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Designing Graceful Degradation into Complex Systems:

The Interaction between Causes of Degradation and the Association with Degradation Prevention and Recovery

Dr. Tamsyn Edwards and Dr. Paul Lee

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Agenda

- Introduction
- 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
- Next steps

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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
- Knowledge of the causes and mitigations of degradation in TBO must be understood

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Overview

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

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- 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?”

Result 1: Causes of degradation - Technology

- Technology
  - Failure – Radar, Communications

    "Everything is working fine and dandy and then it doesn't work. Can you keep up with the inter-phone, 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 1: Causes of degradation - Environment

- Environment
  - Weather
    - Thunderstorms

      "When they say deviate left, now I'm really having to focus"
    - Turbulence

      "If there's severe turbulence and you only have one smooth altitude, everybody's going to want to be at that smooth altitude"
  - Aircraft emergencies
  - Pilot requests

- Moderators of cause-effect relationship:
  - 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

Result 1: Causes of degradation – Human operator

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

"When you start to feel mental fatigue, and you're falling behind, stop, get your priorities straight, and get working"

    - 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(Cont.): Degradation cause and system effect

- Causes can effect system directly or indirectly
- Causes not sufficient to understand impact on ATCO performance or wider system
- Relationship between cause and effect often moderated
  - Cause characteristics
    - Expected vs. unexpected

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

      "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
- Examples:
  - Co-occurrence (Between): Technology and environment

"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"

  - Association (Within): Workload and Stress

- 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 like that, 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

- 'Functional Failure': Tool is operational, but purpose not functional

  "tools that they need don't work or they can't use them because of weather"

- 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
  - Technology
    - Hardware back-ups
    - Fault-tolerant systems
  - Environment
    - Airspace features (shape, crossing routes, location)

"I think most airspaces are built so that you have a little bit of flexibility as far as being able to use somebody else's airspace

  - Human operator
    - Training
    - Preparation information

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

- 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

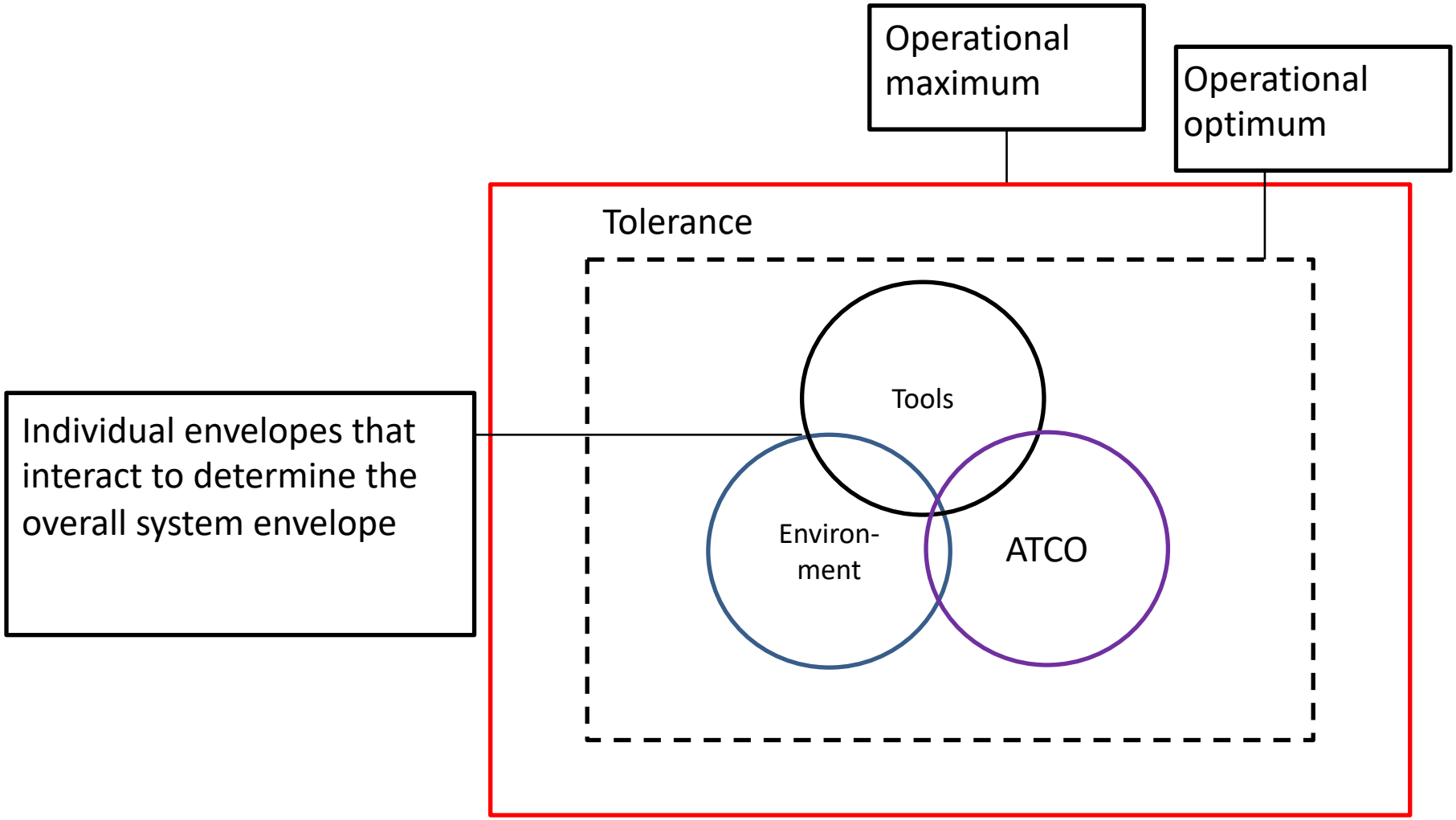
- Technology
  - Become more conservative
  - Increase safety buffers
  - 'Back to basics'

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

- Environment
  - Separation – altitude, lateral distance, speed
  - Utilize surrounding airspace
  - Ground delay/ground stop

- Human operator
  - Strategies focused on reducing the impact of performance-influencing factors, such as workload and stress

Result 4: The system performance envelope



Conclusions & Implications

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Thank you!

tamsyn.e.edwards@nasa.gov