Tactical Tomahawk: strike planning, monitoring and control

Summary of Operator Interface
Prototypes Developed at UVA from 2000-2005

Dr. Stephanie Guerlain
University of Virginia
guerlain@virginia.edu
(434) 924-4438
www.sys.virginia.edu/hci

Stephanie Guerlain, Ph.D.
Relevant Papers


Proposed Tactical Tomahawk Missions

- Default Mission
- Flex Mission
- Emergent Mission

Launch Area

Preplanned Health and Status points

Guidance Waypoint

Time-critical (emergent) Target

Branch Point

Alternate (Flex) Target

Loiter Pattern

Default Target
University of Virginia Role

(Funding from NSWC-DD via ONR KSA FNC)

Conduct early research to feed into Navy systems.

UVA focused on:

- Pre-launch planning
- Launch
- In-flight monitoring and control
- Coordination across multiple platforms/higher-level commander
General Goals:

- Support situation awareness and rapid decision making
- Study level of automation issues
- Develop flexible, interactive automation
Design Philosophy

Two main strategies for aiding human-control behavior:

1. **An algorithmic approach** which determine the course of action based on constraints and objectives.

2. **A representational approach** which represents constraints and objectives through the use of computer-generated, possibly graphical, information displays.

*Understanding the Environment through Interface Design*
Design Philosophy

We develop displays for manually performing tasks rather than relying solely on “black box” algorithms.

- Allows for tradeoffs in decisions
- Allows for exceptions to any “rules”
- Allows for a view into the black box if/when algorithms are used.

→ User maintains situation awareness
Design Approach

- Domain Study
- Subject Testing & Analysis
- Iterate
- Interface Development
Post-launch execution prototypes

Initial prototype

Willis (2001)

Tactical Tomahawk Interface for Monitoring and Retargeting (TTIMR)

Cummings (2003)

Command Overview – 1st generation

Jones and Allen (2004)

Command Overview – 2nd generation

O’Hargan and Rached (2004)
Pre-launch planning prototypes

Mission Planning

Mission to Launch Platform Assignment

.xml scenario files
Summary

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- Implemented initial TTWCS prototype
- Found that timebar is critical
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- Implemented TTIMR, with a decision matrix
- Found performance degradation for *individual operator* at 16 missiles
- Identified potential issues with chat fixation and serial processing

**Cushing (2003)**
- Implemented a mission-platform assignment system
- Found improved performance on interfaces with an overview vs. without

**Jones (2003)**
- Compared TTIMR prototypes with and without a decision matrix
- Found improvement in decision time and accuracy with DM

**Allen (2004)**
- Implemented Command Overview, with target –specific monitoring displays
- Examined potential teaming structures with TTIMR and CO
- Peer teams required less time per assignment
- Supervisor/subordinate teams produced more accurate assignments

**Upcoming Experiments**
- New data visualizations
- Expand to more UV types
- Human-automation interaction strategies for path planning, mission planning, and in-flight control
Interface Design Approach

User Analysis

Task Analysis
- Object Definition
- Retargeting Task Flowchart
- Scenarios
- Functional Requirements

Tools
- Component Prototypes
- System Prototypes
TTWCS Operator User Analysis

Generic levels of user experience

- Novice
- Advanced beginner
- Competent performer
- Expert

• TTWCS operators will coordinate with a multi-tasking Land Warfare or Tomahawk Strike Coordinator.
Players for a Single Strike

Strike Controller

Platforms participating in strike

Team of controllers on single platform

Individual Controller
Distributed Unmanned Vehicle Command and Control Framework

Battlefield
- Target
  - Field Intel
- Vehicle
  - Retargeting Commands

Strike Control
- Strike Visualization and Interaction
  - Strike Planner:
    * Concerned with TARGET status
    * Understand tactical situation
    ^ Analyze intel
    ^ Update target characteristics based on intel
  - In-Flight Monitor:
    * Concerned with VEHICLE status
    * Respond to commands
    * Control vehicle(s) post-launch
    * Make retargeting selections
  - Retargeting Orders
  - Notifies of problems

Strike Coordinator:
- Authorize new launches
- Select/edit (routes) for targets
- Assign missions to launch platforms based on predicted load-outs and locations

Launch Requests

Local Area Coordinator and Shooters:
- Pick primary and backup vehicles to use
- Load mission data into vehicles
- Plan/edit routes
- Launch vehicles based on timetable

Launch Order

Use current design

*Simulation/scenarios already developed at UVA
^Simulation/scenarios planned
Interface Design Approach

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Tools
- Component Prototypes
- System Prototypes
Domain Objects & Properties

Object Types
- Vehicles
- Targets
- Vessels
- Constraints
- Missions
- Battlegroups
- Campaigns
Interface Design Approach

User Analysis

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- Scenarios
- Functional Requirements

Tools

- Component Prototypes
- System Prototypes
Emergent Target Courses of Action
Retargeting Task Flowchart

Reduce the solution space (all inflight missiles) to candidate alternatives

<table>
<thead>
<tr>
<th>COA Identification – Rigid Constraints</th>
</tr>
</thead>
<tbody>
<tr>
<td>Warhead-target match</td>
</tr>
<tr>
<td>Fuel available to reach target</td>
</tr>
<tr>
<td>Proximity to reach e-target prior to expected movetime</td>
</tr>
<tr>
<td>Missile not already retargeted^</td>
</tr>
</tbody>
</table>

Rank alternatives

<table>
<thead>
<tr>
<th>COA Comparison – Minimization Objectives</th>
</tr>
</thead>
<tbody>
<tr>
<td>Time of impact if retargeted (TIIR)</td>
</tr>
<tr>
<td>Priority opportunity cost (POC)</td>
</tr>
<tr>
<td>Loiter opportunity cost (LOC)</td>
</tr>
</tbody>
</table>

Consensual Automation (Level 3)

Full Automation (Level 5)
Interface Design Approach

User Analysis

Task Analysis

Object Definition

Retargeting Task Flowchart

Scenarios

Functional Requirements

Tools

Component Prototypes

System Prototypes
Scenarios → Functional Requirements

- 3 vehicles required
- 1-minute separation required
- Time of impact is flexible
- Vehicles in loiter patterns
- Unplanned, restrictive ACM active in 5 minutes

**Functional Requirements Block**
- Conduct what-if analysis; query results
  - Determine modified (straight-line) times of impact
  - Forecast and display waypoint crossing times
  - Compare events
  - View modified route
Interface Design Approach

User Analysis

Task Analysis

Object Definition

Retargeting Task Flowchart

Scenarios

Functional Requirements

Tools

Component Prototypes

System Prototypes
Functional Requirements Headers

1.0 Monitor and communicate status
2.0 Conduct queries to the system
3.0 Develop and modify plans
4.0 Facilitate retargeting decisions

253 lines of functional requirements stem from these headers
Interface Design Approach

User Analysis

Task Analysis - Decomposition
- Object Definition
- Retargeting Task Flowchart
- Scenarios
- Functional Requirements

Tools - Synthesis
- Component Prototypes
- System Prototypes
Component prototypes

- Symbology and icons
- Missile routes
- Missile-target assignments
- Time bars
- Coverage zones
- Decision support tools
**Components – Icons and Naming**

### Targets

- **Tgt:** T106-D7-S
- **Type:** Default
- **Prty:** 7
- **W/h:** Soft
- **Msl:** M013-D7-S

### Missiles

- **Msl:** M010-D7-S
- **Type:** Default
- **Prty:** 7
- **W/h:** Soft
- **Tgt:** T122-D7-S
  (Flex Target: T213-F4-S)

Symbols conform to the DOD symbology standard (MIL-STD-2525b) to the largest degree possible.
“Straight-line time of impact” (STI) accounts for restrictive airspace control measures and threats, maneuver time for missile turnaround, and vectoring for required attack heading.
Components – Timebar Section During E-targeting

Current Time

E-target time of appearance (exact)
E-target expected movetime (probabilistic)

Candidates

12:08:04
Coverage Zones

- 4 missiles
- 9-minute coverage zone time factor selected
- Significant gap in coverage of area of operations
Interface Design Approach

User Analysis

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Tools
- Component Prototypes
- System Prototypes
Flex Targeting Event

- 2 missiles
- Common flex target
- Flex target increase in priority causes a retargeting event
Emergent Targeting Event

- 4 missile candidates
- Single emergent target
- Difficult comparison without decision support
Hypotheses

- Situational awareness and response times will worsen with:
  - increased number of total objects (missiles plus targets)
  - increased number of candidate missiles
Subject Testing

20 subjects (graduate engineering students)

1. Training:
   2.0 hours classroom training
   Written, graded quiz
   Individual review

2. One practice test run
3. Two test runs

Each run:

<table>
<thead>
<tr>
<th>Initiation</th>
<th>Monitor experiment</th>
<th>Retarget experiment</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 minute</td>
<td>7 minutes</td>
<td>4 minutes</td>
</tr>
<tr>
<td></td>
<td>7 questions</td>
<td>4 questions</td>
</tr>
</tbody>
</table>

Vary:

- # of missiles plus targets (10 vs. 20)
- # of candidate missiles (2 vs. 4)
- Presence of coverage zone feature

Measure:

- Response time, situation awareness
Monitor Results

Model: \[ \text{Response Time} = \beta_1(\text{Objects}) + \beta_2(\text{CZ}) + \beta_3(\text{Objects} \times \text{CZ}) + \epsilon \]

<table>
<thead>
<tr>
<th>Question</th>
<th>R-Square (model)</th>
<th>Significant Terms</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>.0024</td>
<td>None</td>
<td>-</td>
</tr>
<tr>
<td>2</td>
<td>.0305</td>
<td>None</td>
<td>-</td>
</tr>
<tr>
<td>3</td>
<td>.0664</td>
<td>None</td>
<td>-</td>
</tr>
<tr>
<td>4</td>
<td>.2914</td>
<td>Objects</td>
<td>.0023</td>
</tr>
<tr>
<td>5</td>
<td>.1947</td>
<td>Objects</td>
<td>.008</td>
</tr>
<tr>
<td>6</td>
<td>.3095</td>
<td>Objects</td>
<td>.0006</td>
</tr>
<tr>
<td>7</td>
<td>.1518</td>
<td>Coverage Zones</td>
<td>.0377</td>
</tr>
</tbody>
</table>

Model: \[ \text{SA Score} = \beta_1(\text{Objects}) + \beta_2(\text{CZ}) + \beta_3(\text{Objects} \times \text{CZ}) + \epsilon \]

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<th>R-Square (model)</th>
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<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>7*</td>
<td>.3800</td>
<td>Coverage Zones</td>
<td>&lt;.0001</td>
</tr>
</tbody>
</table>

1. Say aloud the Missile ID number of the missile that would reach its default target first if all missiles were commanded to go directly to their default target.
2. Say aloud the Missile ID numbers of all the missiles that will impact before 12:30.
3. In the timebar section, point to the time bar associated with the southern most missile.
4. Say aloud the number of targets that require or prefer more than one missile.
5. Say aloud the Missile ID numbers of soft warhead missiles servicing targets with a priority of 6 or more.
6. How many missiles are you monitoring right now?
7. Describe or show the general areas in which you could NOT service an e-target whose expected move time is 12 minutes from now.
Experimental Conclusions

• Timebar an effective tool for temporal comparisons
• UI not sufficient for retargeting and other comparison decisions
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Upcoming Experiments
- New version of command overview
- Will compare with decision matrix and extend teaming experiments
The TTIMR Project

• Greatly expanded initial prototype, now called, the Tactical Tomahawk Interface for Monitoring and Retargeting (TTIMR)

• Initial research focus – individual performance
  – *What are ballpark response times?*
  – *How many missiles can one person be reasonably expected to control?*
  – *How does increasing workload affect performance and situational awareness?*
Tactical Tomahawk Interface for Monitoring and Retargeting (TTIMR)

Retargeting Display

Monitor Map

(Reads in .xml strike files)
An Emergent Target Appeared
A Missile Failed

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University of Virginia
Human-Computer Interaction Lab
Stephanie Guerlain, Ph.D.
Two Emergent Targets at Once
Chat Box
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‘04 Research

• Studied the effectiveness and impact of various prototype features

• Expanded the simulation to include teamwork issues
  – *Multiple controllers for a single strike*
  – *Study effect of team size and team structure on performance*
Developed a New “Command Overview” (CO) User Interface

**Target-Centric View with Timebar**

**Spatio-Temporal Display**

*Written in Java and connects to TTIMR through Shockwave Multi-User Server*
Designed to track target status & intelligence
(presumably commander not interested in missiles per se)
and to update Target requirements

Tomahawk Command Overview

<table>
<thead>
<tr>
<th>Target</th>
<th>Required/Actual</th>
<th>Missiles</th>
<th>Priority</th>
<th>WOO</th>
<th>Intel</th>
<th>Update</th>
</tr>
</thead>
<tbody>
<tr>
<td>T001U-DL</td>
<td>2 / 2</td>
<td>LM001U-DL</td>
<td>L</td>
<td>16</td>
<td>7:22</td>
<td>Submit Cancel</td>
</tr>
<tr>
<td>T002U-DM</td>
<td>1 / 1</td>
<td>RM005U-DM</td>
<td>M</td>
<td>16</td>
<td>7:10</td>
<td>Submit Cancel</td>
</tr>
<tr>
<td>T003U-DH</td>
<td>2 / 2</td>
<td>RM003U-DH</td>
<td>H</td>
<td>16</td>
<td>7:06</td>
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</tr>
<tr>
<td>T004P-DH</td>
<td>3 / 3</td>
<td>FM002P-DH</td>
<td>H</td>
<td>16</td>
<td>6:51</td>
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<tr>
<td>T005S-DH</td>
<td>1 / 1</td>
<td>FM004S-DH</td>
<td>H</td>
<td>16</td>
<td>7:31</td>
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</tr>
<tr>
<td>T006S-DM</td>
<td>1 / 1</td>
<td>RM007S-DM</td>
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<td>16</td>
<td>7:19</td>
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<tr>
<td>T007S-DL</td>
<td>1 / 1</td>
<td>LM006S-DL</td>
<td>L</td>
<td>16</td>
<td>8:23</td>
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</tr>
<tr>
<td>T012S-DH</td>
<td>1 / 1</td>
<td>FM012S-DH</td>
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<td>16</td>
<td>7:37</td>
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<tr>
<td>T013S-DH</td>
<td>2 / 2</td>
<td>RM014S-DH</td>
<td>H</td>
<td>16</td>
<td>7:26</td>
<td>Submit Cancel</td>
</tr>
</tbody>
</table>

UTC: 07:00:00Z

Diagram showing Tomahawk Command Overview with specific targets and their status.

• **Purpose:**
  – To examine the division of collaborative tasks to maximize operator efficiency and accuracy
  – To compare Supervisor/Subordinate and Peer team structures
Team Structure and Size - Experiments

- Experiments (39 college students)
  
  - Team Structure Experiment
    - 3 peers each with control over 10 missiles
    - 2 peers each with control over 15 missiles plus 1 supervisor watching over all 30

  - Team Size Experiment
    - Comparison of team size (two vs. three person)
      - Two team members - 15 missiles each
      - Three team members - 10 missiles each
    - Teams used only the TTIMR interface
    - Teams were all peer groups
Team Structure and Size – Results

• Results
  – Different team structures
    • Trade off between decision time and accuracy
    • Peer teams required less time per assignment than supervisor/subordinate
    • Supervisor/subordinate teams produced more accurate assignments
    • Target variable was also significant
      – Targets 1 and 2 required less time to solve and were correct more often than 3, 4 and 5
  – Different team sizes
    • No significant difference between performance of 2-person vs. 3-person teams when total strike = 30 missiles
    • Target variable was significant
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• New data visualizations
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Planned ’05-’06 R&D

• Create displays for large strikes (100’s of vehicles)

• Add specification of no-fly zones, flight corridors, launch platform movements in x,y,(z), (time) to planning and run-time scenarios

• Add in human-automation interaction for “smart” route planning and re-planning based on dynamic situation updates
Potential ’05-’06 R&D

• Development of “smart” chat user interfaces.
• Integration of other strike planning tasks, test of real-time planning and execution of several strikes at a time.
• Larger team experiments with “automatic” team members who behave stochastically.
Demo this afternoon…