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Evaluating a Model of Team Collaboration via Analysis of Team Communication

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Analysis of Team Communications to Understand Cognitive Processes used during Team Collaboration

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Macocognition

The internalized and externalized high-level mental processes employed by teams to create new knowledge during complex, one-of-a-kind problem solving (Letsky, Warner, Fiore, Rosen, & Salas, 2007).

- **Mental activities that must be successfully accomplished to perform a task or achieve a goal (Klein, Ross, Moon, Klein, Hoffman, & Hollnagell, 2003).**
- **Macrocognitive functions are generally performed during collaborative team problem solving, where the emphasis is on building new knowledge.**
- **Cognitive processes employed by team members in unique, information-rich, time-compressed collaborative problem solving, such as individual and team knowledge development, shared problem conceptualization, mental model development, and solution option generation.**
- **Detecting problems, developing and sharing situation awareness, generating options, using analogues, mentally simulating courses of action, planning and re-planning, maintaining vigilance, and assessing risk (Klein, 2001).**

Team Collaboration

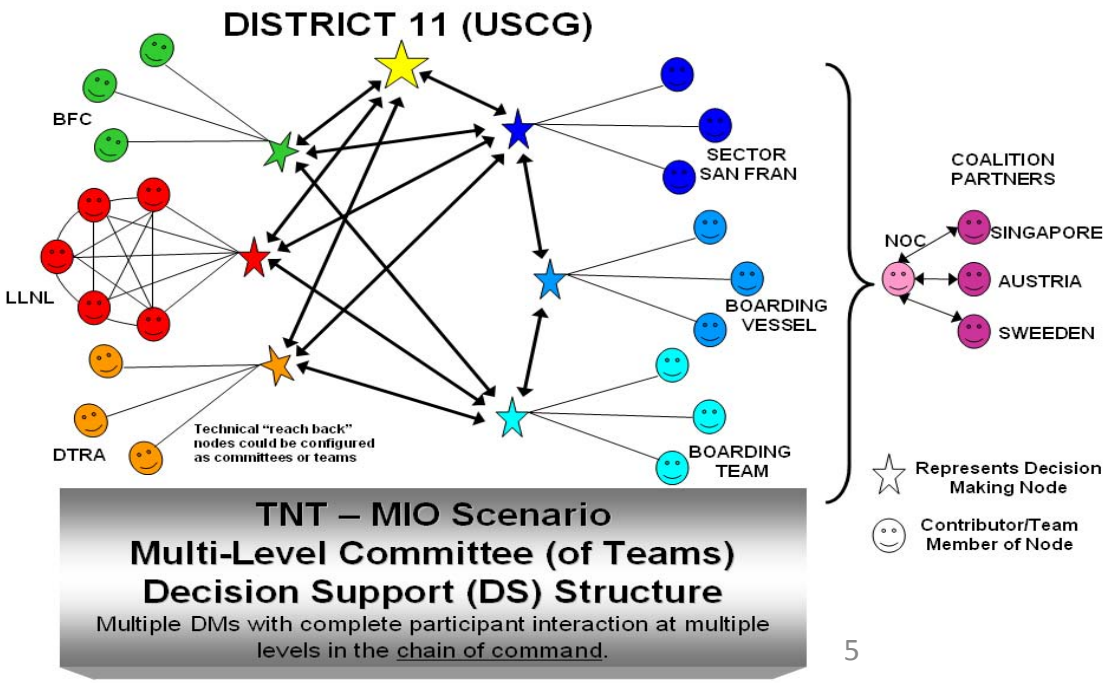
- **Collaboration occurs "when a group of autonomous stakeholders of a problem domain engage in an interactive process, using shared rules, norms, and structures to *act* or *decide* [emphasis added] on issues related to that domain" (Gray, 1928, p.11).**
- **Collaboration provides increased information processing capacity where more minds are enlisted to handle complex problems (Hocevar, Jansen, and Thomas, 2004).**
- **Team members provide several perspectives on an issue for generating, choosing, and *implementing action plans*.**
- **A collaborative approach also provides greater flexibility and innovation where human judgment and experience are leveraged (Hocevar, et al, 2004.)**

Team Types

- **Teams who employ asynchronous or synchronous communications among distributed team members to bring their heterogeneous knowledge to bear to solve the problem.**
- **Each team member plays a functionally distinct role and contributes specialized knowledge and expertise.**
- **Problem-solving teams are often formed to deal with a rapidly emerging difficult situation where consequences for error are severe. These teams are often ad hoc teams brought together in response to a critical situation that requires the expertise of a diverse group of experts.**
- **Typically operate in complex socio-technical settings where the systems employed require technical expertise; operate within organizational constraints where there are often conflicting goals, and the consequences for failure can be severe.**

Types of Problem Solving Situations

- Ill-Structured Decisionmaking Tasks
- Time Pressure
- Dynamic Information
- High Information Uncertainty
- High Cognitive Workload
- Human System Interface Complexity



TNT – MIO Scenario
Multi-Level Committee (of Teams) Decision Support (DS) Structure
Multiple DMs with complete participant interaction at multiple levels in the chain of command.

Dynamic Decision-Making Tasks

- **A series of decisions is needed, that is, the problem-solving event comprises many decisions to effectively deal with the problem as it unfolds, e.g., firefighters, air warfare decision-making, maritime interdiction operations (MIO), NORAD/FAA, and dynamic targeting tasks.**
- **Decisions are not independent because current decisions are constrained by earlier decisions, and, in turn constrain later ones.**
- **The problem state changes during the decision process both autonomously, and as a consequence of the decision maker's actions.**
- **Decisions are made in real time (Brehmer, 1992).**
  - **It is necessary for the operator to consider how the current decision will solve the immediate problem, as well as how it will impact future aspects of the overall problem-solving task.**
  - **It is not sufficient to make correct decisions, "in the correct order, they also need to be made at the correct moment in time" (Brehmer, 1992).**
  - **Dynamic decision making is inherently stressful in part because the decision maker cannot control when these critical decisions have to be made.**

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Dynamic Decision-Making Tasks (cont'd)

- **Decision making is viewed as a form of problem solving, where a person seeks a viable course of action.**
- **Dynamic decision making tasks are found across the spectrum of problem solving domains, including process control plants, patient management in hospitals, managing a business, and fighting a battle.**
- **In Klein's (1993) analysis of decision errors, he refers to (decision) process errors and (decision) outcome errors.**
  - **Making a decision is both a MC *process* and a *product*.**
- **Montgomery's approach (1983, 1989) views the function of decisions, as "to prepare for action and to make sure that actions are indeed carried out" (Brehmer, 1992, p.16).**
- **Implementing the decision often shapes both the problem as well as the cognitive process involved in decision making.**

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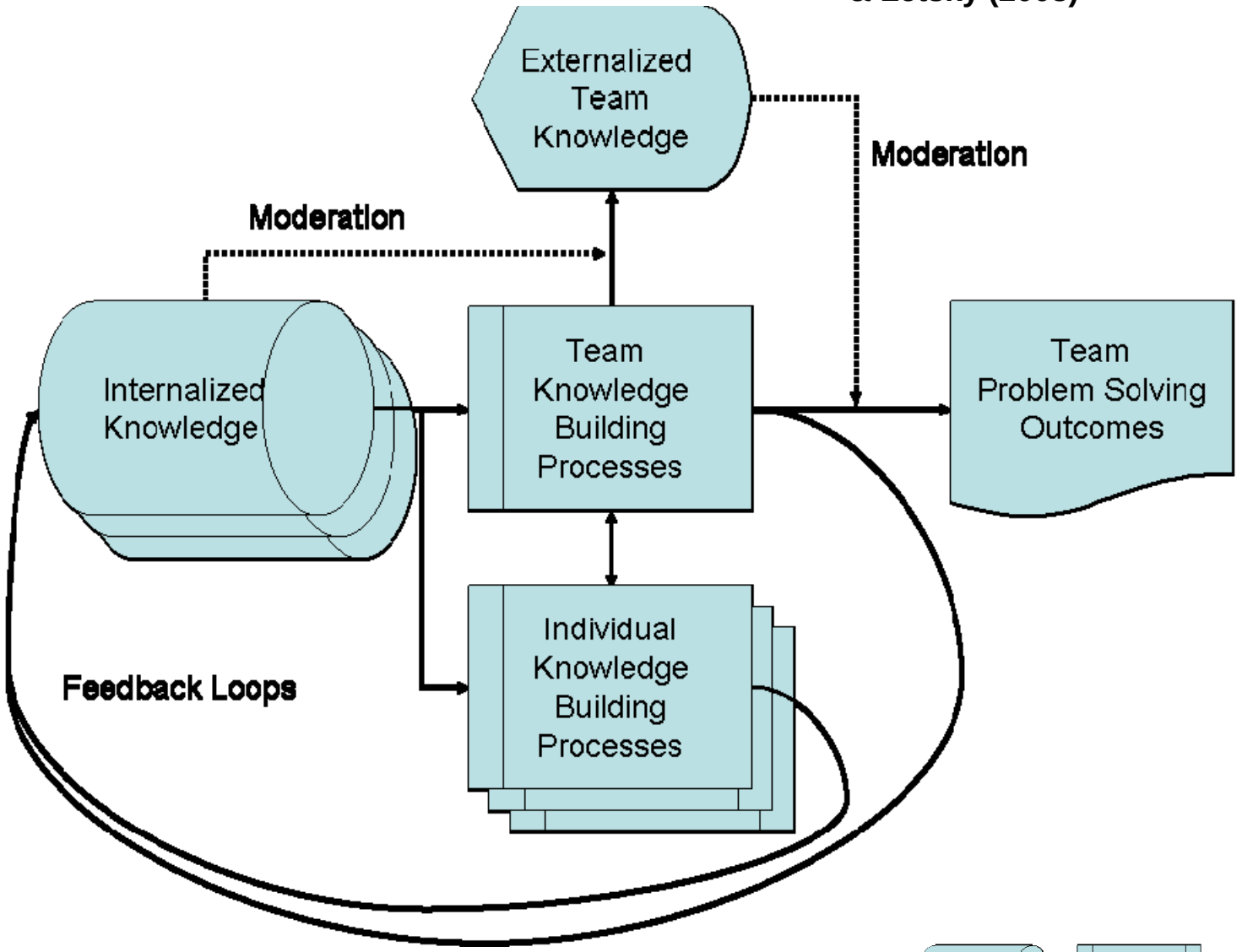
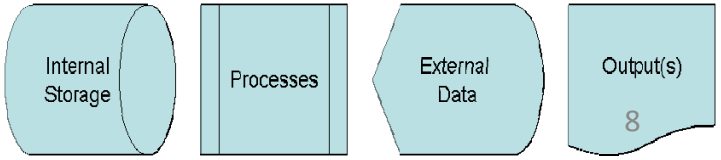
Model of Team Collaboration (From Fiore, Smith-Jentsch, Salas, Warner, & Letsky (2008)



Note: Multiple overlapping symbols indicate representations for multiple team members.

Legend



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Method

- **Verbatim transcripts or chat logs** were analyzed from an Air Force exercise, a real-world event, and an UAV planning experiment where teams collaborated to solve a complex problem
  - Air Force Air Operations Center: Dynamic planning and execution exercise involving time-sensitive targeting
  - North American Aerospace Defense Command (NORAD), on Sept. 11, 2001
  - UAV planning experiment
- Team communications data were analyzed and **coded using the definitions of the macrocognitive processes in the model of team collaboration**, developed by Fiore, Smith-Jentsch, Salas, Warner, & Letsky (2008)
  - Communications were segmented into utterances that referred to a distinct macrocognitive process.
  - Each utterance was typically given a separate code
  - **Two coders for each transcript**
  - Practiced on a separate set of team communications and calibrated their coding after coding 200 lines
  - Coders reviewed their coding with the investigator and discussed differences in interpreting the definitions prior to coding
  - Analysis of the Air Operations Center data: **2493 utterances**
  - NORAD data: **2278 utterances**
- **Calculated inter-rater reliability using Cohen's Kappa coefficient**
  - **High-inter rater reliability: 89.32% and 77%**

Definitions of Macrocognitive Processes Included in Model of Team Collaboration

(From Fiore, Smith-Jentsch, Salas, Warner, & Letsky (2008)

Macrocognitive Process Categories	
Individual Knowledge Building	
Individual Information Gathering	Actions individuals engage in to add to their existing knowledge such as reading, asking questions, accessing displays, etc.
Individual Information Synthesis	Involves comparing relationships among information, context, and artifacts to develop actionable knowledge
Knowledge Object Development	Involves creation of cognitive artifacts that represent actionable knowledge for the task
Team Knowledge Building	
Team Information Exchange	Passing relevant information to the appropriate teammates at the appropriate times
Team Knowledge Sharing	Explanations and interpretations shared between team members or with the team as a whole
Team Solution Option Generation	Describes explanations and interpretations shared between team members or with the team as a whole
Team Evaluation and Negotiation of Alternatives	Describes clarifying and discussing the pros and cons of potential solution options
Team Process and Plan Regulation	Involves discussing or critiquing the team's knowledge building process or plan following feedback on its effectiveness

Definitions of Macrocognitive Processes Included in Model of Team Collaboration

(From Fiore, Smith-Jentsch, Salas, Warner, & Letsky (2008)

Internalized Team Knowledge	
Team Knowledge Similarity	**The degree to which differing roles understand one another (e.g., how well a land/sea vehicle specialist understands a humanitarian specialist), or how well the team members' understand the critical goals and locations of important resources (shared situation awareness).**
Team Knowledge Resources	**Team members' collective understanding of resources/ responsibilities associated with the task.**
Inter-positional Knowledge	**Accurate knowledge regarding position-specific roles, goals, responsibilities, access to information, constraints, and interdependencies with other team positions.**
Individual Situational Awareness	**Accurate awareness of moment to moment changes in the team's environment. The construct has been defined previously by Endsley (1995)**
Externalized Team Knowledge	
Externalized Cue-Strategy Association	**Describes the team's collective agreement as to their task strategies and the situational cues that modify those strategies (and how).**
Pattern Recognition and Trend Analysis	**Refers to the accuracy of the patterns or trends explicitly noted by members of a team that is either agreed upon or unchallenged by other team members.**
Uncertainty Resolution	**The degree to which a team has collectively agreed upon the status of problem variables (e.g., hostile/friendly).**

Definitions of Macrocognitive Processes Included in Model of Team Collaboration

(From Fiore, Smith-Jentsch, Salas, Warner, & Letsky (2008)

Team Problem Solving Outcomes	
Quality of plan (problem solving solution)	**Involves the degree to which the solution adopted by a problem solving team achieves a resolution to the problem (e.g., limit fatalities, limit destruction)**
Efficiency of planning process	**Amount of time it takes a problem solving team to arrive at a successful resolution to a problem**
Efficiency of plan execution	**Quality of the plan (e.g., number of lives saved) divided by the amount of resources used to accomplish this and the amount of time the plan takes to unfold**

Description of Tasks

- **Air Operations Center training exercise in dynamic targeting**
  - **October 2008 to employ operational concepts and training techniques**
  - **Team collaboration recorded in Chat logs across 15 chat rooms**
- **North American Aerospace Defense Command (NORAD) North East Air Defense Sector (NEADS)**
  - **Collaborated with Federal Aviation Administration (FAA) and air traffic control centers to ground all remaining commercial air traffic and to ensure no additional aircraft had been hijacked**
- **Experiment on UAV planning and operation to take photos**
  - **Focus was on planning but participants were also performing the task**

Percentage of Macrocognitive Processes used Across Decision-Making Domains

Code	Macrocognitive Process Categories	Percentage of Speech Turns		
Individual Knowledge Building		Air Ops Center	NORAD	UAV Planning
IIG	Individual Information Gathering	16.66	29.37	32.57
IIS	Individual Information Synthesis	1.04	1.66	0.75
KOB	Knowledge Object Development	0.00	0.00	0.00
Team Knowledge Building				
TIE	Team Information Exchange	37.57	50.44	58.00
TKS	Team Knowledge Sharing	5.45	3.58	4.29
TSOG	Team Solution Option Generation	0.35	2.93	0.00
TENA	Team Evaluation and Negotiation of Alternatives	0.13	0.00	0.00
TPPR	Team Process and Plan Regulation	0.00	0.00	0.00
Internalized Team Knowledge				
ITK	Team Knowledge Similarity	0.03	0.00	0.00
TKR	Team Knowledge Resources	0.06	0.00	0.00
IK	Inter-positional Knowledge (3)	0.06	0.19	0.00
ISA	Individual Situational Awareness (1)	0.00	1.60	0.00
Externalized Team Knowledge				
ECSA	Externalized Cue-Strategy Association	0.13	0.06	0.00
PRTA	Pattern Recognition and Trend Analysis	0.11	0.06	0.00
	Uncertainty Resolution	0.00	0.12	0.00
Problem Solving Outcomes				
QOP	Quality of plan (problem solving solution)	0.00	0.00	0.00
EPP	Efficiency of planning process	0.00	0.00	0.00
EPE	Efficiency of plan execution	0.00	0.00	0.00
Decision to Take Action				
DTA: COA	To subordinate: issuing a course of action	4.72	1.21	0.00

CODE TITLE	ADMIN	MISC	TIE	IIG	IIS	ECSA	TKS	COA	RTA	TSOG	TENA	ITK	UR	PRTA	ECF	TotalCoder 2
ADMIN	**183**	0	0	0	0	0	**1**	0	0	0	0	0	0	0	**1**	**185**
MISC	0	**663**	**6**	0	0	0	0	**1**	0	0	0	0	0	0	0	**670**
TIE	0	**1**	**1134**	**5**	**9**	**1**	**24**	**9**	0	**2**	0	0	0	**1**	**1**	**1187**
IIG	**2**	0	**2**	**521**	0	0	**1**	0	0	0	0	0	0	0	0	**526**
IIS	0	0	**4**	0	**23**	0	**6**	0	0	0	0	0	0	0	0	**33**
ECSA	0	0	0	0	0	**4**	0	0	0	0	0	0	0	0	0	**4**
TKS	0	0	**17**	**1**	**6**	**1**	**136**	**3**	0	**3**	**3**	**1**	0	**1**	0	**172**
COA	0	0	**4**	**1**	0	0	**1**	**138**	**1**	**1**	0	0	0	0	**3**	**149**
RTA	0	0	**4**	**1**	0	0	**1**	0	**78**	0	0	0	0	0	**3**	**87**
TSOG	0	0	**1**	0	**1**	**2**	0	0	0	**6**	**1**	0	0	0	0	**11**
TENA	0	0	0	0	0	0	0	0	0	1	**3**	0	0	0	0	**4**
ITK	0	0	0	0	0	0	0	0	0	0	0	**3**	0	0	0	**3**
UR	0	0	0	0	0	0	0	0	0	0	0	0	**0**	0	0	**0**
PRTA	0	0	0	0	0	0	0	0	0	0	0	0	0	**0**	0	**0**
ECF	0	**2**	**20**	**8**	**33**	**4**	**39**	**3**	**2**	**6**	**5**	**2**	**1**	**2**	**0**	**127**
Total Coder 1	**185**	**666**	**1192**	**537**	**72**	**12**	**209**	**154**	**81**	**19**	**12**	**6**	**1**	**4**	**8**	**3158**

Coding Results

- Coding schemes should be mutually exclusive, exhaustive, and equivalent.
- High Cohen Kappa coefficient indicates the two coder's agreement is substantial (Landis and Koch, 1977).
  - ✓ Indicates the macrocognitive process **definitions are objective**.
- Pivot table of results highlights instances where two coders disagreed
  - Shows codes used by other coder when there were disagreements
  - Disagreements indicate macrocognitive process that are **not mutually exclusive**
    - Definitions may need to be refined to remove ambiguity
- A new macrocognitive process emerged during coding:
  - Decision to Take Action is considered to be a macrocognitive process and a product, indicating **non-exhaustive set** of macrocognitive processes

Examples of Macrocognitive Processes used during Team Knowledge Building (AOC Data)

Origina-tor	Communication	Code
DEC	Self defense applies for hostile acts from Country #3 fighters in Country # 2 or #4 airspace.	TKS
DEC	Enemy forces that employ ordnance, electronic attack or achieve a radar lock against friendly forces have committed a hostile act.	TKS
TDO	If we crater the runway and taxiways, we may be able to effectively stop the target.	TSOG
IOT	Target Duty Officer (TDO): Just throwing this out there, but if you target the roadways, is there a chance you could spook them and they might fire off their missiles and run?	TENA

Team Knowledge Building Stage:
Team Information Exchange and Solution Option Generation

Originator	Communication	Code
DEC	Awaiting radiological impact assessment on watershed if the building is to be strike. Second option in work is to destroy local roads to prevent access in/out.	TIE TSOG
DECD	Aircraft returns watershed non-issue	TIE
SIDO	Airfield is located at (*Removed*); type of aircraft is STOL cargo plane.	TIE/TIE
JOC_JCE	Dynamic effects cell, you have high-value target on your dynamic target list. What is the air combat commander game plan? If you have a good one, I will appoint you the lead but I think SOF needs to be considered.	TIE IIG

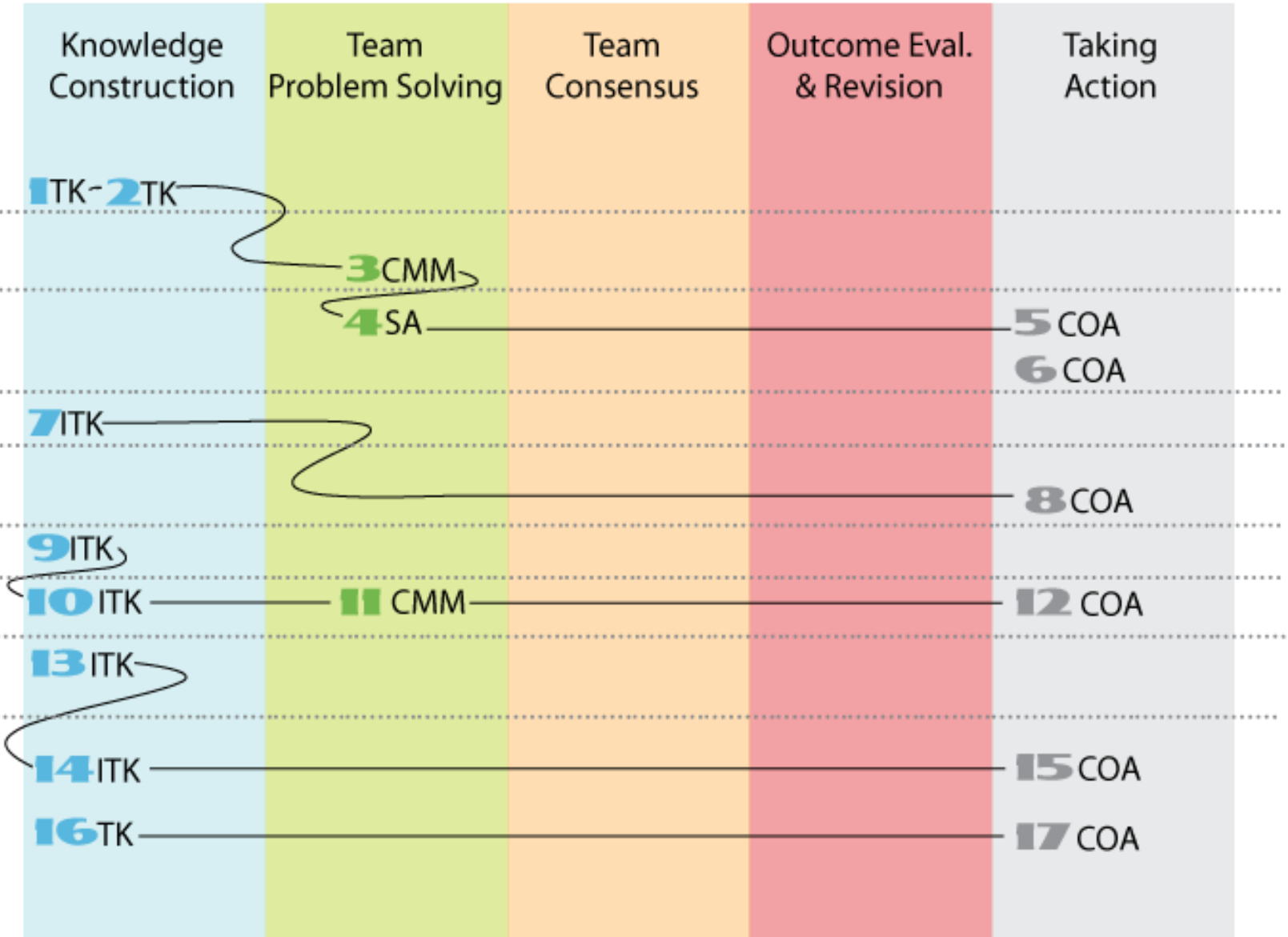
Excerpt from NEADS data to Illustrate the Dynamic Decision-Making Process

Speaker	Message	Code
Male Speaker	Sergeant Demage?	MISC
	We are working a tanker.	TIE
Sergeant M:	There is a bomb on board Boston -	TIE
Male Speaker:	*Expletive*	MISC
Male Speaker:	On board what? Boston 93?	IIG
Huntress:	United.	TIE
Male Speaker:	United?	IIG
Sergeant M:	Bomb on board United 93.	TIE

Problem Solving Includes Taking Actions

mples of Decision to Take Action from NORAD Coding	Code
lots should be loading and just make sure your pilots load up their mode 2 and mode 4.	DTA (COA)
e a track number on that bomb -- that guy going by.	DTA (RTA)
e an arrow, Bud. Scope 2, scope 1.	DTA (RTA)
ke sure its squawking.	DTA (RTA)
r mode 2, make sure that's standard and also make sure you're mode oaded up as well.	DTA (COA)
m around and have him go look.	DTA (RTA)
u help some of these people at tracking this bird?	DTA (RTA)
all mode 3.	DTA (COA)
em call for that.	DTA (RTA)
on't see them, call right away. If you see it and they haven't hit it up, call that center.	DTA (COA)
m we need to know where Air Force One is.	DTA (COA)

Phase 2: Second Plane Hits the World Trade Center (9:03 - 9:58am)



New Coding Category: Decision to Take Action

new macrocognitive process emerged during the coding process:

Deciding to take action is viewed as both a macrocognitive *process* and a *product* of team collaboration.

Many critical tasks include team members taking action in addition to developing new knowledge and agreeing on a final solution.

- **Various actions are taken as part of the overall information gathering process (e.g., MIOs, air warfare, firefighters, etc.).**

Dynamic decision-making tasks entail a series of decisions as part and parcel of problem solving.

- **Many tasks involve an interleaving of knowledge building, decision making and taking action in order to accomplish the mission.**

A constant interplay exists between sharing information to develop new knowledge and maintain situation awareness and then executing, or implementing actions, followed by monitoring and building new knowledge on the unfolding situation.

- **Execution of the mission, or problem-solving problem, would come to a screeching halt without this continual, iterative cycle of developing knowledge of the situation and responding to the current situation by**

Summary

ew macrocognitive process emerged during the coding process: Decision ake action

Deciding to take action is viewed as **both a macrocognitive *process*** and a ***product* of team collaboration**

st Problem-solving tasks – other than planning tasks – **involve making isions** (to take action) **and implementing those decisions** during the rse of the problem-solving scenario.

Supported by results from analysis of five real-world decision making task domains

Many tasks involve an interleaving of knowledge building, decision making and action taking in order to accomplish the task.

ults indicate additional macrocognitive processes need to be included in model to represent decision making which occurs during execution of -world tasks.

crocognition includes the mental activities that must be successfully omplished to perform a task or achieve a goal.

ummary (cont'd)

efinition of Decision:

A mental event that occurs at a singular point in time…that leads nmediately or directly to action." (Hoffman & Yates, 2005, p. 77)

- **A decision is defined as a commitment to a course of action.**

complex problem-solving situation typically entails many decisions.

- **These decisions include implementing actions in response to the prior or existing situation or the prior decision spawned new situations that require new decisions.**
- **Unfolding scenario will often continue to present new events requiring a decision.**

he function of decisions "to prepare for action and to make sure that ctions are indeed carried out." (Brehmer, 1992, p. 16)

nplementing the decision often shapes both the problem as well as the ognitive process involved in decision making.