Applying a Work-Centred Exploratory Design Framework to Joint Fires Coordination

Bruce A. Chalmers
Maritime Information & Combat Systems
Defence R&D Canada – Atlantic
Dartmouth, NS, Canada
bruce.chalmers@drdc-rddc.gc.ca

Lora Bruyn Martin, Julie Famewo, Tamsen Taylor, & Michael Matthews
Humansystems Inc.
Guelph, ON, Canada
lbruyn@humansys.com

15th ICCRTS, 22-24 June, 2010
Outline

- Complex Sociotechnical System Design Problems
- Concept Design Framework
- Work Analysis Framework
- Joint Fires Coordination Capability
- Knowledge Acquisition
- Analysis Methods & Results
- Identification of Design Requirements and Design Concepts
- Developing Options for Experimentation
- Concluding Remarks
Complex Sociotechnical System Design Problems

- Open, dynamic environments
- Variable and unpredictable work demands
- Uncertainty
- High risk, high stress
- Human expertise critical
- ...

➢ Need design methods that can cope with this complexity to support C2 concept development, exploration and testing

➢ Need to provide design knowledge/outcomes about technology, process and organizational structure to structure, support, facilitate cognitive work

➢ Need methods for future systems

  - Initial system concept is only an envisioned one
  - May be no close current analogue for that future capability
  - Current system experts & system operators (if they exist) are current
Concept Design Framework

Top down, formative analysis framework for modeling cognitive work demands of sociotechnical systems

- Nonlinear problem solving framework (a la Klein)
- Both top-down/deliberative and bottom-up/serendipitous design strategies can be employed
- Exploratory prototyping
- Experimentation (e.g., HIL)

**Design Requirement**: What is needed? (solution-independent)

**Design Concept**: A potential solution
**Work Analysis Framework:**

**Emphasis on Formative Approach of Cognitive Work Analysis (CWA)**

<table>
<thead>
<tr>
<th>Phases of CWA</th>
<th>Kinds of Work Constraints</th>
<th>Modeling Tools</th>
</tr>
</thead>
<tbody>
<tr>
<td>Work Domain Analysis (WDA)</td>
<td>Purpose and affordance structure of work domain</td>
<td>Abstraction-decomposition space</td>
</tr>
<tr>
<td>Activity Analysis (Work Org A + ConTA)</td>
<td>Work organization. Goals, decisions, cognitive transformations</td>
<td>Contextual Activity Matrix Decision ladders</td>
</tr>
<tr>
<td>Strategies Analysis (StratA)</td>
<td>Ways that control tasks can be executed</td>
<td>Information Flow Maps, Tables, GDS Flow Charts</td>
</tr>
<tr>
<td>Social Organisation and Cooperation Analysis (SOCA)</td>
<td>Who carries out work and how it is shared</td>
<td>Annotations of other models</td>
</tr>
<tr>
<td>Competencies Analysis (CA)</td>
<td>Kinds of mental processing supported</td>
<td>Skills, Rules and Knowledge models</td>
</tr>
</tbody>
</table>

**Constraints and Boundary:**

- One feasible work trajectory, i.e., how work can be accomplished
- Constraint boundary

**Modeling Tools Diagram:**

- ADS
- CAM
- DL

**Annotations of Other Models:**

- G
- D
- S
**Design of a Future Joint Fires Coordination (JFC) Capability**

**Aim:** Identify design requirements and propose design concepts for a future operational level Canadian Forces JFC capability (JFCC).

With a JFC capability:

- A spotter, observer or other (land, sea or air based) will be able to request calls for fire on emerging and/or time sensitive targets.
- JFC will designate and prioritize a target for engagement by the most appropriate weapon system available within the joint force.

**JFC Roles**
- Pre-planned targets
- Mission support
- Emerging targets
- Time sensitive targets

Presentation will look principally at appln. & results of first 3 phases of CWA.
Knowledge Acquisition

- **Reviewed Relevant Literature**
  - 15 CF doctrine documents (e.g., Firepower, Field Artillery, Close Air Support, Naval Gun Support, …)
  - 4 U.S. doctrine documents (e.g., Joint Fire Support, Joint Targeting)

- **Observed battle phase of an artillery planning exercise at CFB Gagetown**
  - Simulated setting, brigade and division levels

- **Six sets of SME Sessions (1-2 days each), incl.**
  - Surveillance and Target Acquisition training instructors
  - Major (Army; Artillery Officer, TF-Kandahar Fire Support Officer)
  - Major (RC-South, HQ Chief Joint Fires and Targeting)
  - Semi-structured interview sessions to support the specific analysis methods employed
Work Analysis: Specific Analyses

- Augmented Cognitive Work Analysis (CWA)
  - Mission and Organizational Analysis
  - Work Domain Analysis (WDA)
  - Control Task Analysis (ConTA)
  - Strategies Analysis
  - Goal Directed Task Analysis (GDTA)
Mission and Organizational Analysis (MOA): Establishing the JFC System Boundary

Joint Fires Support (JFS): “Fire support is the collective and coordinated use of the fire of land and sea based indirect fire systems, armed aircraft, offensive information operations (IO) and non-lethal munitions against ground targets to support land combat operations at both the operational and tactical levels” (Firepower, 1998).

The ‘to-be’ JFC is to be part of the broader JFS system

- Conducted a mission and organizational analysis of JFS to help establish JFC system boundary
- Identified 8 functionally distinct subsystems of JFS
- JFC primarily includes functions within the Coordination, Planning, Command and Control, Communication and Intelligence subsystems of JFS
Work Domain Analysis (WDA)

**Purpose:** Model JFS system’s functional and decompositional structure in an event-independent manner

**Method:** Build a *modified* Abstraction Decomposition Space (ADS) of JFS

- Over 500 elements in final ADS

<table>
<thead>
<tr>
<th>Abstraction Hierarchy Level</th>
<th>Definition</th>
<th>Example from the ADS</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Functional Purposes</strong></td>
<td>Purpose of the work system and indications of performance</td>
<td>Continually prioritize and plan fires that will put into effect Commander’s Intent and optimize resource allocation</td>
</tr>
<tr>
<td><strong>Abstract Functions</strong></td>
<td>Underlying laws, principles, constraints, values and priorities of the work system</td>
<td>Maximize probability of achieving desired effect</td>
</tr>
<tr>
<td><strong>Purpose-Related Functions</strong></td>
<td>Processes by which Abstract Functions are carried out – found it helpful to use both types of part-whole abstraction in this level</td>
<td>Evaluate weapon capabilities and limitations; Evaluate effect of situational factors</td>
</tr>
<tr>
<td><strong>Object-Related Processes</strong></td>
<td>Capabilities and limitations related to achievement of Purpose-Related Functions</td>
<td>Planning support systems</td>
</tr>
<tr>
<td><strong>Physical Objects</strong></td>
<td>Rather than describe the physical appearance and location of equipment, as is typical at this level of the ADS (for ‘as-is’ systems), analysis provided an inventory of example objects and/or inputs used to meet</td>
<td>Weapon effectiveness table</td>
</tr>
</tbody>
</table>
Control Task Analysis (ConTA)

- **Purpose**: Decompose JFC into critical work functions relevant to JFC; model the cognitive information processing and resulting knowledge states of the control tasks involved; determine what needs to be done in the JFC work domain

- **Method**: Identification of work functions from WDA; Rasmussen’s Decision Ladder (DL)

<table>
<thead>
<tr>
<th>Target Type</th>
<th>Work Function</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pre-planned</td>
<td>Target Development and Selection</td>
</tr>
<tr>
<td>Pre-planned, Emerging</td>
<td>Capabilities Analysis</td>
</tr>
<tr>
<td>Pre-planned, Emerging</td>
<td>Force Assignment</td>
</tr>
<tr>
<td>Emerging</td>
<td>Process (Vet and Validate) Emerging Targets</td>
</tr>
<tr>
<td>Pre-planned (Mission Support)</td>
<td>Force Assignment for Mission Support</td>
</tr>
<tr>
<td>All</td>
<td>Outcome Assessment</td>
</tr>
<tr>
<td>All</td>
<td>Coordination of Components to Synchronize Actions</td>
</tr>
<tr>
<td>All</td>
<td>Management of JFC</td>
</tr>
</tbody>
</table>
**Goals**: Match capabilities to targets (on JPTL or emerging) to achieve desired effects in the most efficient and effective manner (red – pre-planned target only; blue – emerging target only; black – all target types)

- Are the selected capabilities realistic (i.e., is the required capability organic (available within our authority/organization); is it within reach [time and space] to affect the emerging time-sensitive target)? If not, is the capability available through other organizations?
- What is the likelihood of achieving the desired effect with each capability?

**ConTA – DL in Graphical Form**

**Work Function: Capabilities Analysis**

1. **Identify Present State of System**
   - **Information**: Gather/ receive information relevant to operation and desired effects
   - **Alert**: Approved JPTL: Vetted and validated emerging target(s) (intelligence re: call for fire)
2. **Define Task**
   - **Task**: Plan the steps required to perform the tasks
3. **Formulate Procedure**
   - **Procedure**: Timing and sequence of the tasks
4. **Observe Information**
   - **Information**: Gather/receive information relevant to operation and desired effects
5. **Predict Consequences**
   - **Chosen Goal**: All pre-planned targets are matched to capabilities that will achieve the desired effects with efficiency and effectiveness ranking; New emerging targets are matched to realistic (time/space/availability) capabilities that will achieve the desired effect
   - **Options**: Capabilities assigned match the desired effects; Capabilities assigned appropriately based on efficiency and effectiveness; Assigned capabilities do not provide desired effects; Assigned capabilities lead to unacceptable 2nd or 3rd order effects; Assigned capabilities realistic (i.e., not available within the CF; not available within time and space constraints)
   - **System State**: Targets not matched with capabilities or inadequate matching to reach desired effects
6. **Evaluate Performance**
   - **Options**: Risk assessment (e.g., risk to mission success, collateral damage, fratricide, risk of not achieving desired effect, risk of unintended effects); Munitions Effect Assessment (predicting damage weapons can inflict against various types of targets); Weigh the relative effectiveness and efficiency of the capabilities as they apply to target vulnerabilities and the desired effects; Consider effect of capability selection as it shapes other planning considerations such as theatre logistics; Consider capabilities relevant to circumstance of emerging target; End the capability analysis when deemed appropriate
7. **Plan what needs to be done to bring the system to the target state**

**Tasks**: Risk assessment (e.g., risk to mission success, collateral damage, fratricide, risk of not achieving desired effect, risk of unintended effects); Develop full range of capability options (including kinetic, non-kinetic, combinations) available to the commander (unconstrained) as they apply to targets; Specify capabilities through documentation (e.g., target folders); Send capability request to appropriate level of authority when required; Muni Effects Assessment (predicting damage weapons can inflict against various types of targets); Weigh the relative effectiveness and efficiency of the capabilities as they apply to target vulnerabilities and the desired effects; Consider effect of capability selection as it shapes other planning considerations such as theatre logistics; Consider capabilities relevant to circumstance of emerging target; End the capability analysis when deemed appropriate
Strategies Analysis (StratA)

- **Purpose**: Investigate the different ways control tasks can be performed in JFC. These will provide design constraints for future systems (i.e., indicate which strategies may need to be supported somehow).

- **Method**: SMEs presented with activities identified in each work function from the ConTA and probed on how they might be accomplished. Developed a flow chart of the strategy.

**Example**: Determining required capabilities (Capabilities Analysis Work Function)
Identification of Design Requirements and Design Concepts

• Top-down analyses used to identify **design requirements** (opportunities or needs for design interventions) and propose **design concepts** in the following categories:
  – Technological Aid
  – Process/ Policy
  – Organization

  **Design Requirement**: What is needed? (solution-independent)

  **Design Concept**: A potential solution

• The StratA helped identify design constraints
### Identification of Design Requirements and Design Concepts - WDA

- **Method**: Identify information requirements based on assessing each cell in ADS model

#### Abstraction Decomposition Space

<table>
<thead>
<tr>
<th>Functional Purposes</th>
<th>Abstract Functions</th>
<th>Purpose-Related Functions</th>
<th>Object-Related Processes</th>
<th>Physical Objects</th>
</tr>
</thead>
<tbody>
<tr>
<td>Information Requirements (Variables)</td>
<td>Design Requirements for each JFC function</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Abstract Function (ADS)</th>
<th>Information Requirements</th>
<th>Design Requirement</th>
<th>Design Seed</th>
</tr>
</thead>
<tbody>
<tr>
<td>Minimize kill chain timeline</td>
<td>Kill chain timeline</td>
<td>Need awareness of timeline between call for fire and response</td>
<td><strong>Technology</strong>: list of calls for fire and the time that has passed since they were received; coding could be used to indicate calls waiting for response longer than a particular time; could include urgency and priority ratings</td>
</tr>
<tr>
<td></td>
<td>Time call for fire is made</td>
<td>Time response to call is initiated</td>
<td>Time response to call for fire ends</td>
</tr>
</tbody>
</table>

“*How can we measure that?*”
### Identification of Design Requirements and Design Concepts - ConTA

- **Method**: identify decisions to be made during each DL, followed by information requirements

---

**Work Domain Analysis: ADS**

<table>
<thead>
<tr>
<th>Purpose-Related Functions</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
</tr>
</tbody>
</table>

**Control Task Analysis: Work Functions and Decision Ladders (DLs)**

**Decisions with Design Potential**

---

<table>
<thead>
<tr>
<th>Decision</th>
<th>Information Requirements</th>
<th>Design Requirement</th>
<th>Design Concept</th>
</tr>
</thead>
<tbody>
<tr>
<td>Does the current target list need to be changed?</td>
<td>Target list&lt;br&gt;Time/date target list was updated&lt;br&gt;Arrival of new information (e.g., commander’s guidance, new enemy tactics)</td>
<td>Need awareness that target list requires changing</td>
<td><strong>Technology</strong>: alert or coding indicating time/date target list was last updated&lt;br&gt;<strong>Organization</strong>: personnel/system devoted to reviewing target lists&lt;br&gt;<strong>Process</strong>: regular review of target list in conjunction with intelligence</td>
</tr>
</tbody>
</table>
Identification of Design Constraints – StratA

**Method**: Strategies identified in the analyses were examined and ways in which these strategies would constrain designs were specified.

<table>
<thead>
<tr>
<th>Decision</th>
<th>Strategies to be Supported</th>
<th>Design Constraints</th>
</tr>
</thead>
<tbody>
<tr>
<td>How can I represent space and spatial relations?</td>
<td>Paper maps</td>
<td>Systems and/or processes must accommodate the fact that different people prefer different information presentation methods.</td>
</tr>
<tr>
<td></td>
<td>Computer displays</td>
<td>Incorporate a means for easily translating information from a paper map to an electronic map, and possibly vice versa.</td>
</tr>
</tbody>
</table>
Eight overarching design themes emerged in the design landscape for the future JFCC, producing several hundred design requirements and design concepts.

Design themes were:
- Decision, planning and coordination support
- Availability of baseline and real-time information
- Data/information fusion
- Information presentation
- Streamlined communications
- Training
- Measurement of effectiveness and performance
- Team structure
Developing Options for Experimentation

• Design concepts related to some of the primary design requirements identified were aggregated and considered for experimentation potential

• Experimental conditions, metrics, measures, evaluation criteria and design hypotheses were developed for the aggregated design concepts

• Experimentation ideas were categorized based on the expected implementation schedule:
  – Short-term (within 12-18 months)
  – Medium-term (approx. 2-5 years)
  – Long-term (longer than 5 years)
Developing Options for Experimentation: An Example

<table>
<thead>
<tr>
<th>Design Requirement</th>
<th>Short-Term</th>
<th>Medium-Term</th>
<th>Long-Term</th>
</tr>
</thead>
<tbody>
<tr>
<td>Need to update plans when changes are required</td>
<td><strong>General Design Concept:</strong> Alert indicating that plans need to be changed (e.g., plans for targeting, engagement priority, etc.) (Technology)</td>
<td><strong>General Design Concept:</strong> Specialized teams with different responsibilities, such as monitoring different resources or locations, developing MOEs and MOPs versus evaluating plans using the MOEs and MOPs (Organization)</td>
<td><strong>General Design Concept:</strong> System that tracks real-time changes in weather, terrain, battlefield dynamics, resources, etc. and indicates how they pertain to plans (Technology/Process)</td>
</tr>
<tr>
<td><strong>Experimental Conditions:</strong> Alert present or absent; Varying amounts of information present with alert (e.g., explanation as to why changes are required is present or absent)</td>
<td></td>
<td><strong>Experimental Conditions:</strong> Divide team responsibilities associated with planning and updating plans in a variety of ways (e.g., functional vs. divisional team structure)</td>
<td><strong>Experimental Conditions:</strong> Varying degrees of human control over the tracking of information changes (all manual, semi-automatic, all automatic); Manipulations associated with algorithms designed to match information changes with plans (degree of change required to initiate an indicator/alert that plans may be affected)</td>
</tr>
<tr>
<td><strong>Metrics:</strong> Response time to choose to change plans; Appropriateness of plan changes implemented;</td>
<td><strong>Metrics:</strong> Team and team member responsibilities; Time required to develop and change plans; Appropriateness of plans given circumstances</td>
<td><strong>Metrics:</strong> Appropriateness of plan changes implemented;</td>
<td><strong>Metrics:</strong></td>
</tr>
</tbody>
</table>
Concluding Remarks

• The approach was very effective for identifying several hundred design requirements for the ‘to-be’ JFC work domain
  – incorporated into a specification of a potential future JFC operational capability for the Canadian Forces

• Traceability of results from knowledge acquisition through work analysis to design

• Results applicable to DRDC’s Technology Demonstrator Project on JFS
  – Experimentation options
  – Design concepts mapped to a JFS interface
  – Gap analysis of JFC tools
Any questions?