Visualizing Uncertainty in High Time-Stress

Christopher D. Wickens
Head, Human Factors Division
University of Illinois, Institute of Aviation

• Terms
• Model of Influences
• Challenge and Results of Empirical Research
• Human Factors Guidelines for Best Display Practices
Visualizing Uncertainty in High Time-Stress

- **Uncertainty:**
  Spatial-temporal resolution (imprecision)
  Categorical uncertainty
- **Expected Value (Risk)** $PXV$
  People relatively poor at utilizing probabilistic information. Value dominates risk decisions.
- **Visualizing:** Displays. Multi-media (visual, auditory sounds). Not linguistic.
- **Time Stress:** Minimizing cognitive load: best outcome
- Example: the pilot conflict avoidance maneuver.
Source of Uncertainty
Turbulence, Winds,
Future Pilot Control Actions
A Simple Model

Domain Source → Display → Cognition → Action Choice

Attention

Appropriate (Optimal)
Attention Deployment Domain Source

Predicting the future (probablistic world)

Decision Making Process:
1. Domain Source
2. Display
3. Perception
4. Cognition
5. Decision

Diagnosing the Present (Imperfect Sensors)

Present Unc?
- No:
  - Expected Case
  - Worst Case
- Yes:
  - Levels (Resolution)
  - Format Rendering (Modality, Spatial, Numerical)

The Future May Change

Conservative Risky

Accuracy

State of the World

The Choice May Be Wrong

Choice

O₁₁ O₁₂
O₂₁ O₂₂

HUMAN

Predicting the future (probabilistic world)
Empirical Research on “What Works”: The Challenge

Make credible the actuarial experience of probabilities. If low probability events are part of the display rendering, they must be experienced by the participant.

Rendering of p=.01 event, participant must (a) experience the event, (b) experience it 1 out of 100, or (better) 2 out of 200.

Few studies exist that have:
* compared uncertainty representation vs. none.
* compared different formats of uncertainty representation
* collected objective performance data with actuarial experience
**The Empirical Results**

- Display: Uncertainty vs. “expected case” or “worst case”
- No effect? Wickens Gempler & Morphew. Probabilistic display of predicted flight path error does not help conflict avoidance.
- Yeh, Merlo & Wickens. Uncertain intelligence template vs. \(\square\) does not improve attention allocation in military target cueing when \(\square\) explicitly displays degraded spatial resolution (increased position uncertainty) of the cue.
- Smith & Wickens: Highlighting best case, expected case, worst case outcomes does not alter NMD strategic missile launch decisions
Empirical Results: Best Display Practices

1. Levels of resolution: (Danger, Uncertain, Safe)
   (2) D-S (3) D-U-C (5) D- DU U US S

More (than 2) levels help. (St. Johns and Mannes, Schinzer et al). Philosophy of “likelihood alarm”. (Sorkin & Woods). Aviation collision warnings. Why? More of the errors in a higher resolution system are not as “bad”. (This fosters greater trust in the system):

How many levels needed? (Schinzer). > 4 may be all.
How to render?
Nichols et al.
Predictive Probabilistic and Temporal Conflict Avoidance Displays
(courtesy of Jason Telner & Paul Milgram, University of Toronto)

Probability information plotted as a density or a contour graph

Iso- TTC Plot

TTC information plotted as contour or density graph

Iso-probability Plot.

(Masked)

(TTC = Time-to-Conflict)
Empirical Format Comparisons

  but not always (Schinzer et al)
- Visual vs. Auditory, Tactile: Visual wins (Basapur)
<table>
<thead>
<tr>
<th>Condition</th>
<th>Standard Tires</th>
<th>Improved Tires</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cost</td>
<td>$1.95 for 4</td>
<td>$7 for 4</td>
</tr>
<tr>
<td>Annual Blowout Injury Risk</td>
<td>8,000,000 MD drivers: 30 serious injuries</td>
<td>8,000,000 MD drivers: 15 serious injuries</td>
</tr>
</tbody>
</table>

How much would you be willing to pay for improved tires? [ ].

### Box Summary of the *stick figures* condition

<table>
<thead>
<tr>
<th>Condition</th>
<th>Standard Tires</th>
<th>Improved Tires</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cost</td>
<td>$225 for 4</td>
<td>$7 for 4</td>
</tr>
<tr>
<td>Annual Blowout Injury Risk</td>
<td>8,000,000 MD drivers: number of serious injuries</td>
<td>8,000,000 MD drivers: number of serious injuries</td>
</tr>
</tbody>
</table>

---

Kirchenbaum & Aruda

---

Stone et al.
### Schinzer et al: Investment Decisions

<table>
<thead>
<tr>
<th>Range (High)</th>
<th>Numeric Expression</th>
<th>Linguistic Expression</th>
<th>Colored Icon</th>
<th>Arrow Icon</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0%</td>
<td>Absolutely Impossible</td>
<td>**</td>
<td>*</td>
</tr>
<tr>
<td>0-.9</td>
<td>5%</td>
<td>Rarely</td>
<td>**</td>
<td>*</td>
</tr>
<tr>
<td>.9-.18</td>
<td>14%</td>
<td>Very Unlikely</td>
<td>**</td>
<td>*</td>
</tr>
<tr>
<td>.18-.27</td>
<td>23%</td>
<td>Fairly Unlikely</td>
<td>**</td>
<td>*</td>
</tr>
<tr>
<td>.27-.36</td>
<td>32%</td>
<td>Somewhat Unlikely</td>
<td>**</td>
<td>*</td>
</tr>
<tr>
<td>.36-.45</td>
<td>41%</td>
<td>Uncertain</td>
<td>**</td>
<td>*</td>
</tr>
<tr>
<td>.45-.54</td>
<td>50%</td>
<td>Tossup</td>
<td>**</td>
<td>*</td>
</tr>
<tr>
<td>.54-.63</td>
<td>59%</td>
<td>Better Than Even</td>
<td>**</td>
<td>*</td>
</tr>
<tr>
<td>.63-.72</td>
<td>68%</td>
<td>Rather Likely</td>
<td>**</td>
<td>*</td>
</tr>
<tr>
<td>.72-.81</td>
<td>77%</td>
<td>Quite Likely</td>
<td>**</td>
<td>*</td>
</tr>
<tr>
<td>.81-.90</td>
<td>86%</td>
<td>Highly Probable</td>
<td>**</td>
<td>*</td>
</tr>
<tr>
<td>.90-1</td>
<td>95%</td>
<td>Almost Certain</td>
<td>**</td>
<td>*</td>
</tr>
<tr>
<td>1.0</td>
<td>100%</td>
<td>Absolutely Certain</td>
<td>**</td>
<td>*</td>
</tr>
</tbody>
</table>
Best Practices in Time Stressed Environments

• Cognitive limitations: (Sweller: Cognitive load theory) Limited time, limited expertise

• Extensive research on graphical presentation (Tufte, Gillen et al., Wickens & Hollands)

• Information overload: people will filter: what will they process? Ignore?

• What will decision be based on?
  Expected case? Worst case?

• What should decisions be based on?
Best Practices Under Time Stress

1. Eliminate redundant extra information (declutter)

2. Visually link uncertainty representation to uncertain element (Proximity compatibility principle): Why visual display is good.

3. Express uncertainty in the “language of action” for:
   - DIAGNOSIS
     Spatial occupancy contours
   - PREDICTION
     Time windows

4. Need for standardization of contour level (95%?)
Consequences of Supporting Risk-Seeking vs. Risk Aversive Behavior

- What kind of behavior does displaying uncertainty induce, invite? 1. That uncertainty exists. 2. How big it is.
- In high time pressure designer should evaluate the worst case outcomes. Design to avoid these, presenting relatively less probabilistic information as time pressure grows.
- The aborted takeoff decision in aviation (Inagake).

```
Uncertain failure ↓

→ Takeoff (Unfiable airplane) → Abort takeoff  Overshoot runway end
```
Conclusions

More research needed (Echoes calls by others)

Analyze consequences of human knowing uncertainty

Displaying Information will induce specific behavior in high time-stress
References


Nicholls, D., Battino, P., Marti, P., & Pozzi, S. Presenting uncertainty to controllers and pilots.


