Using the Human Performance Envelope to inform Future Trajectory Based Operations

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Agenda

• Human performance envelope?

• Summary of concept development

• Behavioural markers of the edge of performance

• Current research: Application of HPE to Trajectory-based operations

• Work Programme

• Conclusions
Motivation

• ATM is an ‘ultra-safe’ industry

• ATM remains highly ‘human-centric’ – real-time operations

• Mitigations defend against incidents, but still occur

• Need to know when controllers are approaching the edges of acceptable performance
Concept development

• Factor identification
  – 9 key factors in ATC
• Exploration of factor interactions and performance
Edge of the envelope: The performance curve

Edwards et al., 2014
Behavioural markers of degrading performance
Markers are used to indicate edges of performance

- Indicators
  - Internal – subjective to the controller
  - External – overt, observable indicators
    - Compensation strategy
    - Physical change
    - Performance decline
## Markers of workload

- **Low workload:**

<table>
<thead>
<tr>
<th>Category</th>
<th>Internal Marker</th>
<th>Proposed category</th>
<th>External Marker</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cognitive changes</td>
<td>Pay less attention</td>
<td>Perception changes</td>
<td>Incorrect assessment of a situation</td>
</tr>
<tr>
<td></td>
<td>Easily distracted</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Reduced self-awareness</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Changes to control</td>
<td>Leave situations develop</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Trying to create more complex situations</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Less safety buffer</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Subjective feeling</td>
<td>Boredom</td>
<td>Performance changes</td>
<td>Overlooking aircraft</td>
</tr>
<tr>
<td></td>
<td>Relaxed</td>
<td></td>
<td>Forgetting aircraft</td>
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<tr>
<td></td>
<td></td>
<td></td>
<td>Repeated ‘sloppy’ mistakes</td>
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<tr>
<td></td>
<td></td>
<td></td>
<td>Fall behind traffic due to distraction</td>
</tr>
</tbody>
</table>
## Markers of fatigue

### Markers internal to the controller

<table>
<thead>
<tr>
<th>Cognitive changes</th>
<th>Subjective experience</th>
</tr>
</thead>
<tbody>
<tr>
<td>Concentration issues</td>
<td>More effort to control</td>
</tr>
<tr>
<td>Increased assumptions</td>
<td>Don't want to work busy traffic</td>
</tr>
<tr>
<td>Slower</td>
<td>Force self to pay attention</td>
</tr>
<tr>
<td>Mild confusion</td>
<td>Feel tired</td>
</tr>
<tr>
<td>Reduced awareness</td>
<td>Not looking forward to shift</td>
</tr>
</tbody>
</table>

### Observable markers

<table>
<thead>
<tr>
<th>Visible cues</th>
<th>Demeanour</th>
</tr>
</thead>
<tbody>
<tr>
<td>Yawning</td>
<td>Less active</td>
</tr>
<tr>
<td>Laid back</td>
<td>Not as confident</td>
</tr>
<tr>
<td>Eyes closed</td>
<td>Quieter</td>
</tr>
<tr>
<td>Falling asleep</td>
<td>Distracted</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Style of control</th>
<th>Performance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Less flexible</td>
<td>Overlook aircraft</td>
</tr>
<tr>
<td>Reduction in efficiency</td>
<td>Multiple, small mistakes</td>
</tr>
<tr>
<td>Less safety buffer</td>
<td>‘Running behind traffic’</td>
</tr>
<tr>
<td>Incorrect plan</td>
<td>Slow to solve problems</td>
</tr>
<tr>
<td>Slower communications</td>
<td>Forget aircraft</td>
</tr>
</tbody>
</table>
Markers of losing the picture

- Differentiation between markers that indicate losing the picture, and having lost the picture:

  "It starts off by just falling behind a bit. So you might just be a few steps behind what you’re supposed to be doing and if that builds up too much then you will get to the point where you start to lose the picture"

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<th>Category</th>
<th>External Marker</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cognitive changes</td>
<td>Difficulty selecting priorities</td>
<td>Visible cues</td>
<td>Slow at task</td>
</tr>
<tr>
<td></td>
<td>Thinking whilst giving the clearance</td>
<td>Performance changes</td>
<td>Running behind</td>
</tr>
<tr>
<td></td>
<td>Tunnel vision/hearing</td>
<td></td>
<td>Time working ahead degrades</td>
</tr>
<tr>
<td>Subjective feeling</td>
<td>Under confident</td>
<td></td>
<td>Missing calls</td>
</tr>
</tbody>
</table>
Summary of HPE findings

- Factors that influence controller performance (e.g. workload, fatigue) co-vary and appear to interact to create cumulative effect on performance

- Markers can indicate when controllers are reaching performance limits

- Findings support a shift towards research investigating multi-factor co-occurrences and performance associations
Graceful degradation in TBO: Using the HPE to inform research
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

*Adapted from: http://www.faa.gov/air_traffic/flight_across_america/*
Brittle systems vs graceful degradation
Framework of graceful degradation

**Degradation cause**
- System fault or failure
- Off-nominal
- Human operator (Air traffic controller)

**Pre-degradation:**
- Preventative measures to generate graceful degradation
- Active at different stages

**Environment**
- e.g.
  - Airspace design
  - Traffic flows
  - CONOPS
  - Procedures

**Human operator (Air traffic controller)**
- e.g.
  - Training
  - Human-centred interface design
  - Decision support tools

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

**Output**
- Graceful degradation

**Identification**
Application of the HPE: Planning research

- Application of HPE:
  - How do the causes of degradation interact?
  - What are the associations of interactions on controller performance?
  - When can controllers no longer recover the system?

- The operational envelope?

Individual envelopes that interact to determine the overall system envelope

Operational maximum

Operational optimum
Work Program

• Aims
  Identify causes of degradation in TBO
  Identify the limits of recovery for the human operator

Cognitive walk-through
• Down selection of assumptions
• Selection of use cases
• Initial understanding of recovery strategies
• Initial understanding of limits of recovery

Human in the loop simulations
• Identification of human envelope ‘limits’
• Investigation of human and system performance envelope interaction
• Development of solutions to specific TBO issue to create graceful degradation

Re-design of the system
• Propose potential re-design of the system, airspace, or human tasks/procedures
• Monitoring the situation prior to full breakdown,
• Support the recovery phase
Conclusions & Implications

• The Human Performance Envelope uniquely takes into account the multifactorial nature of operational environments
• The specification of the edges of the envelope can be utilized to predict and prevent performance decline and associated performance related incidents
• In relation to graceful degradation in TBO, the HPE allows us to understand the problematic nature of only focusing on solving one element of degradation
• Need to understand limits of system performance AND human performance
• The HPE can be applied to complex, multifactorial problems to guide areas of research
• Applying the HPE also enables hypotheses to be made regarding likely human performance outcomes
Thank you!

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