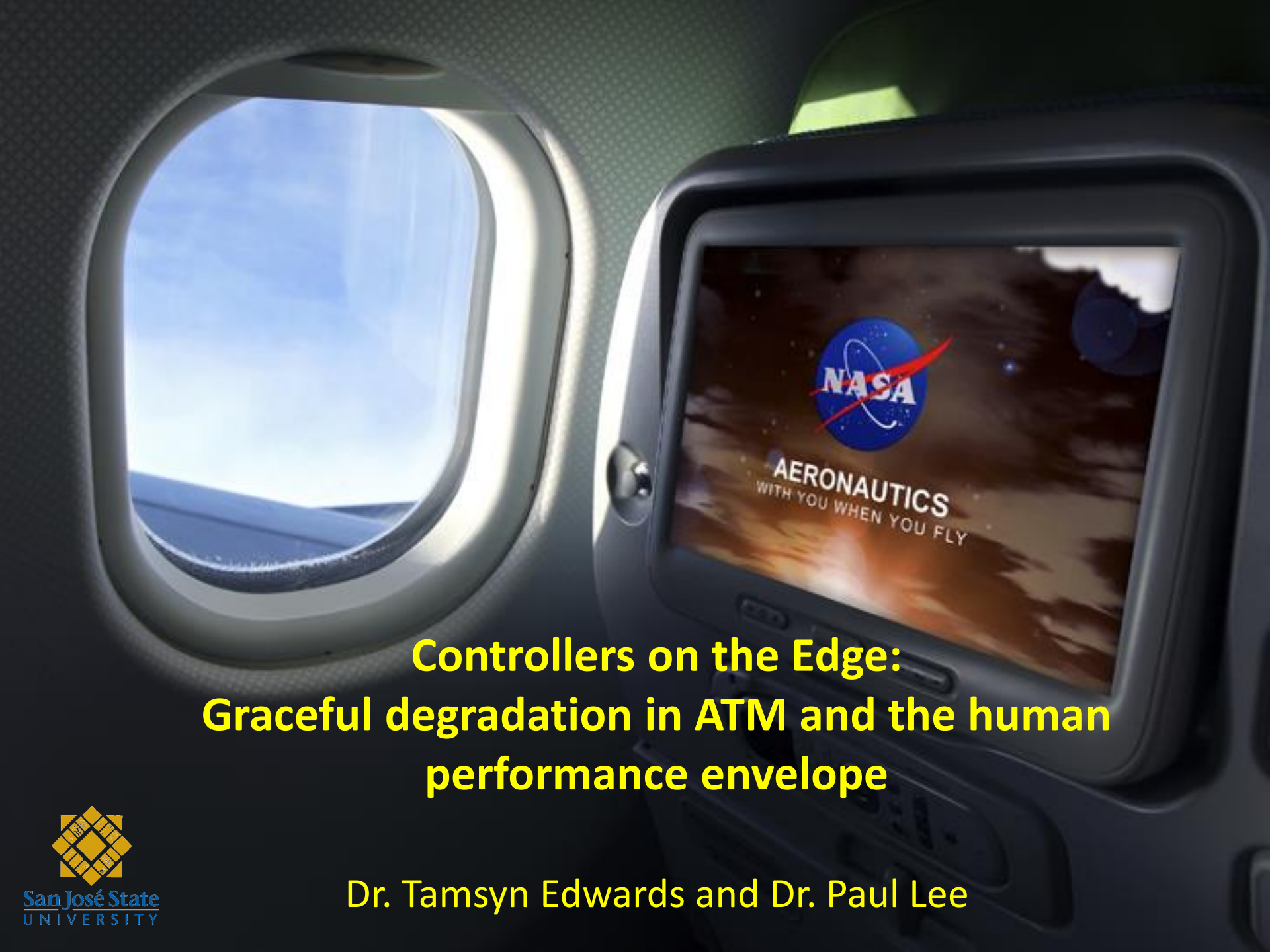

Controllers on the Edge: Graceful degradation in ATM and the human performance envelope

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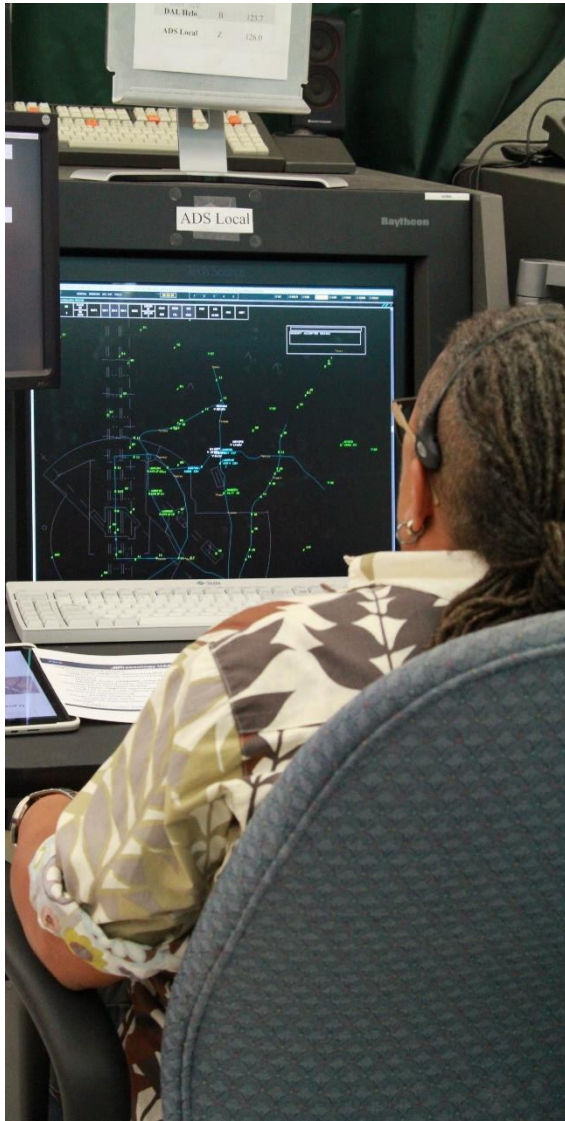
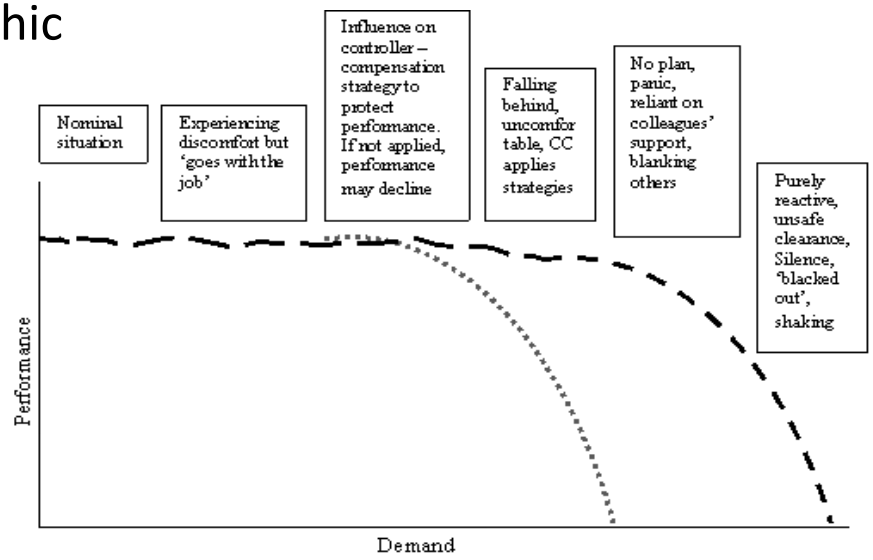
Project overview

- Research and technology advancements enable significant change to ATM
- Changes may include:
  - Narrower tolerances
  - More precise trajectories
  - Strategic vs tactical control
- System resilience is a critical issue
- Future systems must be able to degrade gracefully to maintain safety



What is graceful degradation?

- Graceful degradation describes the ability to tolerate failures
  - Reduced functionality vs catastrophic failure
- Human tend to fail gracefully; machines usually do not
- Previous research has tended to focus on graceful degradation of machines
- To design graceful degradation into future systems, need to understand degradation in ATC operations



Project Aims

- Identify causes of degradation in ATC
- Investigate relationships between degradation causes
- Inform understanding of the role of the controller in graceful degradation
- Identify ATCO degradation prevention and mitigation strategies

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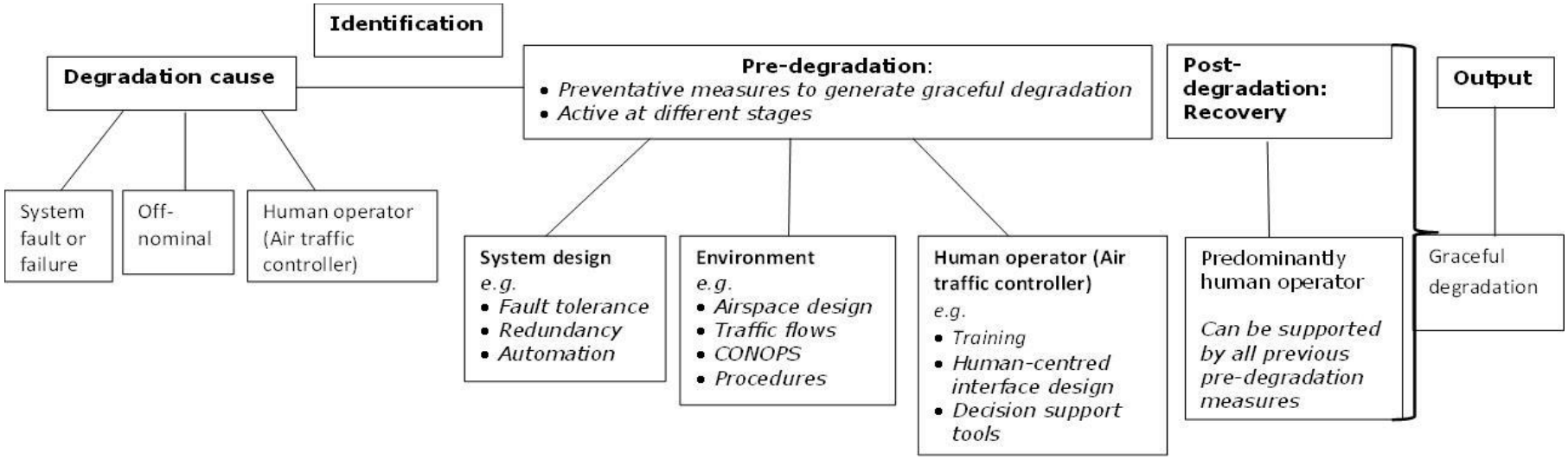
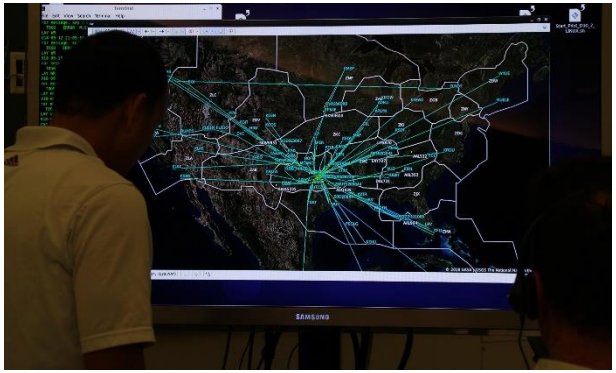
Initial framework of graceful degradation



Method

- Semi-structured interview (2 hours)
- Participants: 12 Retired controllers
  - TRACON and En-route, worked in California
  - Median age 63 years, experience range 20-35 years
- Example questions:
  - “What has caused ‘bad day’ for you in operations?”
  - “What are your control strategies for an aircraft emergency?”
- Interviews transcribed; analysed using thematic analysis



Result 1: Causes of degradation - Technology

- Failure – Radar, Communications

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

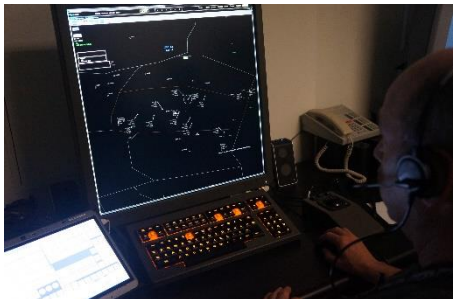
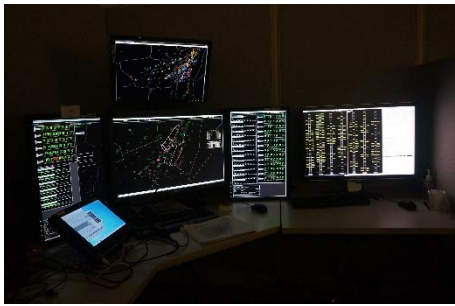
- Unreliability

  "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 1: Causes of degradation - Environment

- Weather
- Aircraft emergencies
- Pilot requests

"They say we want to deviate left. When they say deviate left, now I'm really having to focus on that..."

- 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 1: Causes of degradation - Human operator

- Errors (usually as a result of):
- Human-performance influencing factors, e.g.
  - Workload – underload and overload

"There's a lot of times when you're probably too relaxed, then all of the sudden you're going, I better wake up here"

  - Fatigue

"You do start to feel that mental fatigue, and you're falling behind"

  - 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 2: Degradation cause and system effect

- Causes not sufficient to understand system 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. You're reacting "

  - Sudden or gradual cause

"If I see the weather coming, I'm pre-planning the solution in my head, whereas if all of a sudden, I'm hit with the emergency, then I don't have time to pre-plan"

  - Duration

Result 3: 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"

Examples of associations between human factors

Factors	Quotations
Workload and Stress	Well, whenever your workload goes up your stress goes up. It kind of goes hand in hand (Participant 7)
Teamwork and Trust	"Working with somebody that you know just so smooth. So easy going. You trust that guy. He trusts you. He trusts you to make the right decisions and he knows what to do as far as coordination" (Participant 8)
Teamwork and Workload	"Low traffic teamwork really doesn't come into play. It is when the stress levels move up and the work is harder and there is more going on that is when the teamwork really comes into – into play" (Participant 8)
Fatigue and Workload	I wouldn't want to go back into the pressure cooker you know what I am saying with a 15-minute break. I wouldn't want to (Participant 10)
Stress and Vigilance	I think you wind up overlooking things, not noticing little variable that can turn into something worse later on because your mind is stressed (Participant 9)
Workload and Vigilance	somebody misses his turn and you are busy someplace else and meanwhile he has gone way past where he is supposed to go so now you are getting him back and trying to get him back quickly, so a couple of those and then it can just all start to snowball (Participant 10)
Fatigue and SA	Sitting there at a busy radar sector… my fourth shift of the week, I've already had the quick turn to the day, and then I came in, and I probably got out of bed at 3:30 that morning to come to work, and I'm on my fifth cup of coffee for the day, and I remember just feeling like I'm barely hanging on by my fingernails for dear life (Participant 9)

Result 3: 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 3(Cont.): Function 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]"

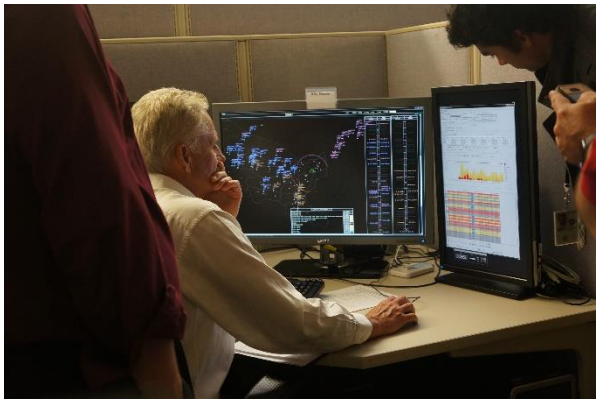
- Implications:
  - ATCO Overload
  - Risk assessment
  - Future system design

Result 4: Prevention and mitigation of system degradation

- Pre-degradation strategies

"You don't want to see a catastrophic failure. That there are safeguards that are built in that you have to rely on"

- In-time prevention and mitigation strategies
  - ATCOs change control strategies to make the system work
  - Strategies are learned through experience
  - Strategies are dependent on awareness



Result 4 (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: **Technology** causes of degradation

Examples of mitigation strategies for radio outages

Strategy grouping	Strategy
Replace function	Coordinate with next center to find a frequency and contact aircraft
	Coordinate with next center to control affected airspace
	Passed information to center - alternative frequency
Prevent worsening situation	Ground or hold traffic in other sectors
	Re-route airborne traffic around the sector

Examples of mitigation strategies for Flight processing/data tag failure

Strategy grouping	Strategy
Control strategy	Resort to basics
	Conservative control
	Verbally ask pilots: Check altitudes
	Try and remember information
Prevent from getting worse	Slow down aircraft into sector call neighboring sector

Result 4 (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: **Environment** causes of degradation

Examples of mitigation strategies for thunderstorms

Strategy grouping	Strategy
Preplan (if possible)	Start organizing traffic early into manageable flows
	More conservative control prior to thunderstorm appearing to leave room for flexibility to change
Gathering information	From pilots: how far to maneuver around it an altitudes affected
	From pilots and/or weather repots: intensity (1-5)
	From weather reports: Location and movement pattern
	Look at basic weather data on radar scope

Strategy grouping	Strategy
Control changes	Back to basic scan – more focused
	Anticipate future: prevent getting behind
	Build new route: ask first pilot to deviate at direction; ask aircraft to follow
	Ask for spacing coming into sector
	Slow down the situation – create more space between aircraft
	Use altitudes to separate if spacing isn't sufficient
	Use neighboring sectors' airspace (point outs)
	Hold at lower altitudes
	Increase distance between aircraft
	More conservative
Stop traffic	Refuse to take handoffs/aircraft

Result 4 (Cont.): Prevention and mitigation of system degradation

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

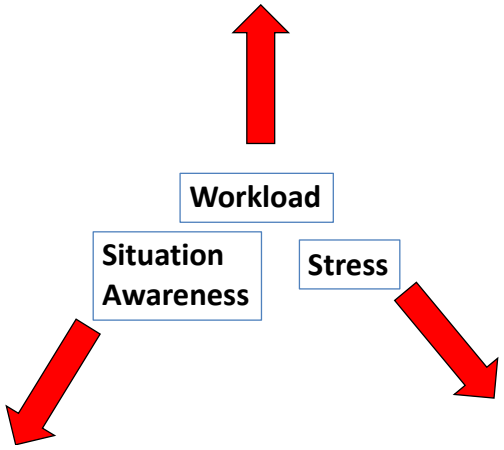
"First, make sure that everyone is separated, and then try and get everyone out of the sectors as quickly as possible"

- Mitigation strategies for **Environment**-related causes of degradation
  - Separation – altitude, lateral distance, speed
  - Utilize surrounding airspace
  - Ground delay/ground stop

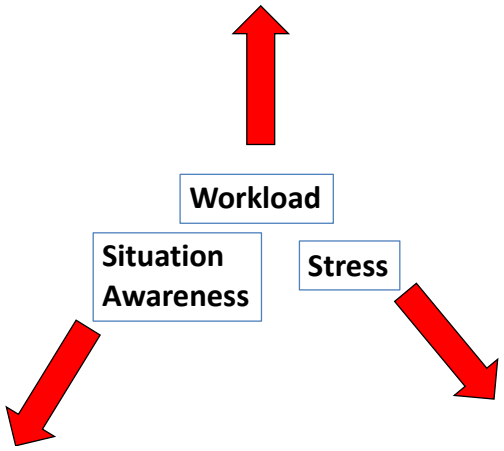
- Mitigation strategies for **Human operator**-related causes of degradation
  - Strategies focused on reducing the impact of performance-influencing factors, such as workload and stress

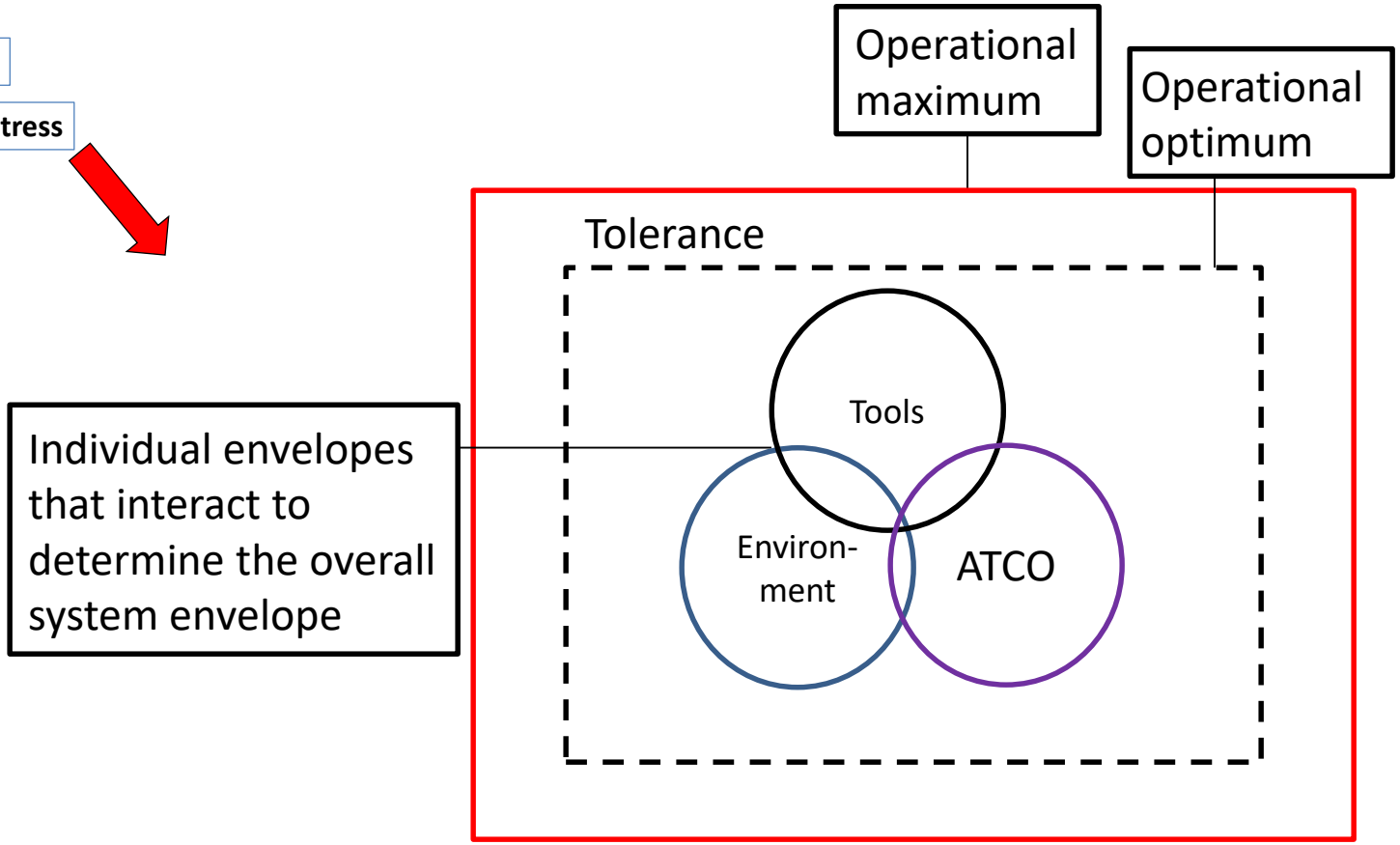
Commonalities Between Strategies: Time and Space

The system envelope



The system envelope



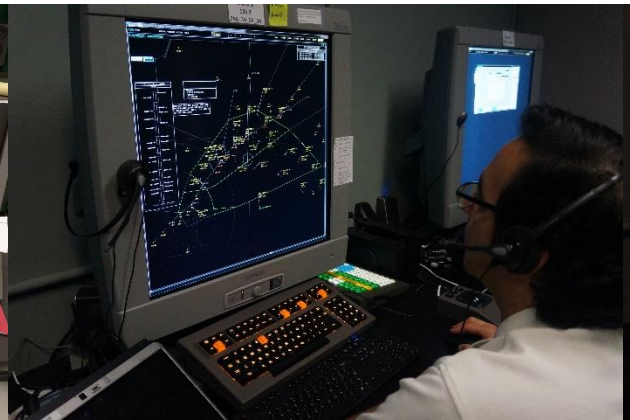


Conclusions

- Graceful degradation is essential for system safety
- ATCOs have a critical role in graceful degradation
- Time and space are essential for online strategies
- Identification of interactions between degradation causes is necessary for future system design and risk prevention
- A System envelope framework may inform research and support designers to ensure the system stays within tolerance

Implications & future considerations

- Future system design needs to be flexible for ATCOs to use mitigative strategies
- Potential interactions should be identified and designed out or mitigated
  - Future design should take into account the context of tool use
- Reduction of interaction relationships through system design
- Implications for future consideration of Artificial intelligence in ATC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Thank you!

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Back up slides

Project Aims

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

Causes of degradation

Technology - related causes

Total equipment and tool failure	**Radar primary, secondary**
	Radio Transmitter/receiver
	Internal communication/phonelines
	Issues with aircraft VHF radio
	Weather prediction tool failure
Degraded technology	Flight plan data partial or complete failure
	Callsign failure (just leaving radar target)
Limitations of automated tools	Conflict probe and alert
	Auto hand-off
	Sequencing tools
	Inadequate design for human use
Technology resulting in a loss of flexibility	"In those situations where you need to have that flexibility and adjustment, sometimes it isn't there" (Participant 6).
Indirect concerns resulting from automation	Skill degradation
	Complacency
	Future traffic increases

Environment - related causes

Sector features	**Shape and size of airspace**
	Crossing routes/conflict points
	Mix of traffic (IFR and VFR)
	Climbing/descending traffic
	Traffic presentation i.e. Integration of arrival streams
Location of sector	Military airspace
	Mountains – takes away airspace/ flexibility
	Mountains – thunderstorms build quickly without notice
Traffic	Traffic amount and complexity

Causes of degradation (cont.)

Human factor related causes

Human Factor	Examples
Workload	Overload and underload
Inadequate Situation awareness	Incorrect mental picture
	Falling behind
Communications	Transposing callsigns
	Incorrect readback/hearback
	Missing calls
Fatigue	Slower at developing plan
	Slower to respond
	Don’t perceive issues are quickly or clearly
Stress	Poor planning
	Inattention
Vigilance	Overlooking things
	Missing hand-offs
Inadequate Teamwork	Passive D-side – needs to be told what to do
	Uncooperative

Interaction of sudden and unexpected causes