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Analysis of Team Collaboration across Decision-Making Domains to Empirically Evaluate a Model of Team Collaboration

Topic 3: Information Sharing and Collaboration Processes and Behaviors

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Abstract

A model of team collaboration was empirically evaluated by applying definitions of the macrocognitive processes included in the model to the team communications that transpired during two real-world decision-making domains. Macrocognition is defined as the internalized and externalized high-level mental processes employed by teams to create new knowledge during complex, one-of-a-kind problem solving. Team collaboration during two unique, information-rich, time-compressed situations was analyzed and coded, using verbatim transcripts or chat logs, to empirically evaluate the model of team collaboration. Many tasks require rapid and accurate coordination of information, expertise, perspectives and behavior to successfully cope with the demands of time-compressed, ambiguous situations with the threat of fatal consequences. We analyzed team communications from the North American Aerospace Defense Command collaborating with other agencies to deal with the Sept 11, 2001, hijacking of four US commercial aircraft and an Air Operations Center team collaborating to conduct time-sensitive targeting. A new macrocognitive process emerged during the coding process: decision to take action. Deciding to take action is viewed as both a macrocognitive process and a product of team collaboration. Results indicate additional macrocognitive processes need to be included in the model to represent decision making which occurs during execution of real-world tasks.

INTRODUCTION

One goal for studying macrocognition is to understand the complexity entailed in inter- and intra-individual cognition. Macrocognition is an emerging field within the area of cognitive engineering that describes the way cognition occurs in naturalistic, or real-world, decision-making events (Cacciabue & Hollnagell, 1995). From this perspective, macrocognition comprises the 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.

For the research reported in this paper, we focus on cognition in collaboration contexts (Warner, Letsky, & Cowen, 2005), where problem solving teams collaborate on short-term situations which require rapid action to be taken against specific missions (Letsky, Warner, Fiore, Rosen, & Salas, 2007). Macrocognition is defined as the internalized and externalized high-level mental processes employed by teams to create new knowledge during complex, one-of-a kind, collaborative problem solving (Letsky et al., 2007). High-level mental processes refer to the cognitive processes involved in combining, visualizing, and aggregating information to resolve ambiguity in support of the discovery of new knowledge and relationships.

This conceptualization of macrocognition views it as a complex, multi-level phenomenon that involves development, refinement, and maintenance of higher-order cognitive processes and emergent states (Burke, 2007). Macrocognition involves the 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. Macrocognition encompasses detecting problems, developing and sharing situation awareness, generating options, using analogues, mentally simulating courses if action, planning and re-planning, maintaining vigilance, and assessing risk (Klein, 2001).

The framework of collaborative problem solving developed as part of the Office of Naval Research (ONR) Collaboration and Knowledge Integration (CKI) Program (Letsky, Warner, Fiore, & Salas, 2007) provides the conceptual foundation for this research. Problem-solving domains analyzed previously for this research include: firefighters responding to the events of Sept. 11, 2001, a Coast Guard boarding party conducting Maritime Interdiction Operations (MIO) on a ship suspected of carrying contraband material, and air warfare teams on a Navy ship (Hutchins & Kendall, in press; Hutchins & Kendall, 2008). Information integration, or knowledge construction, was a major contributor to performance for all teams who were responding to the various problem-solving situations we studied.

The goal for the research reported here is to understand the role of cognition in teams who are collaborating to solve challenging, ambiguous problems. Our objectives are to (1) empirically evaluate the model of team collaboration based upon analysis of real-world complex decision-making events and (2) develop a better understanding of the cognitive processes employed when teams collaborate to solve problems.

Team Collaboration

Many definitions of collaboration are found in the different bodies of research literature. Collaboration derives from the Latin *collaboratus*, past participle of *collaborare*, to labor, and one definition is to work jointly with others or together especially in an intellectual endeavor. 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.) 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 on issues related to that domain" (Gray, 1928, p.11).

Collaborating teams are ubiquitous such that the types of tasks requiring a collaborative effort encompass an ever-increasing range of situations. Scientists collaborate with researchers on a remote space station and with robotic geologists (Clancy, 2004). Military teams collaborate to develop plans as well as during the execution of those plans for a wide variety of mission areas. These teams all have characteristics in common – they engage in tasks that involve critical decisions and must often coordinate their activities to accomplish these tasks effectively.

In the following sections we report on results from a series of studies where we analyzed data obtained from teams and tasks characterized by the descriptions in the following sections.

Team Types
Teams of interest for this research include 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. The teams we studied operate in complex socio-technical settings where the systems employed require technical expertise; teams operate within organizational constraints where there are often conflicting goals, and the consequences for failure can be severe.

Teams can be formally conceptualized as “two or more people who interact dynamically, interdependently and adaptively toward a shared goal (Salas, Dickinson, Converse & Tannenbaum, 1992, p. 4). The interdependence involves all team members sharing their knowledge about the situation, and contributing their respective expertise, to develop and maintain an accurate understanding of the dynamically unfolding situation. In many cases, teams are also making decisions and implementing those decisions in a timely manner to effectively deal with the problem.

Dynamic Decision-Making Tasks
Dynamic decision-making tasks, such as the decision domains investigated for this research, are characterized by situations where: (1) 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, and maritime interdiction operations (MIO). (2) Decisions are not independent because current decisions are constrained by earlier decisions, and, in turn constrain later ones. (3) The problem state changes during the decision process both autonomously, and as a consequence of the decision maker’s actions. (4) 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. More importantly, 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.

In dynamic decision making, 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. All the tasks we examined were dynamic decision-making tasks, as opposed to planning tasks. In Klein’s (1993) analysis of decision errors, he refers to (decision) process errors and (decision) outcome errors. 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.

By implementing a decision, and obtaining feedback on its results, the operator has changed the problem. For example, in an air warfare scenario, taking an action against an inbound aircraft, and observing that aircraft's response, or lack of response to that action, will recast the problem, or change the practitioner's mental model of that task, in terms of determining the intent of the aircraft. In a similar vein, during a Coast Guard maritime interdiction operation (MIO), collecting new information by obtaining the results of analysis of radiological data will move the boarding officer's assessment of the type of cargo further along toward a resolution of the problem (that is, identifying the type of contraband cargo on the ship and what type of response is required).

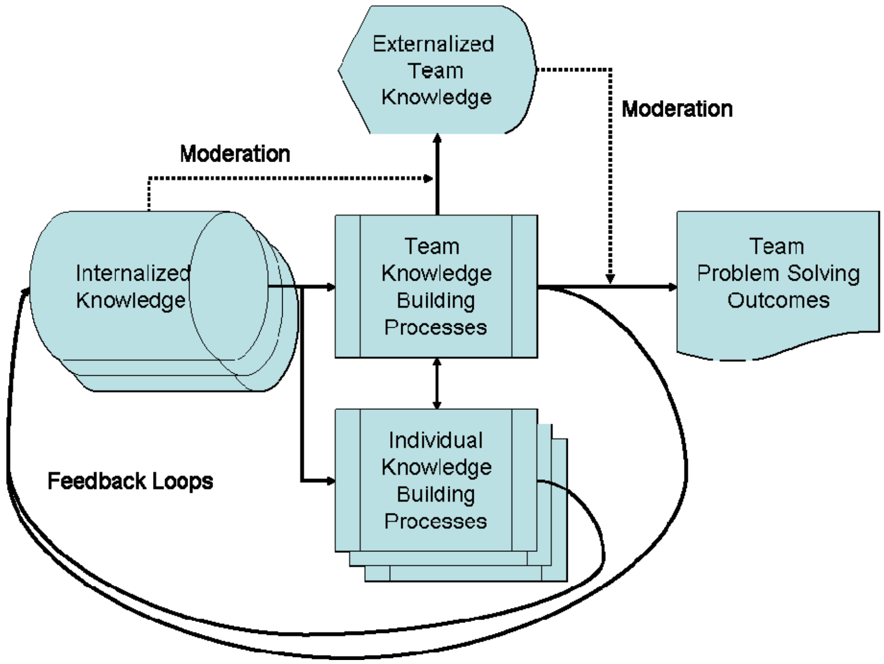
Decision Making Situations are Part of Problem-Solving Tasks. We maintain that decision making is a critical element of team problem solving when a team is executing a task, in contrast to performing a planning task. When team members collaborate they make decisions and implement those decisions as part of executing their mission. Team communications often entail asking or telling a team member to perform some action that will move the problem further along toward completion. This contrasts with a team who is collaborating on a planning task, where deciding on and implementing decisions may not be evident. One definition of a decision is a "mental event that occurs at a singular point in time…that leads immediately or directly to action" (Hoffman & Yates, 2005, p. 77). From this perspective, a decision is defined as a commitment to a course of action (Hoffman and Yates, 2005).

Other researchers state that decision making should be thought of in terms of deciding, and view it as one of a number of macrocognitive processes that it supports and that support it. (Klein, Ross, Moon, Klein, Hoffman, & Hollnagel, 2003). Several factors impact deciding, these include (1) deciding involves instantiating intentions and purposes; (2) actions are intended to bring about states of affairs that serve the interest of particular individuals or groups; (3) commitments to act must be distinguished from action because, for various reasons, not all decisions are actually implemented; and (4) choice among alternatives is never equivalent to choice among consequences, because alternatives rarely lead to single consequences (Hoffman & Yates, 2005).

A complex problem-solving situation typically entails many decisions, "either in the process of implementing a previous commitment" or the prior decision spawned new situations that required decisions. This view contrasts with the perspective that a decision signifies the end of a sequence of mental operations (Hoffman & Yates, 2005). Another viewpoint is of decisions as discrete events with discrete decision points, however there is not always agreement on what events are involved in a given decision (Hirokawa & Poole, 1996).

Model of Team Collaboration

Figure 1 depicts a model developed to describe the dimensions of macrocognition where the focus is on describing these processes in a measurement framework.



(*Note*: multiple overlapping symbols indicate representations for multiple team members)

Legend: 

Figure 1. Measurement model for macrocognition research. (from Fiore, et al, in press).

Table 1 includes descriptions of the macrocognitive processes included in this model of team collaboration, developed by Fiore, Smith-Jentsch, Salas, Warner, & Letsky (in press). *Individual knowledge building* refers to actions taken by individuals to build their own knowledge. *Team knowledge building* is a process that includes actions by teammates to disseminate information and transform information into actionable knowledge. *Internalized team knowledge* refers to the collective current knowledge held in the individual minds of team members. *Externalized team knowledge* refers to the current knowledge overtly expressed to other team members through communication and/or artifacts during collaborative team problem solving. *Team problem solving outcomes* are assessments of the quality relative to a team's problem solving or plan.

Table 1. Definitions of Macrocognitive Processes Included in Model of Team Collaboration.

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.
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).
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.

Method

Coding Process

Verbatim transcripts or chat logs were analyzed from an Air Force exercise and one real-world event where teams collaborated to solve a complex problem: a dynamic planning and execution exercise involving time-sensitive targeting and the communications that transpired between the personnel at the North American Aerospace Defense Command (NORAD), on Sept. 11, 2001. Transcripts included communications that occurred between all team members as well as with decision makers at the distributed sites. 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 (in press). Coders practiced on a separate set of team communications and calibrated their coding after coding 200 lines. The two coders reviewed their coding with one of the authors and discussed any differences in interpreting the definitions prior to coding the communications data to be analyzed. Analysis of the Air Operations Center data and the NORAD data comprised 2515 lines, and 1517 lines of coding, respectively.

Problem-Solving Tasks

We analyzed team communications from two decision-making scenarios described in the following paragraphs.

Air Operations Center. A training exercise in dynamic planning operations was conducted at the Air Force Air Operations Center (AOC), in October 2008. This Training Research Exercise was conducted to employ operational concepts and training techniques from several commands. Participants from the USAF Warfare Center, Naval Strike Air Warfare Center, Special Operations, and US Army worked together on dynamic planning operations. Team collaboration communication was recorded in Microsoft Internet Relay Chat (mIRC) logs across 15 different chat rooms, comprising twelve hours of exercise data that was recorded in six two-hour segments.

NORAD. On Sept 11, 2001, air traffic controllers in New York, Boston, Washington, and Cleveland were scrambling due to the hijacking of four American commercial airliners. In their efforts to bring order to chaos the Federal Aviation Administration (FAA) in communication with Northeast Air Defense Sector (NEADS) and North American Aerospace Defense Command (NORAD) scrambled fighter aircraft to escort the airliners. Transcripts of the team collaboration communications that transpired to bring all aircraft down on September 11, 2001, in response to the terrorist attack were analyzed.

RESULTS

Table 2 presents the percentage of speech turns coded as representing the macrocognitive processes included in the model of team collaboration. The most significant finding is that a new macrocognitive process emerged during the coding process: Decision to take action. Two types of decisions were evident: issuing a course of action and requesting a peer to take action. These two types of decisions are differentiated by the authority relationship between the speaker and receiver and the criticality of the action to be taken. A course of action is issued by a superior to a subordinate and the action to be implemented is more critical to the outcome of the scenario. Requesting a peer to take action involves a lower level type of decision in terms of the authority relationship, that is, peer-to-peer, and the less critical nature of the action to the outcome of the scenario.

Table 2. Percentage of Macrocognitive Processes used Across Decision-Making Domains.

Code	Macrocognitive Process Categories	Percentage of Speech Turns	
	Individual Knowledge Building	**Air Ops Center**	**NORAD**
IIG	Individual Information Gathering	16.66	29.37
IIS	Individual Information Synthesis	1.04	1.66
KOB	Knowledge Object Development	0.00	0.00
	Team Knowledge Building		
TIE	Team Information Exchange	37.57	50.44
TKS	Team Knowledge Sharing	5.45	3.58
TSOG	Team Solution Option Generation	0.35	2.93
TENA	Team Evaluation and Negotiation of Alternatives	0.13	0.00
TPPR	Team Process and Plan Regulation	0.00	0.00
	Internalized Team Knowledge		
ITK	Team Knowledge Similarity	0.03	0.00
TKR	Team Knowledge Resources	0.06	0.00
IK	Inter-positional Knowledge (3)	0.06	0.19
ISA	Individual Situational Awareness (1)	0.00	1.60
	Externalized Team Knowledge		
ECSA	Externalized Cue-Strategy Association	0.13	0.06
PRTA	Pattern Recognition and Trend Analysis	0.11	0.06
UR	Uncertainty Resolution	0.00	0.12
	Problem Solving Outcomes		
QOP	Quality of plan (problem solving solution)	0.00	0.00
EPP	Efficiency of planning process	0.00	0.00
EPE	Efficiency of plan execution	0.00	0.00
	Decision to Take Action		
DTA: COA	Superior to subordinate: issuing a course of action	4.72	1.21
DTA: RTA	Peer-to-peer request a team member take action	2.75	4.09

In general, the large number of speech turns/chat log entries coded as individual information gathering and team information exchange indicate the huge emphasis knowledge construction that is required for both tasks. The results reported here represent an initial analysis; additional analysis is planned.

Problem Solving Includes Taking Actions

These results corroborate results from other analyses based on analysis and coding transcripts from other dynamic decision-making tasks (Hutchins and Kendall, in press; Hutchins and Kendall, 2008). For example, in a 30-minute air warfare scenario, nine decisions to take action were made by the air warfare team. Nineteen percent of the team communications from the Fire Department of New York responding to the Sept 11, 2001, attacks on the World Trade Center were decisions to take action.

Table 3 provides examples of the macrocognitive process Decision to Take Action from the NORAD data. It includes examples of two sub-categories: issuing an order regarding a course of action *(coa)* and requesting a team member take some action *(rta)*.

Table 3. Examples of Decision to Take Action from NORAD Coding.

Speech Turn	Code
Your pilots should be loading and just make sure your pilots load up their mode 2 and mode 4.	DTA (COA)
Give me a track number on that bomb -- that guy going by Cleveland.	DTA (RTA)
Give me an arrow, Bud. Scope 2, scope 1.	DTA (RTA)
Just make sure its squawking.	DTA (RTA)
On your mode 2, make sure that's standard and also make sure you're mode 4 is all loaded up as well.	DTA (COA)
Turn him around and have him go look.	DTA (RTA)
Can you help some of these people at tracking this bird?	DTA (RTA)
And get all mode 3.	DTA (COA)
Have them call Washington Center for that.	DTA (RTA)
If you don't see them, call right away. If you see it and they haven't hit it up, call that center.	DTA (COA)
Tell them we need to know where Air Force One is.	DTA (COA)

Table 4 provides examples from the air operations center Chat log exchanges coded as macro-cognitive processes in the model of team collaboration.

Table 4. Examples from Chat log Entries Coded as Macrocognitive Processes in the Model of Team Collaboration.

	Additional Codes
1	**Administration** ▪ I was told not to be in Special Operation Liaison Element (SOLE) room ▪ **Decd** how copy? ▪ Test ▪ Battlefield Coordination Detachment (BCD**)** Fires do you have communication with the CHOPS?
	Miscellaneous ▪ Have Information Operation (IO) tell (A/C #9) that we'll have some jack in the crack waiting for him ▪ Roger (RGR) Thank You ▪ CO rgr on *TARGET*
	COA: **Course of Action** ▪ Contact (a/c #12) on **TAD** (circuit #2) for clearance to drop. ▪ Intelligence Surveillance and Reconnaissance Cell (ISRC): Move a/c to provide over watch for Special Operation Force (SOF) teams at *TARGET* ▪ **Decsole**: you can move both A/C #2 and A/C #10 to training camp loc vicinity (city #3) and (city #5) to Bakersfield. Upon completion of mission, and NLT 1102Z, both assets return to current location
	RTA: **Request to Take Action** ▪ Please pass reports in Intel Reports ▪ Analysis Correlation and Fusion (ACF): Pass coordinates for (Location) Transload
	Individual Knowledge Building

2	IIG: **Individual Information Gathering** ▪ QUESTIONS: What is the correct way to pass tasking to a predator to attack? ▪ Joint Coordinating Element (JCE) do you know the local threat/ risk in (target location), and do you have imagery location of the locations? ▪ Any Battle Damage Assessment (BDA) reports/imagery post-strike for aircraft?
	IIS: **Individual Information Synthesis** ▪ CO – Negative – Tomahawk Land Attack Missile (TLAM) only hitch is in SEAL teams burn them for ground support. ▪ Senior Intelligence Duty Officer (SIDO), Reliable sources report probably radiological transload site at @LOCATION@ ▪ Reliable sources report known (Country #2) bomb component supplier, is awaiting a large shipment of explosives ▪ It is suspected that (Country #1) uses this location as a storage facility for spent fuel.
	KOD**: Knowledge Object Development** ▪ Code not used
	Team Knowledge Building
3	TIE: **Team Information Exchange** ▪ ***** priority coordinated, entered and pushed to Joint Time Sensitive Targeting Manager (JTSTM) ▪ The actual snatch and grab would be possibility for SOF but we would need the intelligence assist. ▪ ISRC: for your information, @LOCATION@ is now SOF mission; reconnaissance a/c #1 to provide over watch, SOF is in contact with a/c now.
	TKS: **Team Knowledge Sharing** ▪ Self defense applies for hostile acts from (Country #3) fighters in (Country # 2) or (Country #4) airspace ▪ Enemy forces that employ ordnance, Electronic Attack (EA), or fore control systems (achieve a radar lock) against friendly forces have committed a hostile act.
	TSOG: **Team Solution Option Generation** ▪ Awaiting radiological impact assessment on watershed if strike building. Second option in work is deny (destroy) local roads to prevent access in/out. ▪ If we crater the runway and taxiways, we may be able to effectively stop the target. ▪ To shorten timeline for tactical tomahawk we can launch to loiter. ▪ Will attempt to mitigate with weaponeering
	TENA: **Team Evaluation and Negotiation of Alternatives** ▪ 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?
	TPPR: **Team Process and Plan Regulation** ▪ Not used
	Internalized Team Knowledge
4	TKS: **Team Knowledge Similarity** ▪ SIMISM. C2WSPTT always expends all weapons on attack ▪ He wouldn't request return to base he'd tell you he is returning to base
	TKR: **Team Knowledge Resources** ▪ Interpositional Knowledge (IK): I remember sketchy authentication ▪ Individual situation awareness (ISA): a/c #2 is out of position, looks like other strike assets quicker
	Externalized Team Knowledge
5	ECSA: **Externalized Cue-strategy Association** ▪ The DEC Chief stated that if there is an erect launcher in a JSOA his "ROE" is to kill it ASAP and if there is time to deconflict with the teams ▪ He mentioned TLAMs wouldn't be deconflicted either, but I dispute that logic. First, we wouldn't use a TLAM shot to kill a launcher I don't think. Unless it was a last resort. ▪ Can get SOF Team to location as additional resource if we elect to monitor the site for any potential leadership meetings that may occur later given that location is used for meetings and (target) is there now.

	PRTA: **Pattern Recognition and Trend Analysis** ▪ Co, TDO, looks like ****** may be similar to our first target with regards to unknown presence of Radiological containers in facility. We would look at interdiction for containment to prevent travel to/fm that site, your thoughts on best plan/option
	UR: **Uncertainty Resolution** ▪ TLAMs most definitely have to be de-conflicted even for over flight of the Joint Special Operations Area (JSOA)-unless direct otherwise by the Joint Force Commander (JFC)
	Team Problem Solving Outcomes
6	QOP: **Quality of Plan** • Not used
	EPP: **Efficiency of Planning Process** • Not used
	EPE: **Efficiency of Plan Execution** • Not used

DISCUSSION

A new macrocognitive process emerged during the coding process: Decision to take action. Deciding to take action is viewed as both a macrocognitive *process* and a *product* of team collaboration. Results indicate additional macrocognitive processes need to be included in the model to represent decision making which occurs during execution of real-world tasks.

New Coding Category: Decision to Take Action

Many critical tasks that involve team collaboration 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.). Moreover, 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. For example, in MIOs members of the boarding party physically search the ship using sensing equipment to take various readings which are sent to experts at reachback centers for analysis. In some cases, members of the boarding party are then asked to take additional readings to provide more fine-grained data that will help more precisely determine the type of cargo on the ship. This process of physically searching the ship for contraband cargo and suspect people entails a series of actions, as reflected in many speech turns requesting a team member to take an action.

For the task domains reported on here, 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 taking various actions that move the problem along.

Challenges associated with analyzing this type of data include: (1) the need to be familiar with the domain to understand processes employed and jargon; (2) speech turns cannot be coded in isolation – following the many different "threads" being discussed, which are inter-leaved with other threads, necessitates going back through the transcript to follow the thought process for each of the various sub-tasks; (3) resolving differences in coding is a collaborative process where each person expresses their interpretation of the speech turn; (4) in some cases, needing to listen to the audio for intonation; (5) in some cases we accessed subject matter experts to decipher jargon and understand standard operating procedures; and (6) one needs to understand the relationships between team members from different organizations and the hierarchy of the organizations.

Several macrocognitive processes included in the model were not evident in the two decision-making domains analyzed. This is attributed to the perspective used when developing definitions for these processes, which was from a measurement perspective. Measures lean heavily toward laboratory experiments so several are not possible when analyzing transcripts of real-world scenarios. We typically obtain the transcripts after the fact, such as, the Fire Department of New York collaborating to deal with the terrorist attack on Sept 11, 2001, NORAD/FAA collaborating to get all aircraft out of the sky, also on 9-11, etc. so we do not have the ability to ask participants to complete surveys or obtain many of the measures included for the cognitive processes in this model of team collaboration.

CONCLUSIONS

A new macrocognitive process emerged during the coding process: decision to take action. Results indicate additional macrocognitive processes need to be included in the model to represent decision making which occurs during execution of real-world tasks. Deciding to take action—in the dynamic decision-making domains analyzed for this research—is viewed as both a macrocognitive process and a product of team collaboration. Results indicate additional macrocognitive processes need to be included to the model to represent decision making which occurs during execution of real-world tasks.

Many real-world tasks do not have criteria for assessing problem-solving outcomes, such as, MIO, air warfare, firefighters, NORAD, and the AOC. For the tasks analyzed to date for this research, no metrics are available to assess the "goodness" of the team's performance, thus, there was no evidence for several of the macrocognitive processes included in the model. In a similar vein, speed is not always a criterion for good performance, such as planning at the operational level. When planning at the operational level of war, the focus is more on the *quality* of the plan versus time to build the plan. In several cases, these metrics do not transfer to measuring the macrocognitive processes entailed in real-world problem-solving situations.

Through use of a cognitive systems engineering approach researchers can gain insight into cognitive functions used by team members and how teams perform these functions. This insight can then be used to support the cognitive requirements of work, in this case, team collaboration activities. The research reported here represents one aspect of a larger effort with the long-term goal of contributing to the design of collaborative tools to provide better support to collaborating teams.

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