VALIDATING A MODEL OF TEAM COLLABORATION

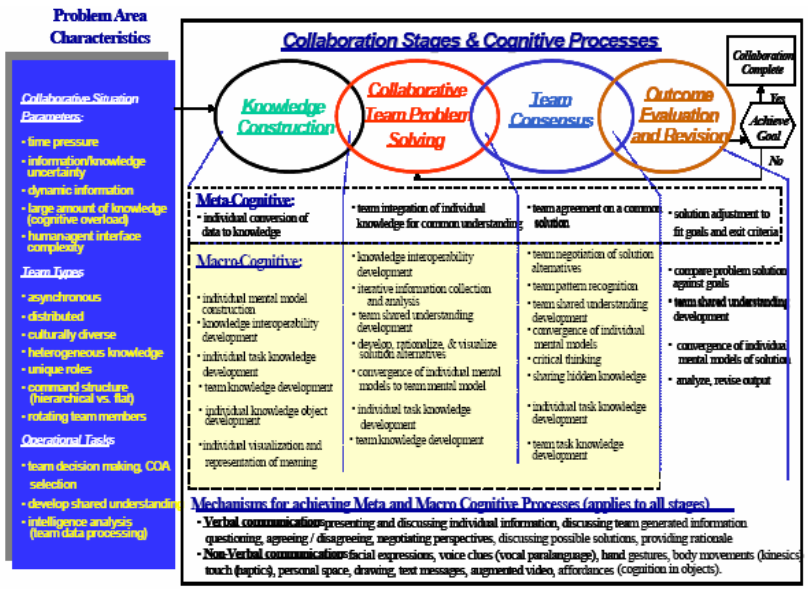
Susan G. Hutchins, Alex Bordetsky, Anthony Kendall, John P. Looney, and Eugene Bourakov

Naval Postgraduate School
Information Sciences Department
Monterey, CA 93943

NPS Testbed for Team Collaboration Model Validation

Objective:

- Better understand cognitive processes employed when teams collaborate to solve problems
- Validate and refine the model of team collaboration and determine how these processes contribute to team performance



Approach:

- Analyze team communications data captured during complex decisionmaking tasks using cognitive process definitions
- Four Maritime Interdiction Operations (MIO) experiments were conducted this year
  - Increased the cognitive complexity of the scenarios for each experiment
- Analyze team communications for four air warfare scenarios

Team Collaboration Model Validation

GOAL: Understand and improve the effectiveness of team decision-making in complex, data-rich situations by validating the model of team collaboration.

<u>Model of Team Collaboration</u>

- **Defines meta-cognitive processes that guide team collaboration**
  - **Individual conversion of data to knowledge**
  - **Team integration of individual knowledge for common understanding**
  - **Team agreement on a common solution**
  - **Solution adjustment to fit goals and exit criteria**
- **Defines information processing components the team performs to achieve each collaborative stage**
- **Emphasizes cognitive aspects of the collaboration process and includes the major cognitive processes that underlie this type of communication:**

  (1) Individual knowledge construction

  (2) Collaborative team problem solving

  (3) Team shared understanding/ consensus

  (4) Outcome evaluation and revision (Warner, Letsky, & Cowen, 2004)

Types of Problem Solving Situations

- Ill-Structured Decisionmaking Tasks
- Time Pressure
- Dynamic Information
- High Information Uncertainty
- High Cognitive Workload (large amount of knowledge)
- Human System Interface Complexity

Team Types

From Adm Cebrowski Network centric warfare

- Asynchronous
- Distributed
- Culturally Diverse
- Heterogeneous Knowledge
- Unique Roles
- Command Structure
- Rotating Team Members

Operational Tasks

- Team Data Processing
- Developing Shared Situational Awareness
- Team Decisionmaking and Course of Action Selection

Office of Naval Research
Collaboration and Knowledge Management (CKM) Program
MODEL OF TEAM COLLABORATION
Focus on Macro-Cognition (September, 2005)

Problem Area Characteristics

Collaborative Situation Parameters:

- time pressure
- information/knowledge uncertainty
- dynamic information
- large amount of knowledge (cognitive overload)
- human-agent interface complexity

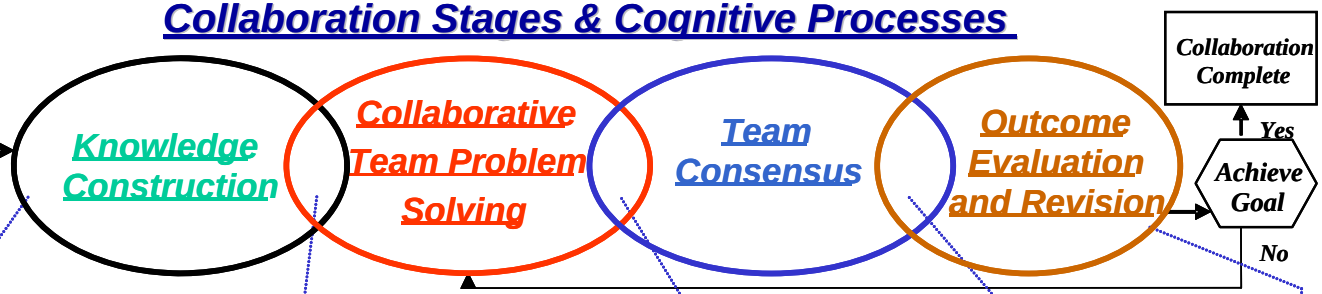
Team Types

- asynchronous
- distributed
- culturally diverse
- heterogeneous knowledge
- unique roles
- command structure (hierarchical vs. flat)
- rotating team members

Operational Tasks

- team decision making, COA selection
- develop shared understanding
- intelligence analysis (team data processing)

Collaboration Stages & Cognitive Processes



Meta-Cognitive:

- individual conversion of data to knowledge
- team integration of individual knowledge for common understanding
- team agreement on a common solution
- solution adjustment to fit goals and exit criteria

Macro-Cognitive:

- individual mental model construction
- knowledge interoperability development
- individual task, team and domain knowledge development
- individual knowledge object development
- individual visualization and representation of meaning

- knowledge interoperability development
- iterative information collection and analysis
- team shared understanding development
- develop, rationalize, & visualize solution alternatives
- convergence of individual mental models to team mental model
- individual task, team and domain knowledge development

- team negotiation of solution alternatives
- team pattern recognition
- team shared understanding development
- convergence of individual mental models
- critical thinking
- sharing hidden knowledge
- individual task knowledge development
- team task knowledge development

- compare problem solution against goals
- team shared understanding development
- convergence of individual mental models of solution
- analyze, revise output

Mechanisms for achieving Meta and MacroCognitive Processes (applies to all stages)

- **Verbal communications:** representing and discussing individual information, discussing team generated information, questioning, agreeing / disagreeing, negotiating perspectives, discussing possible solutions, providing rationale.
- **Non-Verbal communications:** facial expressions, voice clues (vocal paralanguage), hand gestures, body movements(kinesics) touch (haptics), personal space, drawing, text messages, augmented video, affordances(cognition in objects).

METHOD

- Verbatim transcripts were analyzed from two series of experiments where teams collaborated to solve a complex problem
  - Maritime Interdiction Operations (MIO)
  - Air warfare decisionmaking
- In both problem-solving tasks, assessment is particularly difficult because the available information is often incomplete or ambiguous.
  - Transcripts included communications that occurred between all team members as well as with decisionmakers at the distributed sites.
- Analyze and code team communications data using the cognitive process definitions developed by Warner, Letsky, & Cowan, 2004.
  - Focus of collaboration model is on knowledge building among team members and developing team consensus for selection of a course of action
  - Builds on previous work to validate this model (Warner, et al, 2004)
  - Similar methodology applied to two different decisionmaking scenarios

Experiment I: Maritime Interdiction Operations

- Test tech'l/oper'l challenges of developing a global Maritime Domain Security testbed
  - Wireless network for data sharing during MIO to facilitate reach back for radiation source analysis and biometric data analysis
- Evaluate use of networks, advanced sensors, and collaborative tech'y for rapid MIO.
  - Rapidly set-up ship-to-ship communications that permit them to search for radiation and explosive sources while maintaining contact with the mother ship, C2 organizations, and collaborating with remotely located sensor experts.
  - Geographically distributed command centers and subject matter experts collaborate w/ boarding party in real time to facilitate situational understanding and course of action selection.
- Boarding team boards the suspect vessel, establishes collaborative network and then begins their inspections and data collection processes.
  - Boarding officer boards the vessel with his laptop so he can collaborate with all other members of the team
  - Co-located on the ship, physically spread out (searching for contraband material and obtaining fingerprints of crew members)
  - Virtual members of the boarding team – experts at reach back centers
  - Commercial uses for certain radioactive sources, positive identification of the source in a short time is imperative
  - Pressure to conduct the MIO quickly so as to not detain the ship

MIO Team Members

- **Participating Units and Role Players**
  - **SF Police Dept, Marine Unit, initial drive sensing**
  - **Alameda County Sheriff's Office Marine Patrol unit**
  - **US Coast Guard: MIFC, Dist 11 Watch Officer, PAC Area WO, MSST Level Two capable boarding team with**
  - **Lawrence Livermore National Labs (LLNL) with portable radiation detection devices and "reach-back"/ remote analysis**
  - **DOE Radiation Assistance Program**
  - **Defense Threat Reduction Agency (DTRA), biometrics measurements of fingerprints/video imagery checked against remote databases**
  - **Special Operations Command (SOCOM), provides guidance on handling hazardous material**
  - **Boarding Officer, a Coast Guard officer**
  - **Austrian team, scenario injects via Groove and video feed**
  - **Swedish team**
  - **Medical Coordination Center, New Jersey**
  - **NPS Network Operations Center**

Maritime Interdiction Operations Scenario

- US Coast Guard ordered cutter to stop, board, and search commercial vessel of foreign origin suspected of transporting uranium enriching equipment.
- Boarding party brings radiation detection and biometric gear, drawings of dangerous equipment and people, and video recording capability.
- Data collected on suspicious material, equipment, and people and sent to specific experts at distributed reach-back centers.
  - Reach back to LLNL and DTRA to assist in identification of suspect cargo.
- Biometric team took digital prints of the crew to be compared to known criminal prints and latent prints from terrorist and crime scenes.
  - Support from the National Biometric Fusion Center used to quickly and accurately discriminate between actual vessel crewmembers and non-crew suspect persons.
- Groove collaborative workspace brought expert services into the boarding party team's tool set
  - Facilitated voice and text communications between all members of the virtual boarding party and physical boarding party.
- Requests, transmitted by text message -- taken for action, and radiation source spectrum captures were made of suspect containers that were detected to have a radiation signature presence.
- Analysis led BO to recommend vessel be quarantined for further inspection.

Air Warfare Decisionmaking

- Air warfare decisionmaking - conducted in combat information center of Navy ship
- Identification of a large number of air tracks under high time pressure
  - Multiple hypotheses regarding the level of threat they pose to the battle group due to the high level of ambiguity associated with the data
  - Nature of the data, complex judgments required, and a socio-technical environment that is characterized by high workload, and high stakes, create an challenging problem for the air warfare team
- Incoming information arrives via various sensor systems (radar, electronic support measures system, IFF, etc.), and various reports, e.g., intelligence reports, other platforms in the area pass messages regarding situation reports on various tracks
- Reports passed by team member who operates that sensor, or who receives the message, to the rest of the team over a common communications net
  - Generally heard by all other team members, all on the same comms net, although reports are typically addressed to a specific team member/s, and sometimes they are addressed to “all.”
  - Key decisionmakers -- commanding officer and the tactical action officer
- Reports on specific tracks are interleaved with reports on other tracks
- Communications are passed as soon as information is received; updated reports are passed as soon as new information is obtained
  - In a series of speech turns, five separate contacts may be discussed at various levels – initial reports, updated reports, sharing information on the response/ lack of response, by contact to action taken by the ship, etc.

Air Warfare Team Members

- Six collocated team members consisted of
  - Commanding officer (CO)
  - Tactical action officer (TAO)
  - Air warfare coordinator (AAWC)
  - Electronic warfare supervisor (EWS)
  - Identification supervisor (IDS)
  - Tactical information coordinator (TIC)
- Combat information center team members also communicate with several non-collocated information sources, e.g.
  - Battle group commander
  - Saudi air tower controller
  - Assets passing intelligence reports
  - Pilots of potential threat aircraft
  - Other ships and friendly aircraft in the vicinity of the battle group
- To gather additional information from them and keep them apprised of the unfolding scenario as they collaborate to identify and prosecute air tracks.

Air Warfare Decisionmaking

- Identification and responding to numerous contacts. CIC personnel work as a team to identify/determine if A/C poses a threat and engage threat tracks.
  - High ambiguity can often make threat assessment a very difficult task.
  - Many pieces of data fit multiple hypotheses
  - Global response choices (engage, monitor, do nothing) largely determined by ship's orders and the current geopolitical situation
  - Specific actions (such as, change course, issue verbal warnings, illuminate with radar, challenge with other sensors, etc.) depend on local conditions and the relative positions of the inbound contact of interest and own-ship
    - Determining which actions are likely to be effective depends on maintaining an accurate assessment which requires continually updating based on iterative situation assessments
- Critical air contacts ident'd based on ambiguous info. under time pressure
- High mental workload -- constant stream of info. must be continuously evaluated, e.g., when the info often pertains to several different air contacts
- Team must assess, compare, and resolve conflicting information, while making difficult judgments and remembering the status of several evolving situations.
- Tasks are interleaved with other tasks, such a making reports to higher authority and requesting assets
- Situation assessment & action selection

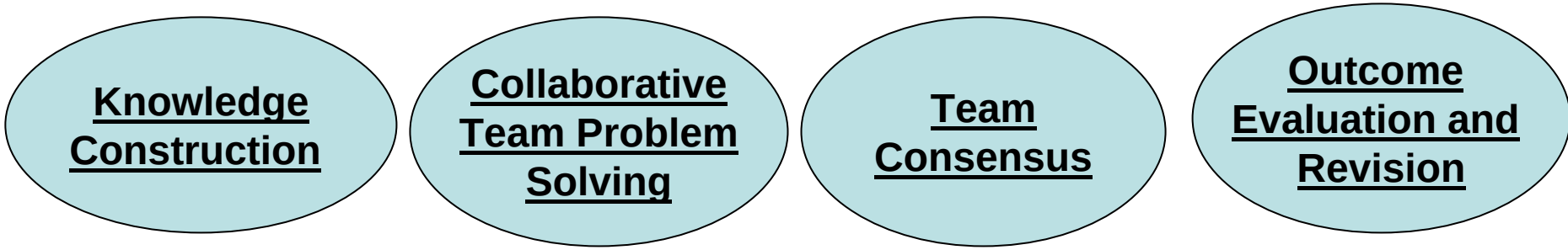
Coding Process

- Cognitive process coding definitions were used to code speech turns.
- Attempted to develop criteria for applying the coding schema as some coding categories appear to have similar meanings.
  - Codification of the coding process is part of the overall validation of the model, in that one goal is to have high inter-rater reliability between coders.
- Important to pay attention to which track a team member was talking about when coding the speech turns.
- First time discuss a track -- coded as a 2 (*individual mental model* (IMM) construction – where an individual team member, using available information, develops his/her mental picture of the problem situation).
- After three speech turns that discussed the same track (typically involving at least four, of the six or more team members) it was coded as a 4 (*team knowledge development* (TKM) – where all team members participate in clarifying information to build team knowledge.
- Once five-six team members had been involved in discussing this particular track, it was coded as a 10 – team shared understanding development – which includes discussion among all team members on a particular topic or data item.
- Exceptions to the coding criteria include: “All stations, [track # 7010 is a comm-air.]” -- he is telling all team members this evaluation of the track.
  - Because addressed to all TMs & reported a higher level/ more final assess’t of the track, i.e., a comm-air, was coded as a 10.
- As more TMs discuss contact (i.e., more reports and/or updates have been shared among TMs), cognitive process coding category reflects a higher level of team understanding of the situation.

New Coding Categories

- ***Issuing an order regarding a course of action*** **-- person with higher rank**
  - **Tells them to take some specific action against a potential threat track.**
    - **Issuing verbal warnings, illuminating or locking-on with radar, developing a firing solution, covering with missiles, etc.**
    - **Includes responding/ reporting have taken the action/ acknowledging**
- ***Request a team member take some action*** **-- tell team member to do something**
  - **Not a direct action against a threat track.**
    - **"Can you try and change 7006 and 7005 to assumed hostile."**
- ***Prodding a team member*** **to jog their awareness**
  - **To make sure they are following the discussion**
  - **Push or suggest to one or more team members to go out and generate knowledge, e.g., "You should go back and see if there is …."**
  - **Might act in a role as teacher gently pushing collaborative effort certain way**
  - **"*Contrarians*" when a person says "Let's re-evaluate/ reconsider**
    - **Person disagrees with the current thinking of the team**
    - **"Outlier" who makes the team consider another viewpoint, or**
    - **"Pulls back the reins"**

Boarding Party Discussion: Knowledge Construction Stage of Team Collaboration



These both look like legitimate radiation alarms (DTI) (1)

Please put in Dist 11 workspace (RTA)

Request current location of vessel (ITK) (3)

Boarding officer and team have boarded target vessel. Radiation search Underway; Biometrics on crew members underway. (IMM) (2)

ALCON: Biometrics data loaded under files (this workspace) (TK) (4)

Be advised, the target vessel cannot anchor in the channel. (TK) (4)

We are proceeding at a slow speed. (TK) (4)

The skipper indicated that there was one shipment that was listed as (KIO) (8) Radioactive – a medical source of some kind. Not clear whether the container is properly marked. There is one other container with late change in manifest that may not be captured in the paper work. This one is for /CalMart Distributors, and manifest indicated "Uranium."

…

Excerpt from MIO Scenario Communications Coding: Team Shared Understanding Development

MIO Team Communications		Cognitive Process Coding	
Speaker		**Code**	
DTRA	Cesium 137 can be used to make an RDD. If there are no explosives, then it is not configured as a weapon yet. Recommend material be confiscated.	MCsa	Develop, rationalize and visualize <u>solution alternatives</u>; using data to justify a solution
BO	Roger will confiscate.	MCitk	<u>Individual task knowledge</u> development; individual TM clarifying data.
BO	Make sure you handle carefully. Cs-137 is an external gamma hazard.	MCkio	<u>Knowledge interoperability</u>: TMs exchanging *knowledge* among each other.
BO	Roger. Will take precautions.	MCkio	<u>Knowledge interoperability</u>: TMs exchanging *knowledge* among each other.
SOCOM	Does CG ship have proper storage area for material confiscated?	MCitk	<u>Individual task knowledge</u> development: individual TM clarifying data, asking for clarification.
SOCOM	Search team will report size of material and its current containment condition; then make recommendations.	MetCcu	Team integration of individual TM knowledge for <u>common understanding</u>; one or more TMs combine individual pieces of knowledge to achieve common understanding.

MIO Scenario Communications Coding: Knowledge Interoperability Development and Agreement on a Final Plan

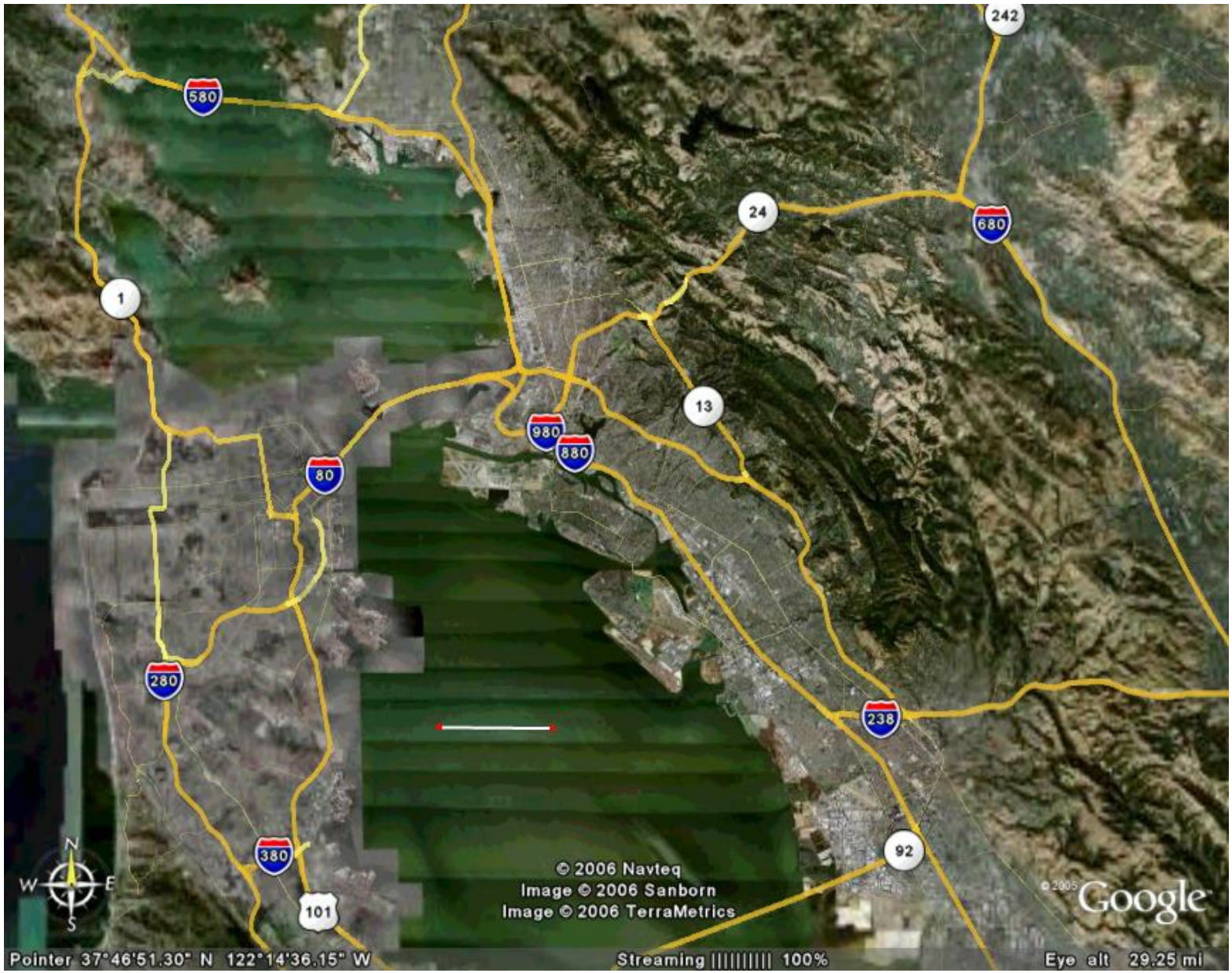
MIO Team Communications		Cognitive Process Coding	
Speaker		**Code**	
BO	Negative for explosives Station 2.	MCkio	<u>Knowledge interoperability</u>: TMs exchanging *knowledge* among each other.
LLNL	Finally received RAD data from station 2.	MCkio	<u>Knowledge interoperability</u>: TMs exchanging *knowledge* among each other.
SOCOM	Will need to resolve RAD containment hazard if it exists.	MetCcu	Team integration of individual TM knowledge for <u>common understanding</u>; one or more TMs combine individual pieces of knowledge to achieve common understanding.
DTRA	If you have plutonium, you need to confiscate. It's an alpha hazard, but still must be handled carefully.	MCica	Iterative information collection and analysis to come up with a solution but <u>no specific solution mentioned</u>.
BO	Roger.	Misc	Acknowledge report.

Knowledge Interoperability Development and Agreement on a Final Plan

DTRA	**By the way, if plutonium is in solid metal form, your team can handle safely with rubber gloves and a dental face mask, depending on how much is there.**	**MCkio**	**<u>Knowledge interoperability development</u> = team members exchanging <u>knowledge</u> among each other.**
BO	**Talking to search team to see if this is within their capabilities or if we will need outside assets.**	**Macica**	**Iterative information collection and analysis = *collecting and analyzing* information to come up with a solution but <u>no specific solution mentioned</u>.**
LLNL	**Hazard is probably minimal, can isolate and confiscate.**	**Metcs**	**Team agreement on a common <u>solution</u> = all team members agree on the <u>final plan</u>.**

	Cognitive Processes Included in Model	Scen D-Run A	Scen D-Run B	CG 59	DDG 54
1.	Data to information (dti)	1	4	--	37
2.	Individual mental model (imm)	8	11	18	25
3.	Individual task knowledge development (itk)	25	30	31	29
4.	Team knowledge development (tk)	11	5	18	1
5.	Knowledge object development (ko)	--	--	--	--
6.	Visualization and representation (vrm)	--	--	--	--
7.	Common understanding (cu)	--	6	--	
8.	Knowledge interoperability (kio)	--	5	--	1
9.	Iterative collection and analysis (ica)	1	11	--	--
10.	Team shared understanding (tsu)	1	17	28	34
11.	Solution alternatives (sa)	--	3	--	--
12.	Convergence of mental models (cmm)	1	--	--	--
13.	Agreement on Common solution (cs)	--	2	--	--
14.	Team negotiation (tn)	--	--	--	--
15.	Team pattern recognition (tpr)	--	--	--	--
16.	Critical thinking (ct)	--	--	--	--
17.	Sharing hidden knowledge (shk)	--	2	--	--
18.	Solution adjustment against goal (sag)	--	--	--	--
19.	Compare solution options against goals (csg)	--	1	--	--

Bay Brg
Situational Awareness
NOC
Message Box
Info
Alerts
Preferences
Device State Change
2004.01.01 Thu 16:21:57
Internet
PelcoNet 300 Homepage (Server Push) - Microsoft Internet Explorer
Server Pushed Video
Video Streaming
Stiletto 192.168.0.88
Google


242
580
24
680
1
13
980
880
80
280
238
380
92
101
N
W
E
S
© 2006 Navteq
Image © 2006 Sanborn
Image © 2006 TerraMetrics
© 2005 Google
Pointer 37°46'51.30" N 122°14'36.15" W
Streaming |||||||||| 100%
Eye alt 29.25 mi

242
580
24
680
1
13
980
880
80
280
238
380
92
101
© 2006 Navteq
Image © 2006 Sanborn
Image © 2006 TerraMetrics
Google
Pointer 37°46'51.30" N 122°14'36.15" W
Streaming 100%
Eye alt 29.25 mi

Discussion

- Differences between two scenarios - how the team's behavior maps to the model
  - Course of action selection air warfare tasks done less collaboratively, due to the inherent time pressure to make decisions and take actions.
  - Decisions made unilaterally by the tactical action officer or the commanding officer -- do not typically involve discussion with the rest of the team. Decisions regarding course of action selection entailed very little collaboration for the air warfare tasks due to the speed of the potential threat aircraft.
  - When actions need to be taken very quickly in an attempt to determine the intent of an inbound track, time is not available to discuss alternative courses of action.
- Air warfare consists of situation assessment ("what's going on") and action selection ("what to do about it").
  - Decisionmakers use a recognition-primed decisionmaking strategy (Klein, 1989)
    - Situation itself either determines or constrains the response options
    - Recognition primed model of decisionmaking fuses two processes — situation assessment and mental simulation (Klein, 1993).
      - Simplest case the situation is recognized as familiar or prototypical, using feature matching, and the obvious response is implemented
      - More complex case -- decisionmaker performs conscious evaluation of response, using mental simulation to uncover problems prior to implementing
      - In most complex case -- evaluation reveals flaws requiring modification, or option is judged inadequate/rejected in favor of next typical reaction
- Experienced decisionmakers make 90% of all decisions w/o considering alternatives
    - If situation appears similar, pattern recognized and COA is usually obvious.

Conclusions

- New Start – began in Jan 2006
  - Still coding MIO scenarios
- Pattern for MIO comms is different – more comms are coded as discussion of Team Consensus and Outcome Evaluation and Revision
- Will continue coding more complex MIO scenarios