The Role of Cartographic Interface Complexity on Decision Making: A Preliminary Hazardous Waste Trade Case Study

Kristen Vincent*
Robert E. Roth
Sarah A. Moore
Qunying Huang
Nick Lally
Carl M. Sack
Eric Nost
Heather Rosenfeld

University of Wisconsin-Madison
July 4th, 2017    #ICC2017DC
Outline

- Introduction
- Research Questions
- Methods
- Results
- Conclusions
- Design Recommendations
Introduction

• Social, environmental, and economic problems = visual

• Increasingly interactive (Muehlenhaus 2013)

• Few empirically-derived guidelines exist for designing interactive maps to support decision making (MacEachren 2015)

• Goal: Improve decision making with interactive maps

• How?: Map-based survey with 122 participants
Research Questions

1. Does cartographic interface complexity influence the success of spatial decision making?
Interface Complexity (RQ1)

Scope: the number of interactive operators within the map

Freedom: the precision that each operator can be interactively adjusted

Harrower & Sheesley 2005, Cooper et al. 2007
Research Questions

1. Does cartographic interface complexity influence the success of spatial decision making?

2. Does geographic decision complexity influence the success of decision making when using an interactive map?
Decision Complexity (RQ2)

Criteria: The factors that go into making a decision

Outcomes: Potential decision choices (i.e., sites)

Crossland et al. 1995, Jelokhani-Niaraki & Malczewski 2015
Research Questions

1. Does cartographic interface complexity influence the success of spatial decision making?

2. Does geographic decision complexity influence the success of decision making when using an interactive map?

3. Is the influence of cartographic interface complexity and geographic decision complexity dependent upon the expertise of the decision maker?
Methods: Case Study

- North American hazardous waste trade
- Hazardous materials between Canada, Mexico, and the U.S.
- Ignitable, corrosive, reactive, and/or toxic
- Manufacturing by-products
- Batteries
- Acetone
- Paint

gеography.wisc.edu/hazardouswaste
Methods: Materials

• 2x2 factorial design
• Interface complexity (*simple, complex*)
• Decision complexity (*simple, complex*)
• Texas and Ohio
• 2 decision scenarios
  • Manager of a hazardous waste facility
    • Rank preference for doing business with
  • Regulator at the EPA
    • Rank urgency for site visits
# Methods: Materials

<table>
<thead>
<tr>
<th>Interface Complexity (Factor 1)</th>
<th>Simple</th>
<th>Complex</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Basic slippy map</td>
<td>Shneiderman’s Mantra</td>
</tr>
<tr>
<td>• Pan</td>
<td></td>
<td>• Pan</td>
</tr>
<tr>
<td>• Zoom</td>
<td></td>
<td>• Zoom</td>
</tr>
<tr>
<td>• Retrieve</td>
<td></td>
<td>• Retrieve</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Decision Complexity (Factor 2)</th>
<th>3 Criteria</th>
<th>5 Criteria</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Kilograms imported</td>
<td></td>
<td>• Kilograms imported</td>
</tr>
<tr>
<td>• Percent non-white population</td>
<td></td>
<td>• Percent non-white population</td>
</tr>
<tr>
<td>• Air quality watches per capita</td>
<td></td>
<td>• Air quality watches per capita</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Percent in poverty</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Soil permeability</td>
</tr>
</tbody>
</table>
Methods: Map Survey

MapStudy: github.com/uwcart/mapstudy

122 Participants
110 Non-experts
12 Experts
Results: Overall Decision Performance

- 56.6% of decisions were statistically correct
- Difficulty: 2.3 / 5
  - 5 is very difficult
- Confidence: 4.1 / 5
  - 5 is very confident
- 99.6% interacted
- 5,900 total interactions!
- Interaction strategies emerged

Location was not a factor (Texas vs. Ohio)

Order was not a factor (1st vs. 2nd)
Results: Interface Complexity

Simple

- **68.4%** of decisions were statistically correct*
- Difficulty: **2.1** / 5*
- Confidence: **4.2** / 5*

Complex

- **41.7%** of decisions were statistically correct*
- Difficulty: **2.5** / 5*
- Confidence: **3.9** / 5*

With simple map, participants were:
- More correct
- Thought decision was easier
- More confident
# Interactions: Interface Complexity

## Interface Complexity

<table>
<thead>
<tr>
<th>Operator</th>
<th>Sample Size</th>
<th>Extensiveness</th>
<th>Frequency</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Descriptive</td>
<td>Total</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Percentage</td>
<td>Percentage</td>
</tr>
<tr>
<td>Retrieve</td>
<td>136</td>
<td>136 / 136</td>
<td>100</td>
</tr>
<tr>
<td>Pan</td>
<td>136</td>
<td>95 / 136</td>
<td>69.9</td>
</tr>
<tr>
<td>Zoom</td>
<td>136</td>
<td>36 / 136</td>
<td>26.5</td>
</tr>
<tr>
<td>Overall</td>
<td>136</td>
<td>136 / 136</td>
<td>100</td>
</tr>
</tbody>
</table>

### Simple

- **Retrieve**: 108 interactions, 87 out of 108 (80.6%) used, 1,172 total, Avg per Decision: 10.85, Standard Deviation: 24.54
- **Pan**: 108 interactions, 94 out of 108 (87.0%) used, 918 total, Avg per Decision: 8.50, Standard Deviation: 89.76
- **Overlay**: 108 interactions, 89 out of 108 (82.4%) used, 664 total, Avg per Decision: 6.15, Standard Deviation: 55.25

### Complex

- **Zoom**: 108 interactions, 42 out of 108 (38.9%) used, 207 total, Avg per Decision: 1.92, Standard Deviation: 29.34
- **Filter**: 108 interactions, 35 out of 108 (32.4%) used, 334 total, Avg per Decision: 3.09, Standard Deviation: 39.09
- **Overall**: 108 interactions, 107 out of 108 (99.1%) used, 3,295 total, Avg per Decision: 30.51, Standard Deviation: 103.20

<table>
<thead>
<tr>
<th>Operator</th>
<th>Sample Size</th>
<th>Extensiveness</th>
<th>Frequency</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Total</td>
<td>Avg per Decision</td>
</tr>
<tr>
<td></td>
<td></td>
<td>243/244</td>
<td>99.6%</td>
</tr>
</tbody>
</table>

---

*Note: Values and calculations are illustrative and for demonstration purposes.*
Interactions: Interface Complexity

- Retrieve frequency different between *simple* and *complex*

- 2 interaction strategies
  - *Simple*: retrieve-based (more successful)
    - All criteria, 1 outcome
  - *Complex*: overlay-based
    - 1 criteria, all outcomes

- *Interface complexity had significant impact on decision making*
Results: Decision Complexity

Simple
- 54.1% of decisions were statistically correct
- Difficulty: 2.3 / 5
- Confidence: 4.0 / 5

Complex
- 59.0% of decisions were statistically correct
- Difficulty: 2.2 / 5
- Confidence: 4.1 / 5

No difference in:
- Correctness
- Difficulty
- Confidence

*Interface complexity = important!
# Interactions: Decision Complexity

## Decision Complexity

### Simple

<table>
<thead>
<tr>
<th>Operator</th>
<th>Sample Size</th>
<th>Extensiveness</th>
<th>Frequency</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Descriptive</td>
<td>Total</td>
</tr>
<tr>
<td>Retrieve</td>
<td>122</td>
<td>112 / 122</td>
<td>91.8</td>
</tr>
<tr>
<td>Pan</td>
<td>122</td>
<td>93 / 122</td>
<td>76.2</td>
</tr>
<tr>
<td>Overlay*</td>
<td>54</td>
<td>43 / 54</td>
<td>79.6</td>
</tr>
<tr>
<td>Zoom</td>
<td>122</td>
<td>37 / 122</td>
<td>30.3</td>
</tr>
<tr>
<td>Filter*</td>
<td>54</td>
<td>14 / 54</td>
<td>25.9</td>
</tr>
<tr>
<td>Overall</td>
<td>122</td>
<td>122 / 122</td>
<td>100</td>
</tr>
</tbody>
</table>

### Complex

<table>
<thead>
<tr>
<th>Operator</th>
<th>Sample Size</th>
<th>Extensiveness</th>
<th>Frequency</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Descriptive</td>
<td>Total</td>
</tr>
<tr>
<td>Retrieve</td>
<td>122</td>
<td>111 / 122</td>
<td>91.0</td>
</tr>
<tr>
<td>Pan</td>
<td>122</td>
<td>96 / 122</td>
<td>78.7</td>
</tr>
<tr>
<td>Overlay*</td>
<td>54</td>
<td>46 / 54</td>
<td>85.2</td>
</tr>
<tr>
<td>Zoom</td>
<td>122</td>
<td>41 / 122</td>
<td>33.6</td>
</tr>
<tr>
<td>Filter*</td>
<td>54</td>
<td>21 / 54</td>
<td>38.9</td>
</tr>
<tr>
<td>Overall</td>
<td>122</td>
<td>121 / 122</td>
<td>99.2</td>
</tr>
<tr>
<td>Total</td>
<td>244</td>
<td>243/244</td>
<td>99.6%</td>
</tr>
</tbody>
</table>

Total

Table containing decision complexity metrics for various operators.
Interactions: Decision Complexity

- No differences between *simple* and *complex*

*Decision complexity had no significant impact on decision making*
Results: Expertise

Experts
- 58.3% of decisions were statistically correct
- Difficulty: 2.4 / 5
- Confidence: 3.6 / 5*

Non-Experts
- 56.4% of decisions were statistically correct
- Difficulty: 2.3 / 5
- Confidence: 4.1 / 5*

Non-experts were:
- More confident
# Interactions: Expertise

## Hazardous Waste Expertise

### Experts

<table>
<thead>
<tr>
<th>Operator</th>
<th>Sample Size</th>
<th>Extensiveness</th>
<th>Frequency</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Descriptive</td>
<td>Total</td>
</tr>
<tr>
<td>Retrieve</td>
<td>24</td>
<td>20 / 24</td>
<td>346</td>
</tr>
<tr>
<td>Pan</td>
<td>24</td>
<td>20 / 24</td>
<td>174</td>
</tr>
<tr>
<td>Overlay*</td>
<td>12</td>
<td>12 / 12</td>
<td>114</td>
</tr>
<tr>
<td>Zoom</td>
<td>24</td>
<td>9 / 24</td>
<td>34</td>
</tr>
<tr>
<td>Filter*</td>
<td>12</td>
<td>5 / 12</td>
<td>41</td>
</tr>
<tr>
<td>Overall</td>
<td>24</td>
<td>24 / 24</td>
<td>709</td>
</tr>
</tbody>
</table>

### Non-Experts

<table>
<thead>
<tr>
<th>Operator</th>
<th>Sample Size</th>
<th>Extensiveness</th>
<th>Frequency</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Descriptive</td>
<td>Total</td>
</tr>
<tr>
<td>Retrieve</td>
<td>220</td>
<td>203 / 220</td>
<td>2,810</td>
</tr>
<tr>
<td>Pan</td>
<td>220</td>
<td>169 / 220</td>
<td>1,238</td>
</tr>
<tr>
<td>Overlay*</td>
<td>96</td>
<td>77 / 96</td>
<td>550</td>
</tr>
<tr>
<td>Zoom</td>
<td>220</td>
<td>69 / 220</td>
<td>300</td>
</tr>
<tr>
<td>Filter*</td>
<td>96</td>
<td>30 / 96</td>
<td>293</td>
</tr>
<tr>
<td>Overall</td>
<td>220</td>
<td>219 / 220</td>
<td>5,191</td>
</tr>
<tr>
<td>Total</td>
<td>244</td>
<td>243 / 244</td>
<td>5,900</td>
</tr>
</tbody>
</table>

Hazardous Waste

Experts

Non-Experts
Interactions: Expertise

Extensiveness and Frequency

- Very different!
- *Experts*: overlay
- *Non-experts*: retrieve
- Resembles interaction strategies

*Experts not significantly worse, but interacted differently, so expertise matters!"
Conclusions

• Interface complexity affected decision making
  • Simple = better
  • More functionality not always better

• Decision complexity did not affect decision making
  • Simple vs. complex = no difference
  • Additional information may clarify

• User expertise did not affect decision making
  • Experts less confident, less likely to act
  • Interact differently
Design Recommendations

• Simple, easy to use interface is best
• Include retrieve!
• Provide data for multiple criteria for each outcome (site)
• Increased interactivity alright for experts
Thank You!

- This project was supported in part by:
  - NSF Award #1539712
  - NSF Award #1555267
  - UW-Madison Geography Department Trewartha Research Grant
  - AAG Cartography Specialty Group Master’s Thesis Research Grant
  - Wisconsin Alumni Research Foundation
User Expertise (RQ3)

- **Education**: amount of formal education with the subject
- **Experience**: amount of time with the subject
- **Familiarity**: self-proclaimed knowledge of the subject

Expertise can be with the:

- **Tool** (interactive map)
- **Domain** (decision topic)
- **Computers** (device user is working with)

Roth 2009
 Related Work

RQ1: Interface Complexity

RQ2: Decision making

RQ3: Expert vs. Non-Expert

MacEachren 1994
## Decision Making Stages

<table>
<thead>
<tr>
<th>Information Seeking</th>
<th>Sensemaking</th>
<th>Action</th>
</tr>
</thead>
<tbody>
<tr>
<td>(Identifying the Need)</td>
<td>(Determining Problem Context and Alternatives)</td>
<td>(Identify Best Route, Given Obtained Information)</td>
</tr>
</tbody>
</table>
Related Work

- Slippy map
  - Pan, zoom, retrieve

- Shneiderman’s Visual Information Seeking Mantra (Shneiderman 1996)
  - Overview first, zoom and filter, details on demand

- Roth (2013) work operator primitives
Methods: Preparatory Research

1. FOIA requests to EPA
Methods: Preparatory Research

1. FOIA requests to EPA
2. Design Challenge 2015
3. Semi-structured interviews with domain experts (n=3)
4. Pilot study with UW-Madison Cartography Lab students (n=8)
Methods: Participants

- 122 Participants
  - 110 Non-experts (Amazon Mechanical Turk)
  - 12 Experts (n=3 from the EPA/state government and n=9 from Design Challenge 2015)

- English as 1st language

- Currently living in the United States (but not Texas or Ohio)

- 18 years or older

- Non-mobile devices
Methods: Procedure

- Consent & Eligibility Pages
- Example Map
- Decision #1
  - Confidence, Difficulty, & Decision Making
- Map Reading Tasks
- Decision #2
  - Confidence, Difficulty, & Decision Making
- Exit Survey
Methods Procedure

- Amazon Mechanical Turk for *non-experts*
- Email for *experts*
- Random group and order assignments
- Interface complexity varied between groups
- Decision complexity varied within groups
- Recorded survey answers AND interaction logs
Methods: Measures and Analysis

• Correctness
  • Kendall Rank Correlation Coefficient
    (Crossland et al. 1995, Mennecke et al. 2000, Kiker et al. 2005)

• Confidence
  • z-test
  • t-test

• Difficulty
  • z-test
  • t-test

• Interaction Logs
  • Frequency (t-test)
  • Extensiveness (t-test)
Conclusions: Interactions

- Interface complexity: 2 interaction strategies
  - *Simple*: retrieve-based (more successful)
    - All criteria, 1 outcome
  - *Complex*: overlay-based
    - 1 criteria, all outcomes

- Decision complexity: no difference
  - Additional information may clarify

- *Experts* and *Non-Experts*: Differences
  - *Experts*: overlay

- *Non-experts*: retrieve