Recall the USS Vincennes Incident…
- Misperceived Cues (descending not a climbing plane)
- Misdiagnosed pilot’s intent (as hostile instead of neutral)
- Chose (decided) to fire, on the basis of the wrong diagnosis

Learning objective
- Understand constraints on decision making
  - Imposed by people
    - Decision making processes
  - Imposed by systems design
    - And seen through cognitive task analysis

DECISION MAKING
Theoretical approaches to decision making

- Optimal expected value decision making
- Naturalistic decision making
- Information processing

Optimal expected value theory

- Specify costs/benefits
- Chose the option with the highest expected value

Optimal expected value example

Would you wager money that the outcome of the roll of two dice would be an even number greater than 4 if winning yielded $1.75 per every $1 bet?

Optimal expected value theory example

<table>
<thead>
<tr>
<th>Outcome</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
<th>10</th>
<th>11</th>
<th>12</th>
</tr>
</thead>
<tbody>
<tr>
<td>Payoff</td>
<td>-$1</td>
<td>-$1</td>
<td>-$1</td>
<td>-$1</td>
<td>+$1.75</td>
<td>-$1</td>
<td>+$1.75</td>
<td>-$1</td>
<td>+$1.75</td>
<td>-$1</td>
<td>+$1.75</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Outcome</th>
<th>Win</th>
<th>Lose</th>
</tr>
</thead>
<tbody>
<tr>
<td>Probability</td>
<td>4/11 (.36)</td>
<td>7/11 (.64)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Outcome</th>
<th>Win</th>
<th>Lose</th>
</tr>
</thead>
<tbody>
<tr>
<td>Utility</td>
<td>1.75</td>
<td>-1.00</td>
</tr>
</tbody>
</table>

Expected Value = \( \sum U_i p_i \)
= \( (1.75 \times .36) + (-1 \times .64) \)
= 0
### Optimal expected value theory

- Specify costs/benefits
- Chose the option with the highest expected value
- Research focuses on why humans depart from the optimal

### Naturalistic decision making

- Argues it is impossible to specify costs, values and probabilities in the real world
- Thus, recognition-primed decision making used for situation assessment
  - “I know X when I see it”
- Mental simulation used for choice rather than consideration of all possible outcomes
  - Select option that has been successful in the past in this situation

### Naval barrier

### Poorer barrier
Alternative barrier

Information processing
- Cue seeking & perception
  - Diagnosis (situation assessment)
  - Choice
  - Emphasizes heuristics and biases

Heuristics and Biases
- Heuristics
  - Mental “shortcuts” that usually work adequately (but not perfectly)
  - May be considered optimal under time pressure, or when cognitive resources are limited
- Biases
  - Systematic distortions
  - Lead to sub optimal decision making

Biases
- Fixation/anchoring
- Confirmation
- Salience/availability
- Framing
Tversky & Kahneman

- Asked people to calculate product of 8 numbers
  - $1 \times 2 \times 3 \times 4 \times 5 \times 6 \times 7 \times 8$
  - $8 \times 7 \times 6 \times 5 \times 4 \times 3 \times 2 \times 1$
- But… only given 5 seconds, so had to estimate
- Mean estimate 512 vs. 2250
- Actual answer = 40,320

Fixation/anchoring bias

- Fixation: inability to take a new perspective on a problem
- Anchoring: Decision maker anchors their belief that “a” is correct, because it is supported by the first arriving cue
  - Less likely to shift their belief with subsequent cues
  - Particularly bad if information declines in reliability over time: “old vs. new data”
- Related to cognitive or attentional tunneling and change blindness

Three numbers…

- Give you three numbers, a three number sequence
- And I have a rule in mind that these three numbers obey
- Want you to try to figure out what that rule is by giving me three numbers
- I will tell you if they follow the rule and then you can guess the rule

The three numbers…

2, 4, 8
**Confirmation bias**
- Tendency to seek subsequent information to confirm that “a” is the correct diagnosis
- People do not look for, nor identify, cues that might support an alternate interpretation
  - if they find them, they “discount” them

**Saliency/availability bias**
- The tendency to overestimate the likelihood of events with greater “availability” in memory
- Can be influenced by
  - Recency of the memory
  - Uniqueness of the memory
  - Emotional charge associated with the memory

**Saliency/availability bias**
- All cues equally valid
  - C1
  - C2
  - C3
- What makes cues salient?
  - The loudest voice in the room
  - The brightest alarm flashing in central vision (Three Mile Island)
  - The smoothest, most articulate eye witness
  - The cue that arrives first

**Framing**
- Theater ticket
- Gain vs. loss
  - Sure gain of $3,000 vs. 80% chance of winning $4000 and 20% chance of winning nothing
  - Sure loss of $3000 vs. 80% chance of losing $4000 and 20% chance of losing nothing
  - Expected value is $3200 in both cases
    - $(4000 \times 0.8) + (0 \times 0.2)$
Framing bias

- With negative framing, people are biased to choose the *risky option*, even when the expected value favors the sure negative
- When choice is framed as between two *positives*, people bias toward the sure thing

Bias affects Performance

- For example … in the forensics domain

Confirmation bias in visual assessment of skeletal remains

- Skeleton selected from collections curated by the Museum of London
- Actual remains probably female, age range of 36-45 years, no observable pathology, good bone preservation; ancestry not recorded (likely Caucasian)
- Remains were of a full body, and included a complete skull, and mandible, with the majority of postcranial elements presented in good condition
- 41 non-novice participants in 3 groups

Nakhaeizadeh, Dror, & Morgan, 2014
An actual case

An image of a car, taken from camera #6 at 00:17.20

This is the only frame that includes the registration plate of the car

Answer depends on question asked

- Questions:
  - Can you identify the registration plate number?
  - Can you confirm that this plate number is shown in the image?

Hindsight Bias

- Can you see something in hindsight that you couldn’t see ahead of time?
  - Radiology
  - Car crash

Latent fingerprint analysis

- Six examiners given latent fingerprints to analyze
- Using fingerprints that had previously been identified as “match” or “no match”
- Manipulated context:
  - Likelihood that prints would be a match
- Judged 8 prints against suspect prints

Dror and colleagues
Context affected decisions

- Examiner conclusion changed on 5 of 47 total judgments
  - Dror & Charlton, 2006; Dror & Rosenthal, 2008

- Caveats
  - Strong manipulation of context
  - “Difficult” prints

Modeling the decision making process

Motivation (Values for Outcomes)

State of the World:
- Current/Predicted

Decision Choice

Outcome A
Outcome B

State A1(P1) State A2(P2)

Value times probability
Value times probability

State A1(P3) State A2(P4)

Value times probability
Value times probability

Wickens, Keller and Shaw, in press
Climbing example

Motivation
- Prestige
- Personal health protection
- Family responsibilities
- Money

Weather will:
- Forecast
- Current
- Skies
- Feeling in toes

Situation Assessment
- Weather will:
  - Worsen
  - Stay Good

Decision Choice
- Continue
- Turn Back

- Self confidence in climbing skills
- Self confidence in weather forecasting
- Knowledge of weather, route ahead

- Make all cues equally perceptually available
- Make more diagnostic cues more salient

- Instruction on biases/heuristics ("debiasing")
- Instruction to entertain reasons why their hypothesis (situation assessment) might be wrong

- Automation

Wickens, Keller and Shaw

Human factors solutions to biases and heuristics

Keys to understanding decision making

- Different theories of Decision Making
  - Optimal expected value decision making
  - Naturalistic decision making
  - Information processing (Biases)

- Implications for improving decision making can be understood by looking at a model of the decision making process

Wickens & Hollands, 2000

BREAK
Cognitive task analysis

- Description of cognitive and physical actions needed to perform a task proficiently
- Particularly valuable for tasks that depend on cognitive aspects of expertise (e.g., decision making, problem solving)
- Focuses on actions and cognition required to reach the goal state while completing a task
- Actions selected influenced by:
  - The system
  - Individual differences in strategies

Task analysis vs. cognitive task analysis

- *What vs. why* something is being done
  - That is, task/activity vs. goal
- *Why* usually focuses on:
  - Non-observable tasks, like planning, predicting, problem solving, maintaining situation awareness and decision making
  - The vocabulary, information needs and concepts as understood by the worker (usually an expert)

CTAs provide the basis for design recommendations

- Information displays
- Strategies for adaptive and dynamic deployment of automation
- Design of training programs
- Personnel selection
- Staffing and function-allocation decisions
- Input to workload analysis and human reliability modeling
How is a CTA built?

- Start w/ hierarchical task analysis (HTA): Hierarchy of operations and plans to achieve goals
- Operations help achieve goals within task constraints
  - Operations achieved through subordinate operations and plans
  - [Re-description needed?]
- Stopping rules: in this case, when down to the level of cognitive operators

Example: The hierarchy (subordinate operations)

- Start at the top with overall goal/task
- Each element is uniquely numbered
- Work downward to goals/tasks that must be satisfied/performed to achieve the goal
- Keep working downward until expected cost of not completing a task is trivial — NOTE: no cognition in this example

Wickens et al, 2004

Example: The plan

- Plan represents the constraints on performing elements across any level of the hierarchy
- Described verbally (or by code), e.g.:
  - 1 before 2
  - 1+2
  - Do both 1 and 2
  - Do 1 OR 2
HTA for correcting spelling in a document

0. Correct Spelling in Document

1.0 Identify misspelled word
2.0 Correct Misspelled Word

Adding the plan

0. Correct Spelling in Document

1.0 Identify misspelled word
2.0 Correct Misspelled Word

Plan 0: Do 1 and then 2
Plan 2.0: Use method 1 or 2

How do you incorporate alternatives?

0. Correct Spelling in Document

1.0 Identify misspelled word
2.0 Correct Misspelled Word

Plan 0: Do 1 and then 2

Alternates for correcting a misspelled word

- Sub-goal 2: Correct a misspelled word
- Alternate methods:
  - Highlight word, delete word, re-type word
  - Place cursor at start/end of word, move cursor to incorrect letter, delete incorrect letter(s), re-type correct letter(s)
  - Place cursor somewhere in word, right-click to bring up possible correct spellings, scroll to desired option, click on option
Choice of methods

Plan 2.0 Do 2.1, 2.2, OR 2.3

- 2.0 Correct Misspelled Word
  - 2.1 Highlight/Delete/retype
  - 2.2 Place cursor at incorrect letter/retype
  - 2.3 Use suggested spellings option

Method 1 (Plan 2.1)

- 2.1 Highlight/Delete/retype
  - 2.1.1 Highlight Word
  - 2.1.2 Delete Word
  - 2.1.3 Re-type word

Method 2 (Plan 2.2)

- 2.2 Place cursor at incorrect letter/retype
  - 2.2.1 Place cursor at start/end of word
  - 2.2.2 Move cursor to incorrect letter
  - 2.2.3 Delete incorrect letter(s)
  - 2.2.4 Re-type incorrect letter(s)

Spreadsheet version

0. CORRECT SPELLING IN DOCUMENT
1.0 Identify misspelled word
2.0 Correct misspelled word (using Method 1 or 2

METHOD 1 (2.1)
  - 2.1.1 Highlight word
  - 2.1.2 Delete word
  - 2.1.3 Re-type word

METHOD 2 (2.2)
  - 2.2.1 Place cursor at start/end of word
  - 2.2.2 Move cursor to incorrect letter
  - 2.2.3 Delete incorrect letter(s)
  - 2.2.4 Re-type incorrect letter(s)
Adding cognition

- Operators at the level of elementary operations of
  - Cognition
  - Perception
  - Motor acts
- Can be referred to as “CPM”

Adding cognition/perception/motor

1.0 Identify Misspelled Word
   1.1 Look at word
   1.2 Read word
   1.3 Decide if correctly spelled

Adding cognition/perception

1.0 Identify Misspelled Word
   1.1 Look at word
   Motor (move eyes)
   1.2 Read word
   Perception (interpret)
   1.3 Decide if correctly spelled
   Cognition (match to words in memory)

Adding timing

- Times reflect
  - Expert performance
  - Routine behavior
- Times derived from observational data
Operators

<table>
<thead>
<tr>
<th>Operator</th>
<th>Shorthand</th>
<th>Time to Execute Operator</th>
</tr>
</thead>
<tbody>
<tr>
<td>Button (down/up)</td>
<td>B</td>
<td>.1</td>
</tr>
<tr>
<td>Home (move hand to keyboard/mouse)</td>
<td>H</td>
<td>.4</td>
</tr>
<tr>
<td>Keypress (typing)</td>
<td>K</td>
<td>.28</td>
</tr>
<tr>
<td>Mental</td>
<td>M</td>
<td>1.2</td>
</tr>
<tr>
<td>Move Eyes</td>
<td>ME</td>
<td>.5</td>
</tr>
<tr>
<td>Perceive</td>
<td>Pr</td>
<td>.32</td>
</tr>
<tr>
<td>Point</td>
<td>P</td>
<td>1.1</td>
</tr>
<tr>
<td>Read (single item)</td>
<td>R</td>
<td>.32</td>
</tr>
</tbody>
</table>

NOTE: Times refer to routine behaviors carried out by experts

Barnes, 1963

Adding timing

1.0 Identify Misspelled Word
   1.1 Look at word
      Motor (move eyes)
      .5 (ME from table)
   1.2 Read word
      Perception (interpret)
      .32?? Or .32*characters (R from table)
   1.3 Decide if correctly spelled
      Cognition (match to words in memory)
      1.2 (M from table)

Total time 2.02

Parallel versus sequential activities

- Methods described so far only allow actions to be carried out serially
- However, people can carry out some activities in parallel
- Need representation that allows this to be accounted for in developing predicted execution times
A telephone operator workstation

- A telephone company wants to replace old telephone operator workstations with a new workstation
- For this company, each second saved per call translates into a savings of $3 million/year in operating costs
- Will the new workstation be faster than the current workstation, and if so, how much will it save each year?

Gray, John & Atwood, 1993

Activity analysis

Handle-calls
Handle-call
Initiate-call
Receive-information
listen-to-beep
read-screen
Request-information
greet-customer
Enter-who-pays
Receive-information
listen-to-customer
Enter-information
enter-calling-card-number
Enter-billing-rate
enter-billing-rate

Operator: "New England Telephone may I help you?"
Customer: "Operator, bill this to 412-555-1212-1234."
Operator: hit F1 key
Operator: hit appropriate key

Activity analysis

Handle-calls
Handle-call
Initiate-call
Receive-information
listen-to-beep
read-screen
Request-information
greet-customer
Enter-who-pays
Receive-information
listen-to-customer
Enter-information
enter-calling-card-number
Enter-billing-rate
enter-billing-rate

Operator: "New England Telephone may I help you?"
Customer: "Operator, bill this to 412-555-1212-1234."
Operator: hit F1 key
Operator: hit appropriate key
Two “activities” at the CPM level

Quantitative predictions

- Use the CPM model of the benchmark call on the current workstation as a baseline
- Modify the model to reflect design decisions
  - substitute the layout, response times and procedures of the proposed workstation
- Obtain quantitative predictions of the effects on performance time

Qualitative explanations

Examine the critical path of the different models to explain the quantitative predictions. E.g., why this call is longer on the proposed than on the current workstation.

Predicted that the new workstation would be 3% SLOWER than the existing workstation!!
Telephone Operator Workstation

Proposed workstation: Start of call

- Perceive Operator
- silence (a)
- verify bill
- initiate

- 2 keystrokes removed from the slack time in the beginning of the call
- But... no change to the critical path

Telephone Operator Workstation

Current workstation: End of call

- initiate
- home
- attend
- initiate Eye Movement

Added a keystroke to the critical path, reduced the system RT. Net increase in time to handle call.

Directed design effort

- For this system, should we redesign
  - keyboards?
  - screens?
  - system response times?
Directing design effort

How much of the time is each activity on the critical path?

<table>
<thead>
<tr>
<th>Call Cat.</th>
<th>Sys RT</th>
<th>Talking</th>
<th>Keying</th>
<th>Reading</th>
<th>Ring/coin</th>
</tr>
</thead>
<tbody>
<tr>
<td>cc01</td>
<td>25%</td>
<td>40%</td>
<td>1%</td>
<td>3%</td>
<td>31%</td>
</tr>
<tr>
<td>cc02</td>
<td>3%</td>
<td>93%</td>
<td>0%</td>
<td>4%</td>
<td>0%</td>
</tr>
<tr>
<td>cc03</td>
<td>20%</td>
<td>71%</td>
<td>2%</td>
<td>6%</td>
<td>0%</td>
</tr>
<tr>
<td>cc04</td>
<td>25%</td>
<td>31%</td>
<td>6%</td>
<td>4%</td>
<td>35%</td>
</tr>
<tr>
<td>cc05</td>
<td>19%</td>
<td>44%</td>
<td>3%</td>
<td>2%</td>
<td>22%</td>
</tr>
<tr>
<td>cc06</td>
<td>12%</td>
<td>79%</td>
<td>2%</td>
<td>6%</td>
<td>0%</td>
</tr>
<tr>
<td>cc07</td>
<td>30%</td>
<td>57%</td>
<td>8%</td>
<td>3%</td>
<td>0%</td>
</tr>
<tr>
<td>cc08</td>
<td>28%</td>
<td>41%</td>
<td>23%</td>
<td>10%</td>
<td>0%</td>
</tr>
<tr>
<td><strong>Average</strong></td>
<td>16%</td>
<td>64%</td>
<td>6%</td>
<td>5%</td>
<td>8%</td>
</tr>
</tbody>
</table>

Cognitive workload:
A measure of busyness?

<table>
<thead>
<tr>
<th></th>
<th>System A</th>
<th>System B</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cognitive</td>
<td>31</td>
<td>18</td>
</tr>
<tr>
<td>Perceptual</td>
<td>14</td>
<td>8</td>
</tr>
<tr>
<td>Motor-mouse or key down only</td>
<td>6</td>
<td>0</td>
</tr>
<tr>
<td>Saccades</td>
<td>6</td>
<td>3</td>
</tr>
<tr>
<td><strong>TOTALS</strong></td>
<td>57</td>
<td>29</td>
</tr>
</tbody>
</table>

Keys to using cognitive task analysis

- Develop model to level of detail needed in baseline model
- Build model(s) of alternative designs
- Use qualitative and quantitative data to compare alternatives
  - Direct design effort
  - Specify design requirements

Learning objective

- Understand constraints on decision making
  - Imposed by people
    - Decision making processes
  - Imposed by systems design
    - And seen through cognitive task analysis
Applying this knowledge…
Lecture 14: Decision Making & Cognitive Task Analysis
Deborah A. Boehm-Davis
George Mason University

References/For Further Reading


