Cognitive Workload and Visual Attention Analyses of the Air Traffic Control Tower Flight Data Manager (TFDM) Prototype Demonstration*

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Motivation

• Multiple display technologies currently used at major US airports:
  – Paper flight strips
  – ASDE-X (Airport Surface Detection Equipment, Model X)
  – RACD (Remote Arts Control Display)
  – IDS (Integrated Display System)
  – etc.

• Desired from NextGen ATC tower:
  – System integration
  – Increased efficiency
    Decision support tools
    Automation
  – Safety & cost reduction
Tower Flight Data Manager Prototype

- Decision Support Algorithms
- Controller Interfaces
- External Stakeholders

Information Bus

- Message broker
- Archive

Common Services

Surveillance & Data Fusion

Data Sources
- Flight Plan
- Traffic Constraints
- Surveillance

Other ATC Facilities
Airline Operation Centers
Airport Authority

Weather Obs and Forecasts
## Tower Flight Data Management (TFDM)

### Human Machine Interfaces

<table>
<thead>
<tr>
<th>Tower Information Display System (TIDS)</th>
<th>Flight Data Manager (FDM)</th>
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### Tower Flight Data Management (TFDM) Human Machine Interfaces Analyzed in Study

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TFDM Testing at Dallas-Fort Worth (DFW)

- **DFW-1**: 8/24-9/3 in 2010, focus was on surveillance validation and initial user feedback on interfaces

- **DFW-2**: 4/26-5/5 in 2011, focus on incorporation of decision support tools and camera usage

  - **Participants**:
    
    Each day 2 controllers switched off between Ground Control (GC) and Local Control (LC) positions
    
    Total: 12 ground, 12 local

  - **Shadow operation of East Tower**

  - **Data collected**:
    
    Human performance data (audio, video)
    
    Questionnaires *(not reported here)*
    
    Technical performance data *(not reported here)*
Human Performance Data

- Video/audio of participants and East Tower Controllers (ETC) was compiled into one seamless video playback system

Measurements

- Verbal Command Analysis
  - Verbal control commands
    Participant vs. ETC (control group)
  - Gap time & response rate
    Causes of longest gap times

- Visual Dwell Analysis
  - Manual gaze evaluation
  - Individual dwell time & total dwell time
    Causes of longest dwells
Verbal Command Analysis Results

- Appx. 72% of the time, GC and LC issued instructions before or within one second (neutral to) ETCs

- LC issued commands first more frequently than GC, $t(9) = 3.30$, $p < 0.01$

- Discarded from analyses:
  - Interacting with an observer
  - Incongruous operational strategy (2% of GC cases, 10% of LC cases)

- When issuing commands after ETC, participant controllers appeared to be distracted by operating the TFDM display
Gap Time Charts

- Gap time plots created to investigate causes of high gap times for purposes of prototype design improvement.

![Gap Time Chart](image-url)
Gap time plots created to investigate causes of high gap times for purposes of prototype design improvement.
Gap Time Charts

- Gap time plots created to investigate causes of high gap times for purposes of prototype design improvement

Highlighted & editing flight strip on FDM

Editing FDE and passing it through appropriate bays to hand over to LC

Time instruction was issued
• Gap time plots created to investigate causes of high gap times for purposes of prototype design improvement.

Highlighting & editing flight strip on FDM

Editing FDE and passing it through appropriate bays to hand over to LC

Distracted by observer

Before
Neutral
After

Time instruction was issued
Design Implications of Verbal Command Analysis

- Specific issues found:
  - FDM field highlighting feature / FDM text changes
  - Confusion when transferring electronic flight strips to different controllers
  - ATIS code change

<table>
<thead>
<tr>
<th>Issue</th>
<th>Ground Control (# of instances)</th>
<th>Local Control (# of instances)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Issued command after hearing ETC</td>
<td>7</td>
<td>12</td>
</tr>
<tr>
<td>Interacting with flight strip: Moving flight strip</td>
<td>7</td>
<td>2</td>
</tr>
<tr>
<td>Interacting with flight strip: Editing flight strip</td>
<td>4</td>
<td>1</td>
</tr>
<tr>
<td>Looking for flight strip</td>
<td>10</td>
<td>2</td>
</tr>
<tr>
<td>Using Search to find flight strip</td>
<td>2</td>
<td>0</td>
</tr>
<tr>
<td>Looked at RACD</td>
<td>0</td>
<td>3</td>
</tr>
<tr>
<td>FDE not sent in time by GC</td>
<td>N/A</td>
<td>3</td>
</tr>
<tr>
<td>Tracking flight on TIDS</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>TOTAL (all gap times over 3 sec)</td>
<td>54</td>
<td>37</td>
</tr>
</tbody>
</table>
Visual Dwell Analysis Results

Percent Total Dwell Time

• More time spent head-down ($M = 81.9, SD = 12.8$) than head-up ($M = 17.2, SD = 12.4$), $t(43) = 17.12, p < .001$

• More time looking head-up out the window over “Other” dwell areas ($M = 2.3, SD = 1.9$), $t(43) = -7.87, p < .001$
Design Implications of Visual Dwell Analysis

FDM

- **Ground Control**
  - Forgetting to update FDE
  - Searching for flight strip
  - Editing flight strip

- **Local Control**
  - Confusion over flight strip not sent over to local control

TIDS

- **Viewing/Monitoring**
- **Using Picture in Picture camera view inside TIDS**

<table>
<thead>
<tr>
<th></th>
<th># of dwells over 15 sec</th>
<th>% of dwells over 15 sec</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Ground (#)</td>
<td>Local (#)</td>
</tr>
<tr>
<td>FDM</td>
<td>104</td>
<td>28</td>
</tr>
<tr>
<td>TIDS</td>
<td>81</td>
<td>56</td>
</tr>
<tr>
<td>Up</td>
<td>12</td>
<td>8</td>
</tr>
<tr>
<td>COHU</td>
<td>3</td>
<td>5</td>
</tr>
<tr>
<td>RACD</td>
<td>0</td>
<td>8</td>
</tr>
<tr>
<td>Misc</td>
<td>0</td>
<td>2</td>
</tr>
<tr>
<td>Total</td>
<td>200</td>
<td>107</td>
</tr>
</tbody>
</table>
Conclusion

- Development of a quantified and non-intrusive behavioral measure of workload and gross visual attention in a field environment

- TFDM features requiring significant focused attention and resulting in spikes in workload identified for improvement

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<tr>
<th>Issues Discovered Through:</th>
<th>Verbal Instructions</th>
<th>Visual Attention</th>
</tr>
</thead>
<tbody>
<tr>
<td>Manually searching for flight strips on FDM</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Editing &amp; updating flight strips</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Moving flight strips</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>Difficulty using “Search” function</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>Tracking flight on TIDS</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>Forgetting to update a flight strip</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>Slow when using FDM keyboard</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>Adjusting TIDS camera view</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>Inconclusive cause</td>
<td>X</td>
<td>X</td>
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</tbody>
</table>
Additional Gap Time Plots

* Asterisk indicates difference in operational strategy

Local Controller 11

<table>
<thead>
<tr>
<th>Gap Time (sec)</th>
<th>First</th>
<th>Second</th>
<th>Neutral</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>10</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>15</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>20</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>25</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>30</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Local Controller 6

<table>
<thead>
<tr>
<th>Gap Time (sec)</th>
<th>First</th>
<th>Second</th>
<th>Neutral</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
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Asterisk indicates difference in operational strategy.

Additional Gap Time Plots
LC seems to disagree with live controller commands, but repeats them

Asterisk indicates difference in operational strategy

Additional Gap Time Plots

* Asterisk indicates difference in operational strategy
Additional Gap Time Plots

* Asterisk indicates difference in operational strategy

LC seems to disagree with live controller commands, but repeats them

LC adjusting time on FDE

Asterisk indicates difference in operational strategy

Additional Gap Time Plots
**Additional Gap Time Plots**

* Asterisk indicates difference in operational strategy

- LC seems to disagree with live controller commands, but repeats them
- LC adjusting time on FDE

Large gaps due to difference in operational strategy

**Graph Details**
- **Local Controller 11**
  - Gap Time (sec)
  - Data points marked with asterisks indicate differences in operational strategy.

**Graph Details**
- **Local Controller 6**
  - Gap Time (sec)
  - Data points marked with asterisks indicate differences in operational strategy.
**Additional Gap Time Plots**

* Asterisk indicates difference in operational strategy

Large gaps due to difference in operational strategy

LC adjusting time on FDE

LC busy moving FDEs around to appropriate bays

Local Controller 11

Gap Time (sec)

LC seems to disagree with live controller commands, but repeats them

Additional Gap Time Plots
Tower Information Display System (TIDS)
Flight Data Manager (FDM)

Ground FDM Display

Local FDM Display

Flight Data Entry (FDE)
COHU camera

Fixed view

Fixed view

Tracking view