

Towards designing graceful degradation into trajectory based operations:

A human-machine system integration approach

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Agenda

- Wider sub-project
- Research motivation
- Literature review: Aims
- Framework of graceful degradation
- Literature review: Detailed findings
- The operational envelope?
- Conclusions & Implications
- Next steps

Initial TBO / Integrated demand management sub-project



- Project Objective
 - Develop requirements and procedures to enable unimpeded gate-to-gate TBO that
 - Improves throughput, predictability, reduce delays, enables user-preferred trajectories by
 - Coordinating and managing traffic demand to available capacity across the NAS and
 - Synchronizing access to airspace, airport, and weather constraint bottlenecks across the NAS while
 - Maintaining safe, flexible and resilient operation
- Supports ARMD Strategic Thrust 1
 - Safe, Efficient Growth in Global Operations
- Key Barrier / Technical Challenge
 - Poorly coordinated constraint management across multiple facilities, systems, and different phases of flight
 - Gate-to-gate TBO that rely heavily on automation systems will be fragile to degradations in infrastructure or operational disruptions unless
 - they are designed properly upfront to handle the degraded state with reduced capability and then quickly and efficiently recover to full capacity

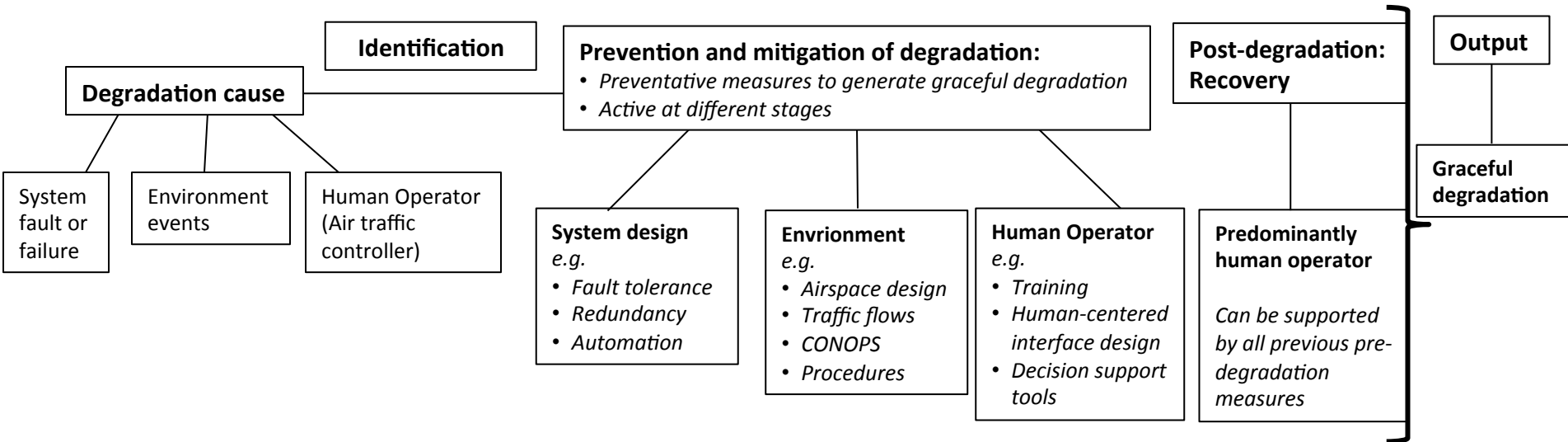
Research motivation

- 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

Literature review

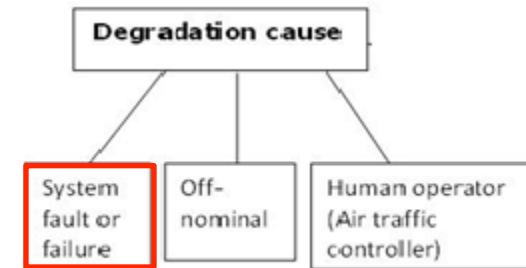
- Aims:
 - Identify causes of degradation in ATC and associated solutions
 - Identify the role of ATCOs in a gracefully degrading system
 - Develop a framework of graceful degradation from the literature
- Expected outcomes
 - Identify causes of degradation and associated solutions applicable to TBO
 - Identify literature gaps and inform future research
 - Implications for ecologically valid understanding of graceful degradation of TBO systems

Framework of graceful degradation



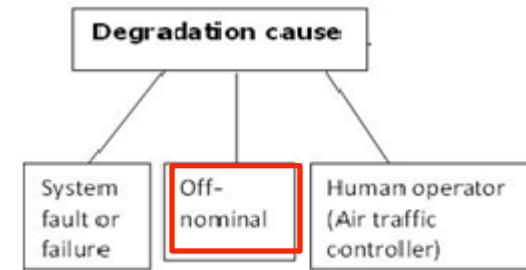
Causes: System fault/ failure

- Widest range of literature
- Primarily focuses on CNS
 - Failure can be full system or partial, such as specific algorithms
- Several categorizations documented, although no consistent agreement
- Causes of hardware failure
 - Physical damage
 - Aging
 - Accidental/malicious interference
- Software failure
 - Modelling errors
 - Integration of independent ATC software
 - Legacy technology and new technology
 - Technology with competing goals



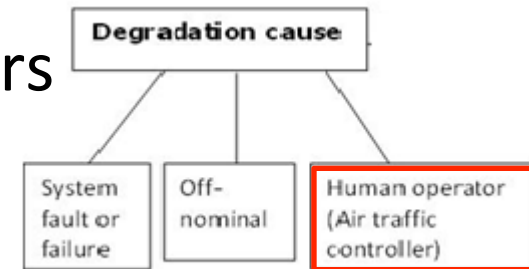
Causes: Off-nominals

- **Airspace design**
 - Number and type of conflict points
 - Size of available airspace
 - Complexity can increase ATCO demand, which may put performance at greater risk
- **Imprecision/uncertainty**
- **Off nominal events**
 - Aircraft emergencies
 - Medical emergencies
 - Unexpected pilot actions
- **Weather**
 - Widely researched
 - Leading cause of aircraft delay
 - Weather avoidance routes are pre-planned but real time updates limited
 - Consequences include manual vectoring, re-routing, delay and cancellations
 - Controllers responsible for maintaining safe operations during these demanding situations



Causes: Human operators (ATCOs)

- Least researched in graceful degradation domain
 - Human error literature in Human Factors domain
- Human performance influencing factors
 - Task demand and high workload
 - Attention and perception errors
 - Communication errors
 - Procedural error
- Human performance influencing factors resulting from use of automation (human-system interaction)
 - Underload
 - Trust
 - Design of automation – transparency and reliability

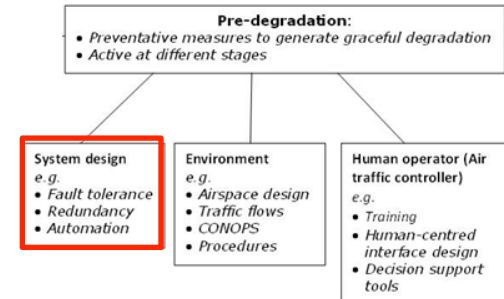


Identification

- Required prior to prevention or mitigation
- Techniques can be separated into:
 - Identifying potential causes prior to degradation
 - Identifying causes during live operations
- Techniques prior to degradation include:
 - Incident and accident analysis
 - Causal modelling
- Techniques of identification during live operations include:
 - System self-monitoring and self-identification
 - System communication to human operator
 - Human operator

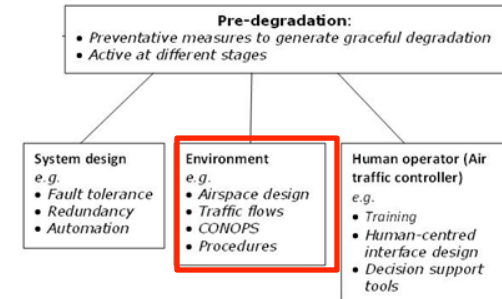
Achieving graceful degradation: System-related solutions

- Well-documented in the literature
- Bertish et al. (2013) - 18 identified mitigations
 - 14/18 related to technology design and regulation
- Hardware/software solutions
 - Failure paths
 - Back up systems
 - Redundancy
- Requirements- based solutions
 - Quality standards
 - Verification and validation
- Technological solutions for environmental and human causes of degradation
 - Decision support systems
 - Automation
 - Tools to reduce uncertainty, such as enhanced weather prediction



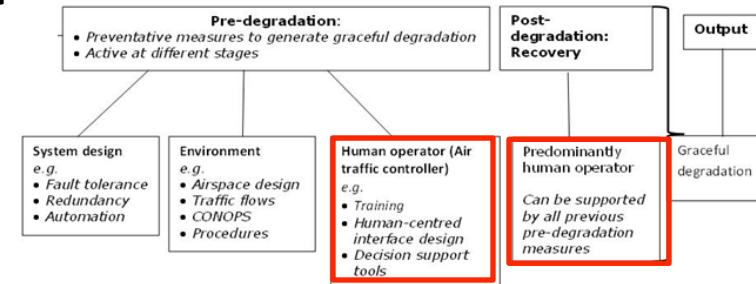
Achieving graceful degradation: Environmental solutions

- Literature primarily focuses on reducing complexity for ATCOs
- Solutions are usually complex
- Airspace redesign
 - Standard traffic flows
 - Flight follow features
 - More efficient reroutes
 - Reduction in complexity – reduction of risk of human error
- Solutions to reduce uncertainty
 - CONOPS
 - Procedures

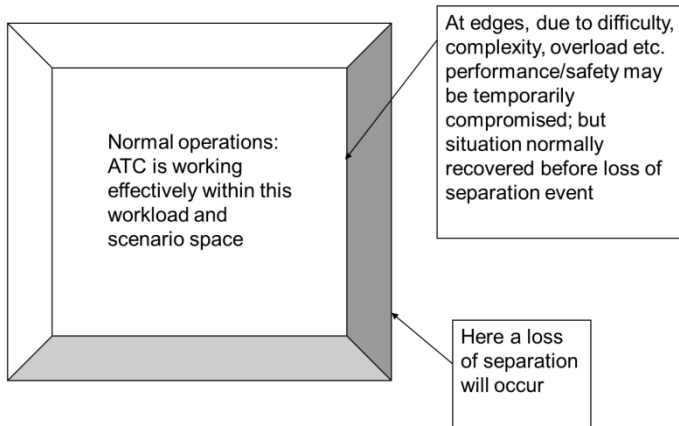


Achieving graceful degradation: Controller

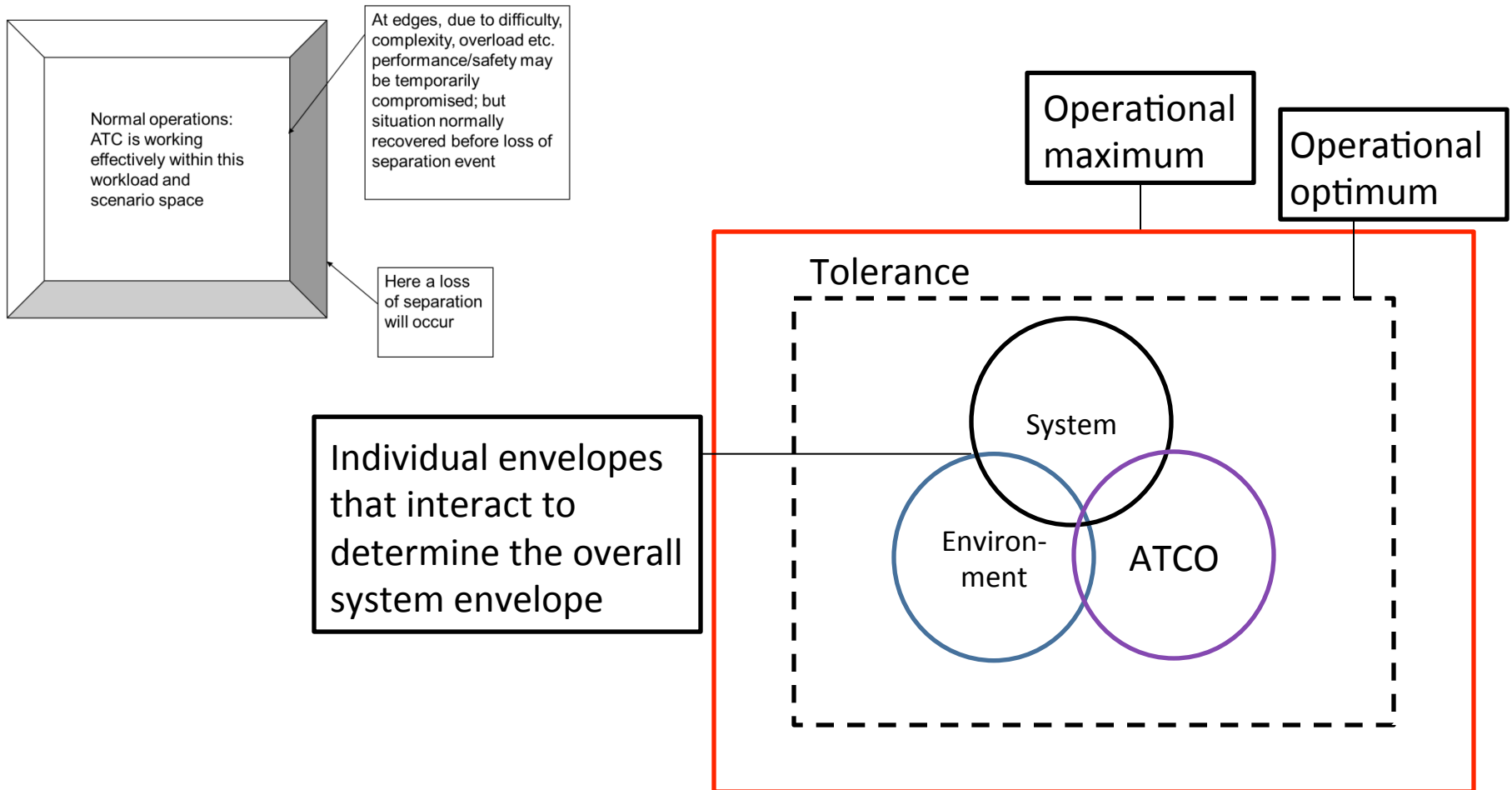
- Contribution of ATCO to graceful degradation is under-researched
- ATCOs maintain safe operations through a high standard of performance
- Dominant contribution post-degradation– recovery
 - Role is an on-line defense between safe and unsafe operations
- Significant implications for TBO
 - System fault/failure when ATCOs are controlling more aircraft than they could without automation?
 - Framework supports breakdown of this issue
- Need for human – systems integration to support graceful degradation in TBO
 - When do ATCOs reach safe limits of performance?



The operational envelope



The operational envelope



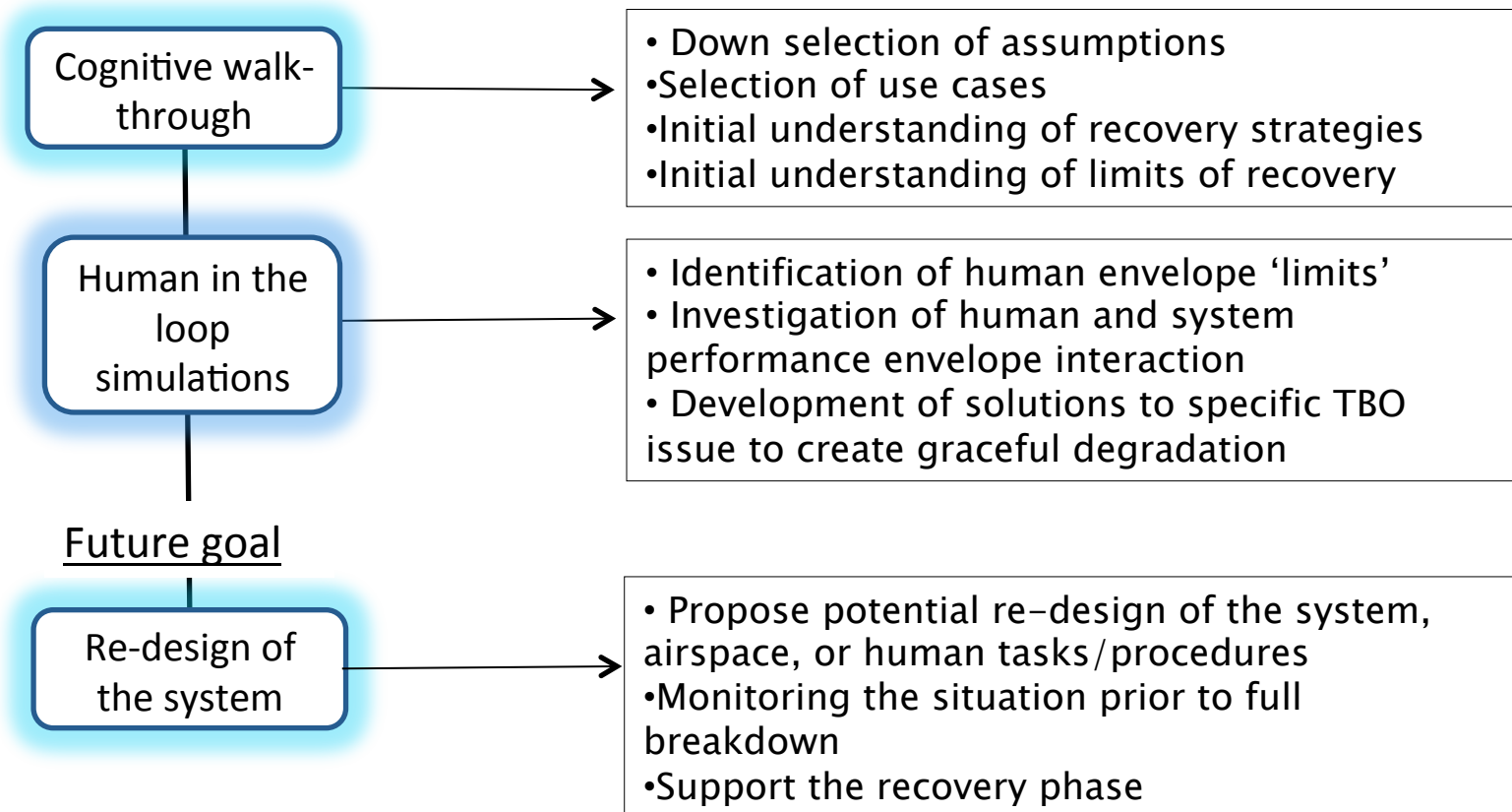
Conclusions & Implications

- Findings
 - Causes of degradation and solutions categorized by systems, environment and human operators (ATCOs)
 - Solutions to degradation can be applied pre- or post-degradation
 - Most research on systems, least on role of the ATCO
 - Research dominantly considers ATCO to be responsible for maintenance of safe operations during degradation
 - No consideration in current literature of interactions between causes and solutions
- Development of graceful degradation framework can be used to:
 - Identify research gaps
 - Identify causes of degradation and solutions
 - Identify interactions
 - Guide requirements for future research
- Human-system interaction approach essential to achieve graceful degradation in TBO
- Need to understand limits of system performance **AND** human performance

Next Steps



- Literature review completed
 - Paper submitted and accepted to Aviation 2017
- Aims of future work
 - Identify causes of degradation in TBO
 - Identify the limits of recovery for the human operator



Thank you!

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