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

Degrada'ion cause
- System fault or failure
- Environment events
- Human Operator (Air traffic controller)

Identification

Prevention and mitigation of degradation:
- Preventative measures to generate graceful degradation
- Active at different stages

System design e.g.
- Fault tolerance
- Redundancy
- Automation

Environ'ment e.g.
- Airspace design
- Traffic flows
- CONOPS
- Procedures

Human Operator e.g.
- Training
- Human-centered interface design
- Decision support tools

Post-degrada'tion: Recovery

Predominantly human operator
- Can be supported by all previous pre-degradation measures

Output

Graceful degrada'tion
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

Normal operations: ATC is working effectively within this workload and scenario space.

At edges, due to difficulty, complexity, overload etc., performance/safety may be temporarily compromised; but situation normally recovered before loss of separation event.

Here a loss of separation will occur.
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Individual envelopes that interact to determine the overall system envelope.

Operational maximum
Operational optimum

Tolerance
System
Environ-
ment
ATCO
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

- Down selection of assumptions
- Selection of use cases
- Initial understanding of recovery strategies
- Initial understanding of limits of recovery

- Identification of human envelope ‘limits’
- Investigation of human and system performance envelope interaction
- Development of solutions to specific TBO issue to create graceful degradation

- Propose potential re-design of the system, airspace, or human tasks/procedures
- Monitoring the situation prior to full breakdown
- Support the recovery phase
Thank you!

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