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STRUCTURAL MODEL OF TEAM COLLABORATION

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Introduction

The purpose of this paper is to describe a structural model of team collaboration emphasizing the cognitive aspects of the collaboration process. The model includes the domain characteristics, collaboration stages, meta-cognitive processes, information processing tasks, knowledge required for each information processing task and the communication mechanisms for knowledge building and information processing tasks. There have been various models of team collaboration (Orasanu & Salas, 1992; Rogers & Ellis, 1994; Stahl, 2000; McNeese, Rentsch, Perusich, 2000; Hurley, 2002; Noble, 2002) each focusing on various aspects while describing those aspects at different levels of detail. However, for a model of collaboration to be an effective mechanism for understanding the operating cognitive mechanisms underlying collaborative team behavior the model needs to be defined at a level of granularity, which covers all the major components and mechanisms of team collaboration. The approach to describing the model is as follows: (1) define the problem domain for the model, (2) define all the various collaboration stages that a team goes through to solve the problem, (3) define the meta-cognitive processes that guide team collaboration, (4) define and describe the information processing components that the team performs to achieve each collaboration stage, (5) define the knowledge required to achieve each information processing component and (6) define the communication mechanisms used by the team to build the necessary knowledge along with supporting the information processing. The cognitive mechanisms in the model are described at a *macro level* (i.e. meta-cognition, information processing, knowledge building and communication mechanisms) rather than at the micro level (i.e. neural-cognitive). The reason for describing the model's cognitive processes at the macro level is driven by our limited understanding of how teams think during collaborative problem solving in asynchronous, distributed environments. In addition, our current metrics for measuring, at the micro level, the cognitive mechanisms teams use to solve collaborative problems are still very inadequate. The model's macro level definition of the cognitive processes (i.e. meta-cognition, information processing, knowledge building and communication mechanisms) permits empirical assessment of these cognitive processes using our current measurement techniques (e.g. verbal protocol, communication analysis). Since the focus of this structural model is on the cognitive aspects of team collaboration specific areas were not addressed. The areas not addressed in the model include: (1) Information Technology / Computer Science, (2) human performance modeling (e.g. ACT-PM, SOAR) and (3) team social behavior. The first two areas are enabling technologies, which when integrated with collaboration tools will enhance team collaborative performance. Team social behavior is a complex area and significantly influences how teams collaborate and needs to be an added module to the model. However, the area of team social behavior was beyond scope for this initial model development effort. In the future, research from team social behavior needs to be included as another component within the model.

Before getting into a detailed model description it is important to understand the scope of the problem area that the collaborative model will be addressing. Figure 1 illustrates the major factors impacting military collaborative teams. These factors include the *Collaborative Problem Environment*, *Operational Tasks, Collaborative Situation Parameters,* and *Team Types*.

The collaborative problem environment has grown in complexity over the past decade (Jensen, 2002). The military problems are becoming more complex requiring *teams* to address the problems. In addition, problems are addressed at an international level requiring agile coalition operations. Developments in information and communication technologies have provided greater communication between coalitions, but information overload is still a problem due to a lack of information management (Information Management Strategic Plan, 1999). There are many operational tasks, which involve team collaboration (Jensen, 2002; Joint Vision 2010, 2002). However, to gain an understanding of the team collaboration process the model will focus on three operational tasks: (1) team decision making, course of action selection, (2) developing shared understanding, and (3) intelligence analysis (team data processing). During team collaboration there are various parameters that can influence collaboration performance (Warner, Letsky & Cowen, 2003). However, the collaborative situation parameters listed in Figure 1 were chosen as the critical parameters to focus our collaboration domain because of their significance to current military requirements (Jensen, 2002). The final factor is team types, which of all the factors has the most number of different categories that can influence collaboration performance. The 7 team type characteristics listed in Figure 1 were selected based on the common characteristics of today's military collaborative teams (Jensen, 2002). In summary, the problem area domain for our structural model of team collaboration can be defined by the respective characteristics under operational tasks, collaborative situation parameters, and team types specified in Figure 1.

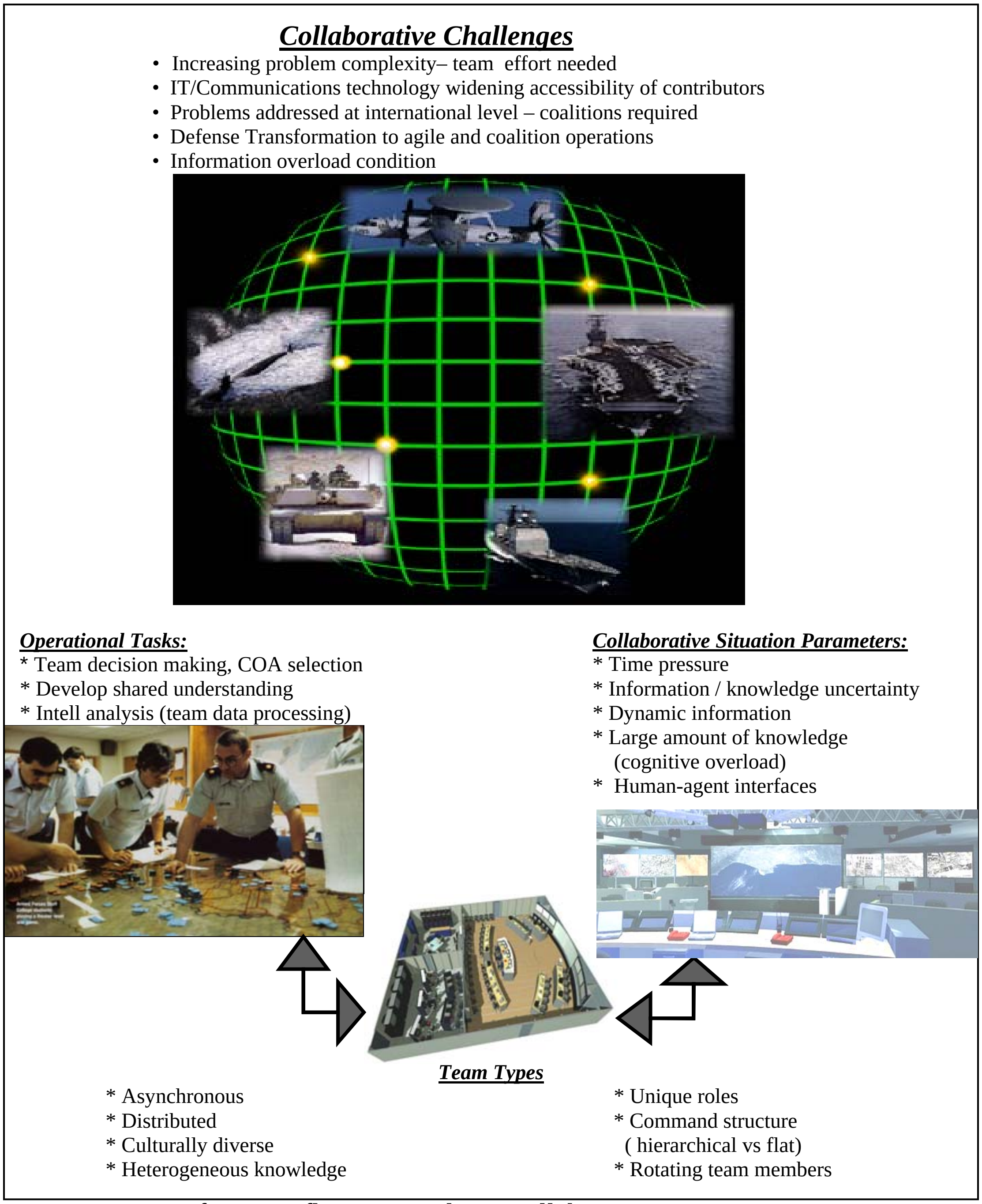


Figure 1: Major factors influencing military collaborative teams.

In addition to understanding the model's problem domain, it is also important to understand how current theories of cognitive psychology impact the model definition and design. One of the key issues in developing a collaboration model is to understand the cognitive processes that team member's use as they perform the various stages of collaboration. To understand these cognitive processes it is necessary to examine the various theories of cognitive psychology. Early philosophers such as Descartes (1641) and Kant (1781) have examined basic questions of the origin of knowledge and human thought. However, it was not until after the failure of behaviorism (Skinner, 1985,1989) to explain internal representations that cognitive psychology emerged. A multitude of theories of human cognition began to develop. Several theories (Turing, 1936; Weiner, 1948; Shannon, 1949; Wickens, 1992) explain human cognition in terms of *an information-processing* model, which focus on information representation, processing, and computation. Other theories (Chomsky, 1957; Cooke, 2003) believe that the development of knowledge and the processes of thought are achieved through human *language*. Piaget's (1970b) focused on *developmental biology*, which described not only the different components of human cognition, but also the developmental stages of cognition. As computer science matured, several theories developed (Newell & Simon, 1956; Feigenbaum & Feldman, 1963; Anderson, 1993; Minsky, 1997) that explain human cognition in terms of a *computer computational model*. These computational models varied in how they explained cognition ranging from computational logic, production rules (e.g. If X Then Y), to frames (data structures). Other theories (Rumelhart, 1990; Churchland, 1989; Rosenburg, 1988) emphasize physiology in understanding human cognition. These theories use *physiological neural networks represented in computational models* to explain cognition and its processes. Davidson, Deuser & Sternberg (1994) proposed a theory of *meta-cognition*, which is knowledge of one's own cognitive processes, in explaining how human cognitive processes are used in problem solving. Each theory has provided unique insight and empirical data to explain various aspects of human cognition and its processes. Current research in human cognition uses a multidisciplinary approach by considering ideas from all the relevant disciplines including philosophy, psychology, linguistics, computer science, anthropology, cognitive neuroscience, and artificial intelligence. However, even with this multidisciplinary approach, there is no generally recognized unified theory of human cognition. This lack of a unified theory is partially due to the recent integration of the various disciplines in studying human cognition along with insufficient objective metrics to measure the cognitive processes. The challenge in representing the cognitive components in a collaboration model is deciding what theoretical approach(s) to utilize during initial model development. There is insufficient empirical research describing the actual cognitive processes that teams use during collaborative problem solving, especially under conditions specified in Figure 1. As a result of this deficit, the cognitive components of the team collaboration model shall be described using current theories of *meta-cognition, human information-processing and human communication.* These theoretical approaches were selected based on our current ability to measure how teams use communication (i.e. written and verbal) to process information and build knowledge during collaborative problem solving. This level of granularity in describing the cognitive processes in team collaboration permits empirical evaluation of the various components of the model. However, this level of granularity will not provide a comprehensive view (e.g. neural components) of the cognitive processes used in team collaboration. A detail description of the model's cognitive components and processes are presented under the model section of the paper.

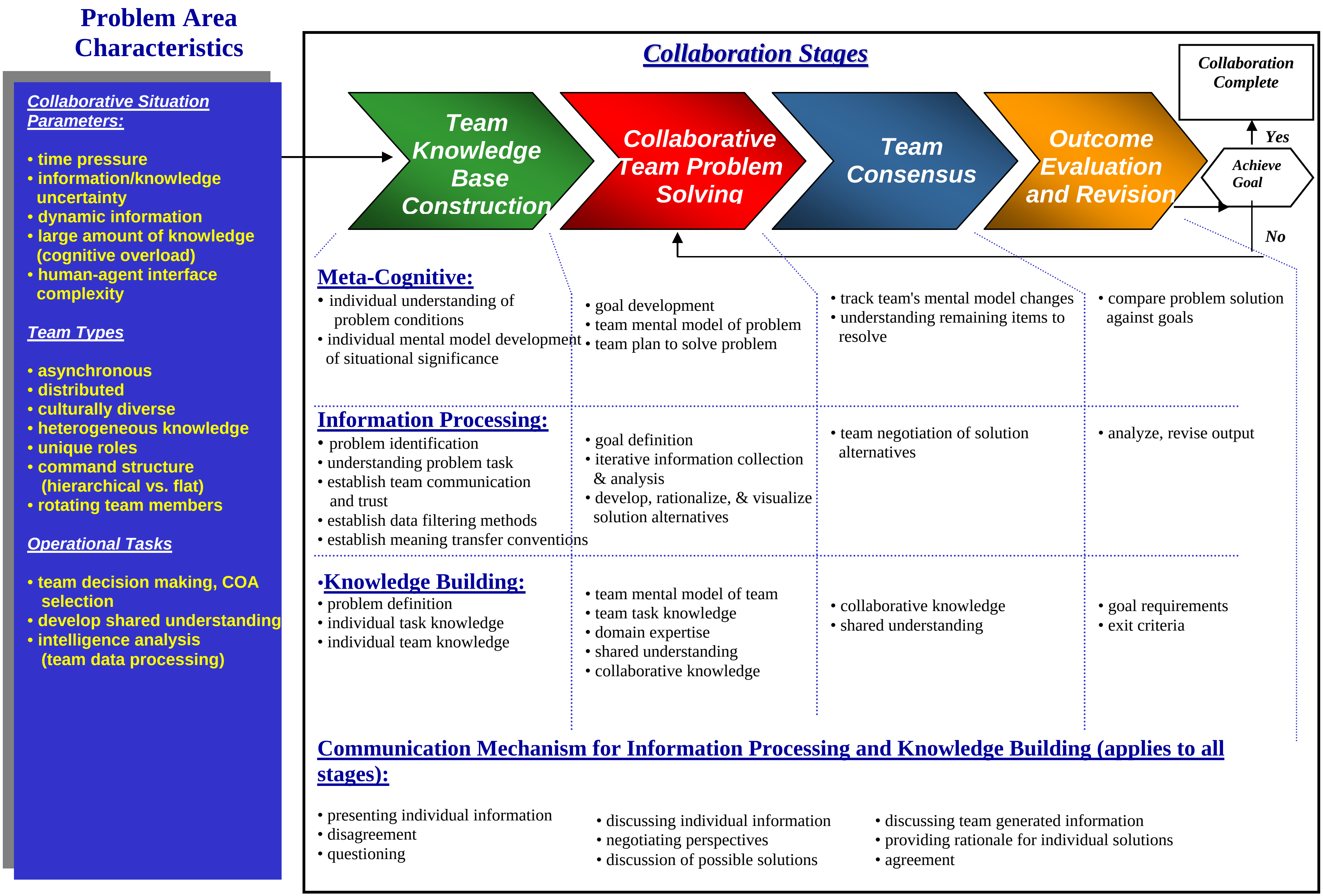
In describing the team collaboration model it is important to understand what is meant by the term model along with understanding the objectives of the model. A *model* is not the system or process itself but an abstract representation that enables researchers to predict behavior and to test hypotheses. Models may be mathematical, physical, or structural. For example, information theory and signal detection theory are mathematical models; neuro-anatomical models are examples of physical models, while information-processing models are examples of structural models. Due to the lack of sufficient objective metrics for measuring cognition, most models in cognitive science are either structural or mathematical not physical models. The *objectives* of the proposed team collaboration structural model are: (1) to understand the cognitive mechanisms and their relationships during team collaborative problem solving, (2) to provide a model-based approach to experimentation of team collaboration, (3) to identify and prioritize required areas of research in team collaboration, and (4) to serve as a design guideline for an agent-based support tool for team collaboration.

Structural Model of Team Collaboration

Figure 2 presents the structural model of team collaboration. The model's domain is defined by the *problem area characteristics*, which were described earlier in this paper. The model consists of general *inputs* (e.g. task description, team roles), *collaboration stages* that the team goes through during the problem-solving task, the *cognitive processes* used by the team and final team output(s) (e.g. selected course of action, recommendations, products). The four cognitive processes include: (1) the meta-cognitive processes, (2) the *information processing tasks*, and (3) the *knowledge required* to support the information tasks, and (4) the *communication mechanisms for knowledge building and information processing*.

Before describing each component of the model it is important to understand how the model was derived. The model is a *synthesis* of the literature in team collaboration, human information processing, and team communication together with the results obtained during the 2003 Annual Workshop on Collaboration and Knowledge Management (Letsky, 2003). During the Collaboration and Knowledge Management (CKM) workshop 12 initial conceptual models of team collaboration were produced each providing some unique information along with overlapping information. The models varied in their approach from information-processing, team recognition primed decision making, transactive memory, discovery and innovation, and hybrids including multi-stage and process models. In addition, the workshop identified major factors to consider in developing a team collaboration model, especially for the problem domain illustrated in Figure 1. Some of the major factors include providing basic input information to the team (e.g. task description), team member roles / responsibilities, communication of significant information between team members (e.g. problem identification, goal definition, solution alternatives), developing team consensus, and building knowledge to support solution alternatives. The collaboration stages within the model were selected by determining the minimum number of unique stages identified in the team collaboration literature together with the 12 models. These stages also had to be supported by some empirical research. The cognitive processes required during team collaboration are based on an information-processing approach, which also includes knowledge building for supporting the information processing tasks. In this model knowledge is built through team communication with the initial communication mechanisms derived from previous research (Stahl, 2000; Cooke, 2003; Warner, Vanderwalker and Verma, 2003)

Figure 2: ***STRUCTURAL MODEL OF TEAM COLLABORATION***



Model Components

Inputs to Model. These inputs represent general information that is required prior to team collaboration. This information includes such items as: (1) a description of the problem task to be solved, (2) team member expertise, (3) organizational structure, (4) team members roles and responsibilities and (5) projected events/future information, (6) resources available, (7) supporting collaboration technology, and (8) the certainty of the information. This representative domain information is provided to the team during team formation to the degree that it is available.

Collaboration Stages and Cognitive Processes. The model has four unique but interdependent stages of team collaboration. The stages are: *Team Knowledge Base Construction*, *Collaborative Team Problem Solving*, *Team Consensus*, and *Product Evaluation & Revision*. There is also a feedback loop for revising team solutions. The stages are not strictly sequential as it may appear in Figure 2. The team may start in the Team Formation stage and proceed onto Collaborative Team Problem Solving, Team Consensus, and Product Evaluation and Revision. However, team communication is dynamic across the stages throughout the collaboration process. The cognitive processes are represented at four levels: *Meta-cognition*, which guides the overall problem solving process, the *Information Processing Tasks* required by the team to complete each collaboration stage, the *Knowledge Required* to support the information processing tasks and the *Communication Mechanisms for Knowledge Building and Information Processing.* For each collaboration stage the respective supporting cognitive processes will be described.

Team Knowledge Base Construction is the first step in team collaboration and begins by identifying the relevant domain information required, selecting the required team members, setting up the communication environment necessary to address the problem, individual team members developing their own mental model of the problem, and developing individual and team task knowledge. The type of teams representative in this model have characteristics such as being asynchronous, distributed, culturally diverse, having heterogeneous knowledge, and rotating team members (see Problem Area Characteristics for complete list).

Meta-cognitive Process: The meta-cognitive component in Team Knowledge Base Construction is the development of individual team member's *understanding* of the elements, relations and conditions that compose the initial state of the problem. Also part of this meta-cognitive process is for each team member to construct an individual mental model of the situation parameters and their relationships.

Information Processing Tasks: The team has several information processing tasks to perform during the team formation stage. The team has to collect information to identify the problem to be solved, to understand the problem task, and establish team communication mechanisms for transfer of meaning to multidisciplinary team members. In identifying and understanding the problem task team members must recognize that a problem exist before they can solve it. Critical elements of the problem need to be encoded in each member's short-term memory while information relevant to these elements are retrieved from long-term memory.

Knowledge Required: Three types of knowledge need to be built and used by the team members in support of completing the information tasks. Each team member needs to develop his or her *individual knowledge* of the task. The team, as a whole, needs to establish a combined representation of the *team's knowledge* of the task. Individual and team task knowledge does not have to be exactly the same. The third knowledge type is the *team's knowledge of the problem to be solved*.

Communication Mechanisms for Knowledge Building and Information Processing: In order for the team to build the required knowledge base needed to support the information processing tasks the team will use the following data collection and human information processing techniques:

- information retrieval
- information filtering
- information fusion
- information display and visualization
- meaning development
- knowledge building
- understanding

Specific communication mechanisms between team members include:

- Presenting individual information
- Discussing individual information
- Discussing team generated information
- Negotiating perspectives
- Providing rationale for individual solutions
- Agreement
- Disagreement
- Questioning
- Discussion of possible solutions

The following *collaboration capabilities* are required to facilitate the team using the above mechanisms during the Team Knowledge Base Construction stage :

- Hardware / software infrastructure for team communication
- agent-based information exchange support (i.e. assisting conversations, terminology, and knowledge interoperability)

- Conventions for information exchange

Collaborative Team Problem Solving is the next stage and begins following completion of the Team Knowledge Base Construction information processing tasks. The collaborative Team Problem Solving stage is where the majority of collaboration occurs among team members. The team's main objective in this stage is to develop viable solutions to the problem.

> *Meta-Cognitive Process:* The meta-cognitive processes involved in this stage includes, overall goal development, developing a team mental representation of the problem and planning how the team will solve the problem. The team mental representation can change during the course of solving the problem. Changes can occur as the team gains more complete understanding of the problem elements, goals or overlooked information. According to Davidson and Sternberg (1984, 1986), new mental representations are constructed through three related mental processes: *selective encoding*, *selective combination*, and *selective comparison*. *Selective encoding* restructures the team mental representation so that information that was originally viewed as being irrelevant is now seen as relevant for problem solution. Also, information that was originally seen as relevant may now be viewed as irrelevant and eliminated from the team's mental representation. *Selective combination* involves putting together elements of a problem task in a way that previously has been nonobvious to the team. This new way of combining the problem elements results in a change in the mental representation. *Selective comparison* involves discovering a nonobvious relationship between new information and information acquired in the past. The realization of a relationship between new and old information results in a change to the mental representation. After the problem has been identified and mentally represented, the team must decide which steps to use in solving the problem. Planning often involves dividing the problem into subproblems and then devising a sequence for how the subproblems should be completed (Hayes, 1981). There are three characteristics of planning (Pea & Hawkins, 1987). First, the team is more likely to engage in planning when the problem situation is novel and complex because there are no known strategies to follow. Second, planning tends to be abstract rather than concrete because the team revises their plan based on how well it is working and available opportunities for modifications. Third, plans have both costs and benefits, which involves time and cognitive resources, but overall improve problem solving efficiency. In team problem solving there are four *heuristics* that are often used (Greeno & Simon, 1988). One is the *means-ends analysis*, which tries to decrease the distance between the team's current position in the problem space and where the team wants to go in that space. A second heuristic is *working forward*, which involves starting at the initial problem state working toward the desired state. The

third heuristic is *working backward*, which involves starting at the desired state and trying to work back to the initial state. The fourth heuristic is *generate and test*, which involves generating alternative courses of action and evaluating whether each course will work.

Information Processing Tasks: In order to develop problem solutions the team performs several information processing tasks. These tasks include definition of the team goal, iterative information collection and analysis, and development, rationalization and visualization of solution alternatives.

Knowledge Required: Five types of knowledge are required in support of completing the information tasks. Each team member needs to continue to develop his or her *individual knowledge* of the task. The team, as a whole, needs to continue to develop the *team's knowledge* of the task. The team, in addition, needs to develop *shared understanding* (i.e. joint agreement of the facts and recognition of team member perspectives but not joint acceptance). *Collaborative knowledge* (i.e. team negotiation of perspectives resulting in a deeper understanding and team agreement of the facts) also needs to be developed by the team. The last knowledge type is *domain expertise*, which is not developed by the team during collaboration, but is required by team members to successfully perform the information processing tasks.

- *Communication Mechanisms for Knowledge Building and Information Processing:* During the Collaborative Team Problem Solving stage the team will use some or all of the communications mechanisms discussed earlier to perform the information processing tasks and knowledge building.

The following *collaboration capabilities* are required to facilitate the team using the above mechanisms during the Collaborative Team Problem Solving stage:

- infrastructure for team collaboration including
    - agent-based structural collaboration model
    - data retrieval, fusion and presentation
    - critical thinking and negotiation
    - knowledge retrieval among team members
    - identification of team differences
    - joint data visualization
    - hidden knowledge elicitation

<u>Team Consensus</u> is the next collaboration stage and *begins* when the team has several viable solution alternatives to the problem. The main objective of team consensus is to achieve team agreement of the common output.

<u>Meta-cognitive Process:</u> The meta-cognitive processes involved in this stage includes, the team keeping track of what they have already done, what they are currently doing, and what needs to be done. In other words, the team needs to track changes to the team's mental model.

<u>Information Processing Tasks</u>: In order for the team to achieve agreement of the common output, the members' mental models of the solution must converge forming a unifying team mental model. The information-processing task under this stage is team negotiation of the solution alternatives.

<u>Knowledge Required:</u> Two types of knowledge are required to achieve convergence of the team's mental model and successful team negotiation of solution alternatives: (1) *shared understanding* (i.e. joint agreement of the facts and recognition of team member perspectives but not joint acceptance) and (2) *collaborative knowledge* (i.e. team negotiation of perspectives resulting in a deeper understanding and team agreement of the facts).

- *<u>Communication Mechanisms for Knowledge Building and Information Processing</u>:* During the Team Consensus stage the team will use some or all of the communications mechanisms discussed earlier to perform the information processing tasks and knowledge building.

The following *<u>collaboration capabilities</u>* are required to facilitate the team using the above mechanisms during the Team Consensus stage :

- visual representation of the team's mental model
- agent-based identification of team differences
- joint data visualization
- infrastructure for negotiation

<u>Outcome Evaluation and Revision</u> is the final stage of collaboration. The main objective of this stage is to analyze, test and validate the agreed upon team solution against the goal requirement(s) and exit criteria. Included in this stage is an iteration loop for deriving other solutions for the problem if necessary.

<u>Meta-cognitive Process:</u> The meta-cognitive processes involved in this stage include comparing the problem solution against the goal(s).

<u>Information Processing Tasks</u>: The information-processing task under this stage is for the team to analyze and revise the problem solution, if necessary.

<u>Knowledge Required:</u> In order for the team to perform the information-processing task, two types of knowledge are required: (1) goal requirements and (2) exit criteria for viable solutions.

- *<u>Communication Mechanisms for Knowledge Building and Information Processing:</u>* During the Outcome Evaluation & Revision stage the team will use some or all of the communications mechanisms discussed earlier to perform the information processing tasks and knowledge building.

The following *<u>collaboration capabilities</u>* are required to facilitate the team using the above mechanisms during the Outcome Evaluation & Revision stage:

- infrastructure for comparing team solution against problem space including mission and team decision metrics
- infrastructure for performing what-if analyses and effects-based planning

<u>Model Outputs</u>. The output of the model reflects the type of product from the team collaboration process. The product type will vary depending on the problem domain addressed by the team. This structural model of team collaboration focuses on the following product types:

- selected course of action(s)
- recommendations
- situation assessment
- risk assessment
- product or tool
- opinion
- guidelines

<u>Structural Model of Team Collaboration Example</u>

<u>Background</u>. To illustrate how this model represents team collaboration in a collaborative problem solving environment, a Noncombatant Evacuation Operation (NEO) scenario (Cowen, 2003; OPT Planning Guide, 2001) will be described. This example is designed to show how the Operation Planning Team (OPT) proceeds through the various collaboration stages along with the cognitive processes used to support each stage. Team collaboration during each collaboration stage and the various cognitive processes are very dynamic. It is beyond the scope of this example to capture *all* the team dynamics throughout the problem solving scenario, but this example will illustrate major

team collaborative behaviors and processes. In addition, team collaboration behavior and performance is influenced by the type and extent of collaboration technology employed when solving the collaboration problem (e.g. email, chat rooms, white boards, integrated text/video/audio tools, agent-based collaboration tools). This example will use basic email / chat room / video and web technology as a collaboration environment for solving the NEO scenario problem. It is important to remember that advanced collaboration concepts and technologies (e.g. conventions for transfer of meaning, data visualization techniques, mental model development techniques, team shared understanding techniques, collaboration performance metrics) can enhance team performance in both the collaboration stages and the cognitive processes. It is the challenge of researchers in the field of team collaboration to provide these advanced concepts and technologies, and to map these concepts and technologies into their respective areas within the team collaboration model. The result would be a model that is constantly being updated with new research while serving as a design guideline for new team collaboration tools.

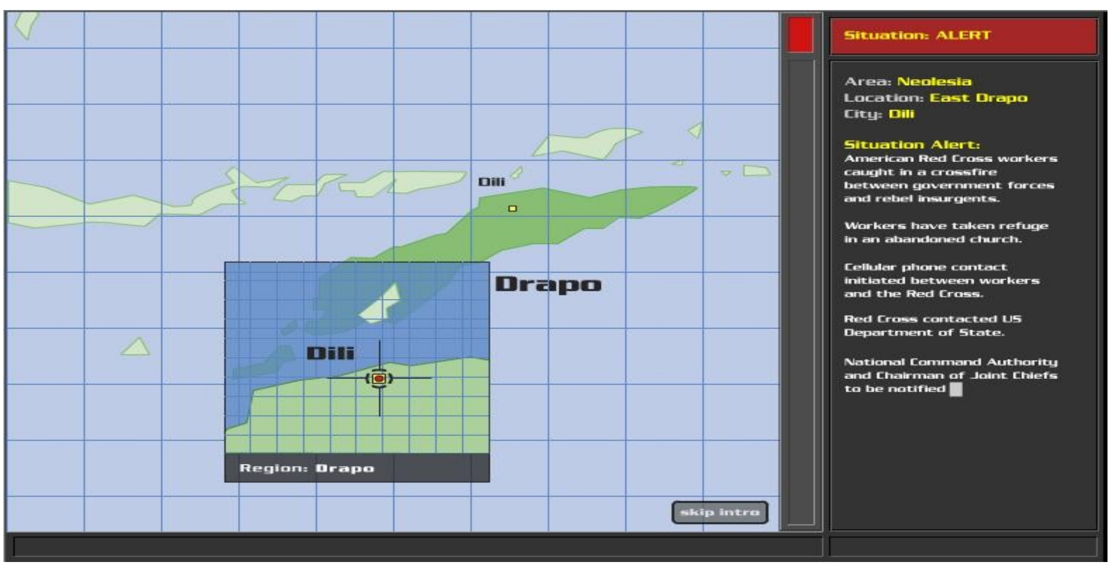
The Noncombatant Evacuation Operation scenario is planned and executed by the *Operation Planning Team (OPT)* at the United States Pacific Command (PACOM). The OPT is responsible for planning all military operations in the PACOM theater of operations. This includes 44 countries covering 51% of the earth's surface. Seventy five percent of all natural disasters occur in the PACOM Theater. The NEO decisions are handled by the **OPT Key Planners**, which has *eight members who are geographically separated*. The eight members are senior staff specialists from different PACOM directorates. The Key Planners has access to 59 OPT personnel consisting of representatives from special staff (legal, medical) and Joint Task Force components as well as the five OPT Core Group members who collect input and assessment information and post to the OPT web page. In addition to the OPT web site, the OPT members meet in a **Virtual Situation Room**, to learn more about the unfolding situation, military assets available, distances between key places, cargo, weather, terrain, local news, intelligence reports about threats, and capability/availability of our assets. The OPT members meet in the **Virtual Planning Room** to draft the execution plan and to monitor and evaluate the plan during execution. Figure 3 illustrates the Virtual Situation Room and the Virtual Planning Room.

Figure 3. Virtual Situation and Virtual Planning Rooms

Team Collaboration Model Example.

Inputs.

The OPT Key Planners are given the following problem:



Increasing tensions on the Southern Pacific island of Drapo have resulted in clashes between Government military forces and rebel insurgents. As the scenario begins, a group of American Red Cross workers traveling a jungle road near the city of Dili in East Drapo becomes caught in a crossfire between government and insurgent forces, and takes refuge in an abandoned church. Luckily, their cellular phone still works, and they contact the American Red Cross office. As word of the workers' plight becomes known, the Red Cross contacts the US Department of State to alert the US Government and seek assistance. DOS notifies the National Command Authority (NCA) and Chairman of the Joint Chiefs of Staff, alerting them to the situation, which results in an Interagency Working Group being formed to support the NCAs decision-making responsibilities. The members of the Interagency Working Group include the Department of Defense, the National Security Council, the Department of State, the Central Intelligence Agency, and the US Agency for International Development, along with the Commander in Chief of the US Pacific Command (PACOM), whose area of responsibility includes the South Pacific. Additional agencies may join the Interagency Working Group as the crisis develops and the NCA considers different options.

Problem Area Characteristics.

This scenario illustrates a distributed, asynchronous team with heterogeneous knowledge working in a flat command structure collecting information and generating alternatives, in performing a COA selection task under time pressure, with information / knowledge uncertainty, large amounts of knowledge and dynamically changing information. Team interactions of interest are defined by four unique but interdependent stages of team collaboration: (1) team knowledge base construction, (2) collaborative team problem solving, (3) team consensus, and (4) outcome evaluation & revision.

Collaboration Stages and Cognitive Processes:

Team Knowledge Base Construction. During this first stage of collaboration, the OPT members have two objectives to achieve: (1) to convene as a team (using the virtual situation room) where they will be notified that a warning order has been received and their assistance is needed to develop and evaluate Course of Action options, and (2) to understand the situation and mission as a team (using the virtual situation room).

Cognitive Processes. In order to achieve the two objectives the OPT members need to develop a team understanding of the problem conditions and their own individual mental model of the situation. Both team understanding and individual mental models are developed as the team builds knowledge about the problem, and as their individual and team task knowledge develops. Problem and task knowledge develops through *communication* among OPT members using the information available in the Virtual Situation Room. This communication occurs in an asynchronous, distributed fashion. Such information includes major events that have occurred, components of the situation that might require military resources, location of the situation, groups and organizations involved in the situation, topography, climate and weather, transportation, telecommunications, politics, coalition capabilities, and enemy capabilities. The communication mechanisms involved for building problem and task knowledge include a subset of those items in Figure 2. Such items include presenting and discussing individual information, questioning, agreeing / disagreeing, and discussing team generated information. After the OPT members develop the initial problem and individual and team task knowledge, the team can then use that knowledge to identify the specific problem to be addressed (i.e. three American Red Cross workers trapped in Dili church surrounded by fighting government and rebel forces) along with having a good understanding of the problem task (i.e. develop several COA's to evacuate three Red Cross workers near the city of Dili within the next 24 hours). Throughout the communication process between team members, team communication is established together with team trust. The team applies their knowledge of the problem, their individual and team task knowledge and their team trust to support the next collaboration stage, Collaborative Team Problem Solving.

Collaborative Team Problem Solving. The OPT has one objective at this stage, which is to develop COA's that fulfill requirements in the warning order. The OPT will use the Virtual Situation Room for team member communication for collecting and analyzing the necessary information to develop the various COA's. The Virtual Planning Room will be used by the OPT to develop the various COA options, provide COA rationalization, COA visualization, and to monitor execution of the selected COA.

Cognitive Processes. For effective team collaboration at this stage the OPT needs to develop a team goal, develop a team mental model of the problem, and develop a team plan to solve the problem. The goal in this scenario is given to the OPT, which is to develop and evaluate various COA's that successfully meet the warning order (i.e. evacuate the three American Red Cross Workers within 24 hours) and to recommend the best COA for execution. The team mental model and team plan will evolve as the OPT collects and analyzes information along with developing, rationalizing and visualizing COA options. In order for the OPT to develop COA options there are several types of knowledge required, individual task knowledge, team task knowledge, domain expertise, team shared understanding and collaborative knowledge. The OPT members have developed *some* individual and team task knowledge from the earlier stage along with the domain expertise they bring. However, there is little team shared understanding or collaborative knowledge at this point because the OTP has been gathering information on the problem with little collaboration. As the OPT collects, analyzes, and discusses information relevant to COA options both team shared understanding and collaborative knowledge will increase. Individual and team task knowledge will also increase. The OPT's mental model of the problem will be further developed as the team goes through the iterative information collection, analysis, discussion process. The type of information collected, analyzed, and discussed include combat forces required, force movement, staging locations, destination, required delivery date of forces, and effect of enemy COA on the success of our COA option. The OPT will use their shared understanding, collaborative knowledge and task knowledge to develop, rationalize and visualize the various COA options. The mechanism for building the knowledge types and the COA options are the same communication mechanisms listed in figure 2 (e.g. discussions of possible solutions, negotiating perspectives, questioning, agreeing). The final outcome at this collaboration stage is a listing of viable COA's with advantages and disadvantages for each option. For this scenario a list of viable COA's for evacuation of the Red Cross Workers could include:

(1) <u>Marine Force Pacific</u> consisting of one AH-1 attack helicopter for air support and one CH-53 helicopter for transporting the evacuees. CH-53 personnel include one-armed squad of ten marines for support, two medical corpsman, five support aircrew, and pilot/co-pilot. All assets are stationed on CV-65 (Enterprise), which is located near Drapo Island.

<u>Advantages</u>:
* air and personnel assets located 100 miles from Drapo Island
* CH-53 holds 40 people
* sufficient air support (i.e. AH-1) against enemy threat
* sufficient armed ground support against potential enemy attack
* no re-fueling of air assets required
* travel time to designation = one hour (one hour return)

<u>Disadvantages:</u>
* air and personnel assets will not be ready for deployment for 10 hours

(2) US Army Pacific consisting of one Apache attack helicopter for air support and one UH-60 Blackhawk helicopter for transporting evacuees. The UH-60 includes one armed squad of five infantry personnel, two medical corpsman, four support crew and pilot/co-pilot. All assets are stationed on an Army base located 600 miles from Drapo.

Advantages:
* air and personnel assets are immediately available for deployment
* UH-60 has sufficient room for all aircrew personnel and evacuees
* sufficient air support against enemy threat

Disadvantages:
* UH-60 and Apache needs to re-fuel twice, once inbound, once outbound.
* minimum armed ground support against enemy attack
* travel time to designation = 6 hours (also 6 hour return)

Team Consensus. The objective at this stage is for the OPT to agree on which COA promises to be the most successful in accomplishing the mission. The OPT will negotiate COA alternatives through their team discussion using the virtual planning room. The virtual situation room may be used by the OPT if additional information is needed by the team to support negotiation.

Cognitive Processes. For the OPT to achieve effective collaborative negotiation and reach consensus on the best COA, the team needs to keep track of the changes in the team's mental model as they conduct COA negotiations. The OPT also needs to understand the remaining items to resolve when trying to reach consensus on the best COA. The OPT will use their team shared understanding and collaborative knowledge, which has been developing throughout the collaboration process, to update their team mental model and monitor remaining items to resolve. The OPT uses the communication mechanisms in Figure 2 (e.g. negotiating perspectives, providing rationale for individual solutions, questioning) during team negotiation to reach team consensus of the best COA. During team negotiation each COA (i.e. Marine option versus Army option) is discussed with respect to (a) the enemy's capability to adversely affect execution of our COA, and (b) the strengths and weaknesses of each COA and its probability of success within constraints of operational factors. This negotiation is a very dynamic cycle of team discussion, which leads to increase team shared understanding, collaborative knowledge and a richer team mental model, that in turn results in deeper team discussions. This dynamic team negotiation cycle is required for team consensus and produce the most effective COA. The final outcome of the team consensus stage is a selection of one COA, with rationale, that has the highest probability of success within the constraints of the mission. For this scenario example, the OPT agreed that the *Marine Force Pacific* Course of Action was the best option to meet mission requirements. The detail team negotiation process and rationale is not presented here, as it is beyond the scope of this example.

Outcome Evaluation and Revision. The objective at this stage is to evaluate the selected COA (i.e. Marine Force Pacific) and revise as necessary. Before executing the selected Marine Force Pacific option, the OPT conducted several what-if simulations to determine any problem areas and how robust the COA is in meeting the mission. No major problems were found and the Marine Force Pacific option was executed. The OPT used the Virtual Planning Room to conduct the what-if simulations and to monitor the COA during execution. **Cognitive Processes**. As part of the process of comparing the selected Marine Force Pacific option against the mission goals, the OPT needs to have a clear understanding of the mission goals. At this point in the collaboration process, the mission goal information has become part of the team's mental model and the OPT will use it's mental model during the COA evaluations. In addition, in monitoring the execution of the COA the team will use its shared understanding and collaborative knowledge to determine problem areas and possible revisions to the COA. The communication mechanisms for the team to evaluate and revise the COA are presented in Figure 2 (e.g. discussing team generated information, presenting individual information, questioning, agreeing). The Marine Force Pacific course of action was successful.

Summary

The proposed structural model of team collaboration is intended to be a starting point for understanding the cognitive mechanisms of team collaboration given the collaborative problem area characteristics presented in Figure 2. This model also offers a model-based approach to experimentation of team collaboration, which aids in designing specific research experiments while at the same enhancing the model through new research findings. In addition, the model will identify and help prioritize important areas of research in team collaboration with respect to ONR's Collaboration and Knowledge Management Program. Finally, the model can also serve as a design guideline for an agent-based support tool for team collaboration.

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Glossary of Terms

Collaboration: the process of shared creation; two or more individuals with complementary skills interacting to create a shared understanding that none had previously possessed or could have come to on their own. The cognitive aspects of joint problem solving for the purpose of attaining knowledge sufficient to complete the common task.

Shared Understanding: agreement by the group achieved through clarification of differences in interpretation and terminology.

Asynchronous Collaboration: a cohesive group of individuals working at different locations and at different times to solve a common task.

Mental Model: a knowledge structure that represents information.

Shared Mental Models: organized knowledge members have in common regarding the task.

Cognitive Process*:* Process by which readers, writers, and viewers actively construct meaning as they engage with texts by organizing, selecting, and connecting information; making inferences; and performing acts of interpretation.

Common Ground: Foundation for mutual understanding.

Computational Models: Calculational tool that implements a set of mathematical equations designed to represent a conceptual model.

Conceptual Models:

(1) Set of qualitative assumptions used to describe a system (or part thereof). These assumptions may cover the geometry and dimensionality of the system, initial and boundary conditions, time dependence, and the nature of the relevant physical, chemical and biological processes and phenomena.
(2) Consists of a set of assumptions that reduce the real problem and the real domain to simplified versions that are satisfactory in view of the modeling objectives and the associated problem.

Consensus: Opinion or position reached by the group as a whole.

Data: Factual information (as measurements or statistics) used as a basis for reasoning, discussion, or calculation. Data on its own has no meaning, but becomes information when it is interpreted.

Data Visualization: Presentation of processed information in a coherent and easily accessible way. Information can be presented in different forms using traditional devices such as pie charts, scatter graphs, line charts etc.

Decision: Passing of judgment on an issue under consideration.

Decision-Making: Form of problem solving in which one tries to make the best choice from among alternative judgments or courses of action.

Distributed Cognition: Acknowledges that in a vast majority of cases cognitive work is not being done in isolation inside our heads but is distributed among people, between persons and artifacts, and across time.

Heterogeneous Teams: Number of dissimilar or diverse constituents associated together in work or activity.

Human-Agent Interface: A connection point that allows for the interaction between a user and a software, which carries out some set of operations on behalf of a user or another program with some degree of independence or autonomy, and in so doing, employ some knowledge or representation of the user's goals or desires.

Information: Knowledge derived from study, experience, or instruction.

Knowledge Building:

(1) Process through which we increase both our individual and our common understanding.
(2) Theory of learning, which emphasizes the collaborative construction of knowledge by a group of learners.

Knowledge Elicitation: Acquiring knowledge from human experts and learning from data. The first stage is the initial understanding and structuring of the domain. The second stage is producing the working system (extract relationships between domain concepts). Finally, the system is tested and debugged. Techniques for knowledge elicitation include interviews, protocol analysis, concept sorting, goal decomposition techniques, limited information tasks, and machine learning.

Knowledge Management: is about connecting people to people and people to information to create competitive advantage.

Knowledge Structures: Organized sets of beliefs about the social environment that summarize, in a general (abstract) and functional way, previous direct and vicarious experience with the stimuli encountered in this environment. These knowledge structures reside in long-term memory and are thought to be organized by stimulus domain.

Knowledge Visualization: Visual explication of conceptual knowledge, which is based on understanding the domain knowledge, applying cognitive principles, exploiting the visual parameters, encoding salient features graphically, providing a useful process, and producing useful outputs.

Open Source Data: Factual information (as measurements or statistics) used as a basis for reasoning, discussion, or calculation that is of potential value, which is available to the general public.

Situational Awareness: Person's mental model of the current state of a dynamic environment; the perception of the elements in the environment within a volume of time and space, the comprehension of their meaning and the projection of their status in the near future.

Team Collaboration: To work jointly with others or together especially in an intellectual endeavor.

Transactive Memory: Consists of the collection of individual understandings and the team mechanisms to exchange information, which update these individual understandings.

Trust: Assured reliance on the character, ability, strength, or truth of someone or something.