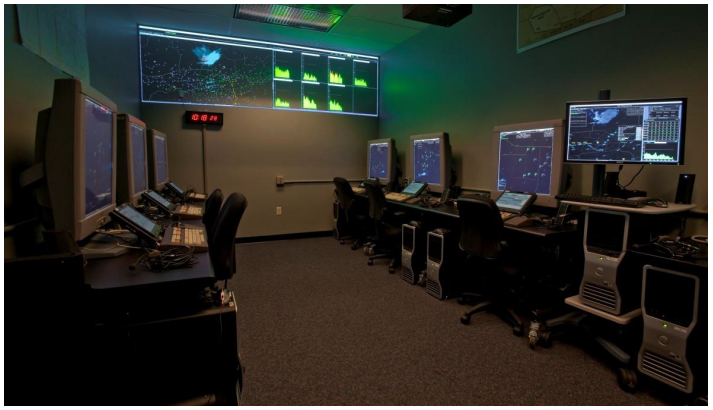
  - Unreliability

"If it doesn't work we just say forget it. It's unreliable…Until someone proves to me that it's going to work I'm not going to base my career on accidentally running an airplane into another guy's sector"

  - Reduction of flexibility

"Engineers designing routes will say, he's doing 160 knots and that's this many miles per minute, so he gets here then. [But] there's weather, there's emergencies, there's pilot errors"

Result 1a(Cont.): Causes of degradation - Environment



- Environment
  - Weather
  - Aircraft emergencies
  - Pilot requests

- Complexity factors:
  - Sector features

    "You've got to make your turns exactly right, your climbs, your speed, so you've got to be on everything"
  - Location of sector

    "The pilot says, 'Can we deviate to the right around it?' I don't have any traffic out there, that's an easy thunderstorm"
  - Traffic level and complexity of traffic

Result 1a(Cont.): Causes of degradation – Human operator

- Human operator
  - Errors (usually as a result of):
  - Human-performance influencing factors, e.g.
    - Workload
    - Fatigue
    - Situation Awareness

"Somebody misses his turn and you are busy someplace else and meanwhile he has gone way past where he is supposed to go"

Result 1(b): Degradation cause and system effect

- Causes can effect system directly or indirectly
- Causes not sufficient to understand impact
- Relationship between cause and effect is often moderated
  - Expected or unexpected cause

    "You did have a plan. Now you don't have a plan"
  - Sudden or gradual cause

"All of a sudden a bubble [thunderstorm] comes up. You just deal with what you have right in front of you"

  - Duration

  - ATCO control strategies

Result 2: Relationships between causes of degradation

- Co-occurrence or association
- Between or within degradation categories

"We had about 17 or 18 operations. It was IFR weather. Maintenance took the radar. I just barely had the picture - If I had looked away I would have lost that"

- Interactions can result in a cumulative impact

"We're very good jugglers. Something goes wrong, you can handle it. Then something else happened. Here comes another ball. Pretty soon, you're going to drop a ball"

"It starts to be exponential as things happen, it never seems to be linear, it just goes a lot faster"

- Understanding interactions is critical:
  - Design of systems capable of graceful degradation design
  - Predicting, preventing and mitigating degradation

Result 2(Cont.): Functional Failure

- Occurs as a result of interactions between technology and context
- Examples:
  - Datalink communications and environmental off-nominal events

    "Direct communications are extremely important. Using automation in a normal flow of traffic is fine. But in emergency situations or heavy traffic situations, it becomes a detriment"
  - Conflict alert in terminal environments

    "In a terminal environment, it's very unreliable. Rarely do we use [it]"

- Implications:
  - ATCO Overload
  - Risk assessment, identification and prevention
  - Future system design

Result 3: Prevention and mitigation of system degradation

- Pre-degradation strategies
- In-time prevention and mitigation strategies
  - ATCOs change control strategies to make the system work
  - Strategies have common goals of achieving more time and/or space
  - Strategies are learned through experience
  - Strategies are dependent on awareness

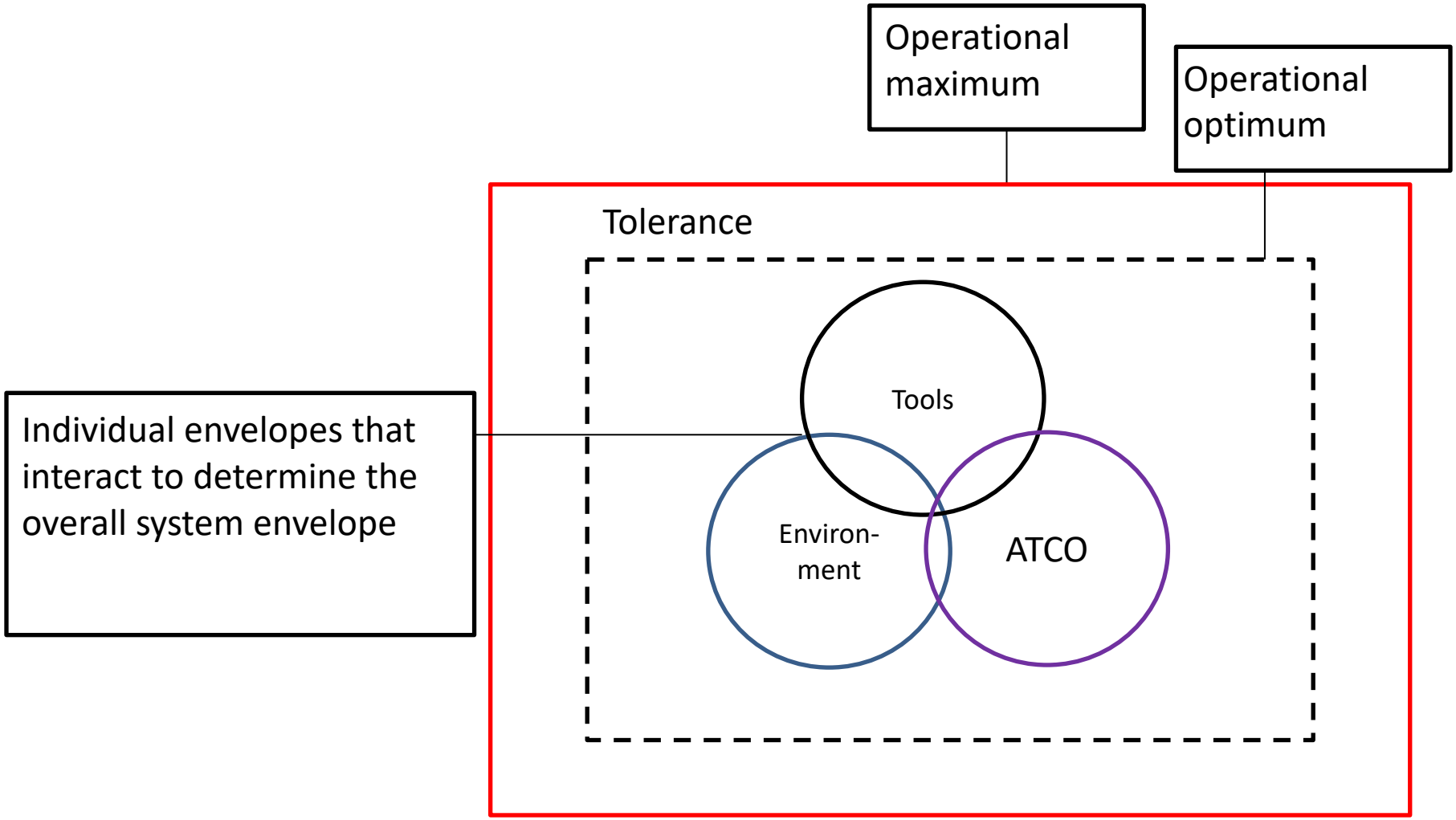
Result 3 (Cont.): Prevention and mitigation of system degradation

- Mitigation strategies for **Technology**-related causes of degradation
  - Become more conservative
  - Increase safety buffers
  - 'Back to basics'

"First, make sure that everyone is separated, and then try and get everyone out of the sectors as quickly as possible"

- Mitigation strategies for **Environment**-related causes of degradation
  - Separation – altitude, lateral distance, speed
  - Utilize surrounding airspace
  - Ground delay/ground stop
- Mitigation strategies for **Human operator**-related causes of degradation
  - Strategies focused on reducing the impact of performance-influencing factors, such as workload and stress

Result 4: The system performance envelope



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Conclusions

- Causes of degradation can be grouped into three broad categories
- The relationship between degradation cause and system effect is often moderated
- Identification of the interactions between causes of degradation is essential to future system design and risk assessment
- The ATCO has a critical role for in-time mitigation
- The concept of a system envelope can be used by designers to ensure the system stays within tolerance

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Implications

- Future system design needs to be flexible for ATCOs to use mitigative strategies
- Future design should take into account the context of tool use
- Potential interactions should be identified and designed out or mitigated
- Reduction of interaction relationships through system design

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Thank you!

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