Bottom-up and Top-down Contributors to Pilot Perceptions of Display Clutter in Advanced Flight Deck Technologies

Amy L. Alexander
Emily M. Stelzer
Sang-Hwan Kim
David B. Kaber

HFES 52nd Annual Meeting
23 September 2008
Advanced information display technologies are under development to support flight efficiency, increase situation awareness, and decrease workload.

Synthetic and enhanced vision systems (SVS and EVS) present database-driven and real-time view of outside world, regardless of visibility.

Added information or simultaneous presentation may produce visual display clutter.

Clutter may inhibit processes or tasks technologies are designed to support.
Contributors to Display Clutter

- Clutter is an unintended effect of displaying visual imagery that may obscure or confuse other information.

- Clutter as a function of density
  - Global: total number of unique entities or items in a display relative to a spatial area
  - Local: amount of information surrounding a critical display area

- Clutter as a function of size or similarity
  - Size of a visual target of interest within a display
  - Similarity of objects to visual target in physical appearance or luminance

- Data-driven or bottom-up factors
Contributors to Display Clutter

- Clutter is an unintended effect of displaying visual imagery that may obscure or confuse other information or that may be redundant or not relevant to the task at hand.

- Pilot expectancy and information value can influence attention allocation and visual processes.
  - Irrelevant information has been shown to hinder information access in terms of locating, attending to, or monitoring display features.
  - Redundant pieces of information contribute to perceptions of clutter.
  - Irrelevance and redundancy are shaped by domain knowledge.

- Knowledge-driven or top-down factors.
Research Objectives

- Bottom-up and top-down parameters generally examined in isolation

- Present study designed to assess pilot perceptions and identification of both bottom-up and top-down contributors to display clutter
  - Pilots expected to report utility of both factors in describing clutter
  - Manipulations of both factors expected to directly influence perceptions of clutter
Method

- **Participants**
  - 4 expert test pilots
  - 3 male, 1 female
  - Age, $M = 47.5$ years
  - Experience, $M = 5325$ total flight hours
  - Experience flying commercial transport aircraft
  - Familiar with advanced technologies such as SVS/EVS
Display Elements

- 5 types of information elements manipulated to drive bottom-up (e.g., density) and top-down (e.g., redundancy) perceptions of clutter
- SVS: wire-frame terrain model representation
Display Elements

- 5 types of information elements manipulated to drive bottom-up (e.g., density) and top-down (e.g., redundancy) perceptions of clutter
- EVS: thermal imagery representation
Display Elements

- 5 types of information elements manipulated to drive bottom-up (e.g., density) and top-down (e.g., redundancy) perceptions of clutter
- TCAS: traffic icons
5 types of information elements manipulated to drive bottom-up (e.g., density) and top-down (e.g., redundancy) perceptions of clutter

Tunnel: pathway guidance
Display Elements

- 5 types of information elements manipulated to drive bottom-up (e.g., density) and top-down (e.g., redundancy) perceptions of clutter
- Symbology: primary mode instrumentation
Experimental Design

- 32 head-up display (HUD) configurations created by presenting 1, 3, or 5 factors
- $2^{5-1}$ Resolution V fractional factorial design - $\frac{1}{2}$ replicate design for 5 factors with 16 images across 4 trials
Presented 16 static HUD images at specific points along standard ILS Runway 16R approach to Reno/Tahoe International Airport

- Flight scenario involving low ceiling with reduced visibility conditions provided context to images
- Airline Transport Professionals (ATP) certified pilot read script to pilots providing aircraft state and air traffic control comms

Pilots provided ratings of overall perceived clutter along 20-pt scale from “low” to “high” after each image

Pilots also rated usefulness of pairs of descriptor terms, addressing bottom-up and top-down factors, along 20-pt scale from “low” to “high” after each image
Descriptor Terms

- Sparse/dense
  - Tullis, 1997

- Not salient/salient
  - Morberly & Langham, 2002

- Dull/sharp
  - Rosenholtz et al., 2005

- Static/dynamic
  - Beijer et al., 2004

- Unsafe/safe
  - Xing, 2004

- Empty/crowded
  - Muthard & Wickens, 2005

- Dissimilar/similar
  - Wang et al., 2001

- Monotonous/variable
  - Beijer et al., 2004

- Indiscernible/discernible
  - Wang et al., 2001

- Monochromatic/colorful
  - Rosenholtz et al., 2005

- Ungrouped/grouped
  - Tullis, 1997

- Redundant/orthogonal
  - Ahlstrom, 2005

- Low workload/high workload
  - Xing, 2004

- Low attention/high attention
  - Ververs & Wickens, 1998
Dependent Variables

1. Overall ratings of clutter
2. Ratings of bottom-up and top-down descriptor term relevance for describing clutter
3. Qualitative data on participant comments

- Results associated with modeling perceptions of clutter based on information elements are available:

Overall Clutter Rating Results

- Overall clutter ratings increased as number of active display features increased ($r = 0.42, p < 0.01$)

  Mean clutter ratings by numbers of HUD features.

<table>
<thead>
<tr>
<th>Number of Active Features</th>
<th>1</th>
<th>3</th>
<th>5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of Observations</td>
<td>50</td>
<td>100</td>
<td>10</td>
</tr>
<tr>
<td>Mean Overall Rating</td>
<td>9.79</td>
<td>12.94</td>
<td>16</td>
</tr>
</tbody>
</table>

- Number of active display features represents a bottom-up contributor to perceptions of clutter
- Visual density of display appears to be key predictor of clutter rating
Purpose was to:
- Identify underlying dimensions of perceived clutter related to similarities among HUD configurations tested
- Test usefulness of descriptor term pairs for describing overall clutter

Factor analysis revealed two principal components which serve as dimensions in MDPREF biplot
- Driven by data matrix including HUD configurations as rows and descriptor term pairs as columns
- Ratings of descriptor term pairs relevance for describing clutter were continuous variables
MDPREF Results

- Analyzing both biplots reveals nature of two principal components
  1. X-axis: *visual* density
  2. Y-axis: *information* density
Comments categorized according to five recurring themes:

1. **Display brightness** – luminance of display features relative to other critical elements
2. **Information density contrasted with visual density** – amount of information presented contrasted with the number of active display elements
3. **Information redundancy** – degree to which display elements provide same information
4. **Trend information** – ability of display elements to provide information about flight trends
5. **Occlusion** – degree to which elements overlapped other display features
Pilot Subjective Comments

- Comments describe clutter in both bottom-up and top-down terms
  - 25% bottom-up
  - 20% top-down
  - 15% contrasted bottom-up/top-down directly
Purpose was to assess pilot perceptions and identification of contributing factors to display clutter in static images incorporating various types and amounts of information.

Pilots reported utility of both bottom-up and top-down factors in describing clutter associated with displays.

Manipulations of bottom-up and top-down factors directly influenced perceptions of clutter.

Subjective comments confirmed notion that perceptions of clutter are derived from bottom-up and top-down factors.
Conclusions

- Examining dual contributors to perceptions of display clutter reveals importance of both and potential interaction
  - Pilots willing to accept higher visual density to the extent that added elements provide information relevant to flight task

- Both visual (bottom-up) and information (top-down) density need to be considered in:
  - Measuring overall amount of perceived clutter in display
  - Designing low-clutter displays

- Follow-on research incorporating larger sample size and dynamic flight simulation to ultimately develop multidimensional model used for quantifying display clutter
Acknowledgments

Thanks to Dr. Nathan Bailey and Dr. Simon Hsiang for input on experiment design.

Thanks to Mr. Karl Kaufmann and Ms. Jennifer Cowley for assistance in data collection.

For additional information, please contact:

Amy L. Alexander  
aalexander@aptima.com

David B. Kaber  
dbkaber@ncsu.edu

This research was sponsored by NASA Langley Research Center under Grant No. NNL06AA21A issued through the Aviation Safety Program. Any opinions, findings, and conclusions or recommendations in this presentation are those of the authors and do not necessarily reflect the views of NASA.