A Cognitive Description of Collaboration and Coordination to Help Teams Identify and Fix Problems

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Abstract

This paper describes how team collaboration and coordination work from a cognitive perspective, with the goal of helping explain guidelines for diagnosing and fixing team problems. These guidelines are based on the tautology that teams provided with appropriate communications connectivity can collaborate effectively if individual team members know what they need to know to do so, and that teams whose members lack this knowledge are prone to various kinds of predictable collaboration problems. The guidelines describe collaboration and coordination problems that arise from various kinds of knowledge shortfalls, provide metrics for the risk and occurrence of these problems, and suggest processes and tools to avoid or fix team difficulties.

The paper begins by summarizing the benefits and costs of teamwork. It next describes the knowledge that team members need to work together effectively, and reviews the interaction of this knowledge with team dynamics. It then summarizes seven causes of team behavioral problems that may arise from knowledge gaps, errors, and inconsistencies. The article concludes by describing the guidelines for diagnosing and correcting team problems.

1. Overview

Collaboration and action coordination are closely coupled activities in which team members work together to produce a product or carry out an action. Collaboration focuses on the problem solving aspects of group work. It is defined here to be "the mental aspects of group problem solving for the purpose of achieving a shared understanding, making a decision, or creating a product." In contrast, action coordination refers to the synchronized actions that people take in pursuit of common goals.

We treat collaboration and action coordination together because the two processes depend on one another and build upon similar requirements for shared understanding. Indeed, it would be rare to find collaboration that does not include important aspects of coordination or to find coordination that does not depend on collaboration.

This description explains what's occurring "under the hood" when people work together to achieve their shared understandings, make a group decision, create such intellectual products as situation assessments, courses of action, plans, analyses, and recommendations, or carry out a

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coordinated action. The description addresses only the cognitive aspects of collaboration and coordination. In the future, it could be augmented to also address social issues, such as motivation and willingness to share and work together.

Developing a straightforward generally applicable description of how collaboration and coordination works is complicated because teams differ in so many ways. For example, teams may be composed of people who have worked together for a long time, or who have just been introduced. The work may be decomposed so that team members can easily work independently, or may be partitioned into tightly coupled dependent tasks. Team members may work at different locations great distances apart, or may work in the same building. They may meet often, or may work separately, with each person performing his part of the work at his convenience, rarely engaging in synchronous conversations with others.

Despite these differences, at a fundamental level all teams have much in common. This explanation of collaboration and teamwork builds on these common characteristics, laying the groundwork for understanding how they manifest themselves depending on the particularities of the team, task, and environment. These core characteristics are:

1. Knowledge is central to collaboration and teamwork [Wegner, 1987]. Teams whose members know what they need to know can work together effectively. Those that do not are prone to various kinds of predictable errors, with the type of error depending on the specific knowledge inadequacy.

2. Knowledge and understandings are usually distributed among members of a team. Everybody does not need to know everything for a team to be effective. But every team member does need to know how to get the information he or she needs.

3. The actual knowledge that individuals need is of two basic types. The first is the knowledge that they would need to carry out their tasks were they acting alone; e.g., the knowledge to support "taskwork." The second is the knowledge required for the team members to work together effectively; e.g., the knowledge to support "teamwork."

4. An important purpose of the collaborative dialog, in which team members exchange ideas to clarify issues and reach consensus, is to put in place the knowledge and understandings that team members must have to achieve the team's mission.

5. In successful teams, team members back each other up [Zsambok, 1993]. To do this, team members need to monitor each others' performance, determine incipient problems, and then act to prevent the problem.

2. Benefits and Costs of Collaboration and Teamwork

Collaboration and coordinated actions provide many benefits, but they also impose costs that if not managed well can undermine the team. Effective teams maximize these benefits while minimizing the costs [Evidence Based Research, 2001].

If a single person could achieve a team's mission goals working alone, then that is often the most efficient way to proceed. However, sometimes a single person cannot or should not perform the

task alone. This may arise when there is too much work for one person to do, when no single person has the needed expertise, when one person cannot be every place where a person is needed, when it's too risky to depend on a single person's judgment, or when everyone who could do it alone is also needed elsewhere. When it is infeasible or undesirable for a single person to do the work alone, then the work can be assigned to a team. This provides such benefits as shared workload, multiple perspectives provided by diverse expertise, extended team reach, and higher reliability.

Unfortunately, performing the work as a team can impose significant overhead. When the mission is to create a product, then the work must usually be decomposed among the team members and the final product must then be reconstituted from the team members' various contributions. To carry out this decomposition/reconstitution process, individual team members need to coordinate so that each person creates the right contributions at the right time. They may need to deconflict resource requirements, know when they need to provide extra help to one another and know how to provide that help. Distributing work also can make problem detection more difficult, for different team members may see different indicators of a problem, none of which by can alert the team to the problem.

When the mission is to generate recommendations or identify alternative courses of action, then other kinds of overhead can arise. Sometimes the right people are not invited or available to join in the needed group discussions, resulting in low productivity meetings that waste the time of those who do attend. Alternatively, if team members do not fully understand the goals or the nature of the problem, then the team can waste its developing non-responsive recommendations.

Teamwork overhead can be substantial even when team members can easily meet together face to face, and even when resources are plentiful and time is adequate. Overhead is even greater when team members are physically distributed, come from different backgrounds, work against a tight deadline, or have difficulty getting the information they need. Because of these difficulties, teams need to be alert to collaboration and coordination shortfalls so that they can catch and correct them quickly.

3. **The Elements of Collaboration**

Figure 1 summarizes four building blocks of collaboration. Three of these building blocks are processes— setting up and adjusting the team, group problem solving, and coordinated actions. The fourth is the knowledge and understandings that team members need to work together effectively. The team processes and team knowledge and understandings interact closely. Knowledge and understandings enable the processes, and the processes help put the needed understandings in place.

3.1   Team Processes and Activities

Team set up and adjustment. Before the team can get started [Katzenbach, 1993], it needs to organize and to obtain the means to collaborate and carry out tasks. The team organizer or leader needs to analyze the mission to determine needed members and resources, and then recruit the team, and assign tasks and resources. He also needs to ensure an adequate infrastructure to support exchange of data among team members, and to ensure data availability and validity.

When the team first meets, team members need to articulate the team mission and goals, develop a plan and organization to achieve the goals, establish accountability, and define the role of the leader. In many teams, the team revises its set up whenever members decide to change their team organization, tasks, or infrastructure.
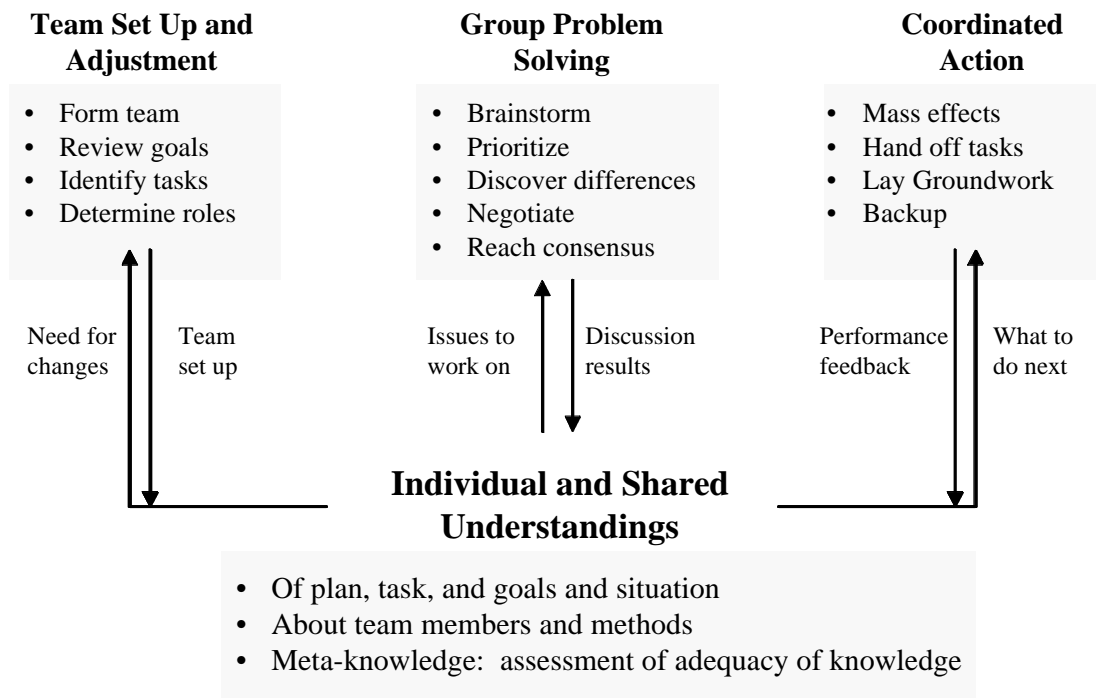
Team Set Up and Adjustment	Group Problem Solving	Coordinated Action
• Form team • Review goals • Identify tasks • Determine roles	• Brainstorm • Prioritize • Discover differences • Negotiate • Reach consensus	• Mass effects • Hand off tasks • Lay Groundwork • Backup
Need for changes Team set up	Issues to work on Discussion results	Performance feedback What to do next

Individual and Shared Understandings

• Of plan, task, and goals and situation
• About team members and methods
• Meta-knowledge: assessment of adequacy of knowledge

Figure 1. Building Blocks of Collaboration and Coordination

Group problem solving. Here, the team engages in its "collaborative dialog" to reach consensus and decide what to do. Team members may brainstorm, critique and enrich, evaluate and prioritize, discover differences, negotiate, reach consensus, identify solutions, and make decisions.

One of the benefits of the collaborative dialog is that it enables teams to leverage expertise and share perspectives in order to consider more and better views on what is happening and what should be done. Thus the team dialog enables the team to entertain:

• More views on what is happening, the reasons for these occurrences, and their possible impact on the team mission

• More possible actions to take in response to the situation

• More criteria to consider when evaluating the desirability of these actions

• More possible consequences of the alternatives being considered

The collaborative dialog can be formal, with specific times being set aside to carry out such activities as brainstorming. Alternatively, it may be informal and spontaneous, with team

members offering suggestions and criticisms, discovering differences, and negotiating and resolving these differences as the need arises.

Coordinated actions. For many kinds of teams and missions, the team breaks up the overall job into individual tasks, which team members then carry out in coordination with each other. This coordination enables the team as a whole to realize the benefits of teamwork. These include enabling task continuity over time and space through coordinated handoffs, increasing physical impact through massing of effects, improved efficiency by team members laying the groundwork for each other, and increased reliability by team members backing each other up.

In coordinated teamwork, each team member carries out his individual tasks in accordance with the plan and the observed needs of others, improvising and adjusting to advance team objectives. Figure 2 reviews a general process that people often use carrying out their individual tasks in coordination with others.

Determine Task Adjustments   **Carry Out the Task**
(consulting with others)   **(with awareness of others)**

Monitor/gather information

- Determine if adjustments are needed
- Consider coordination and synchronization requirements. Balance individual task against need to support others on team
- Identify/update needed resources and information, and determine how to obtain

If team discussion on adjustments needed

Specified adjustment

Review team and own task status in relation to team plans and goals

Identify adjustments to make on own, or identify need to discuss adjustments with others

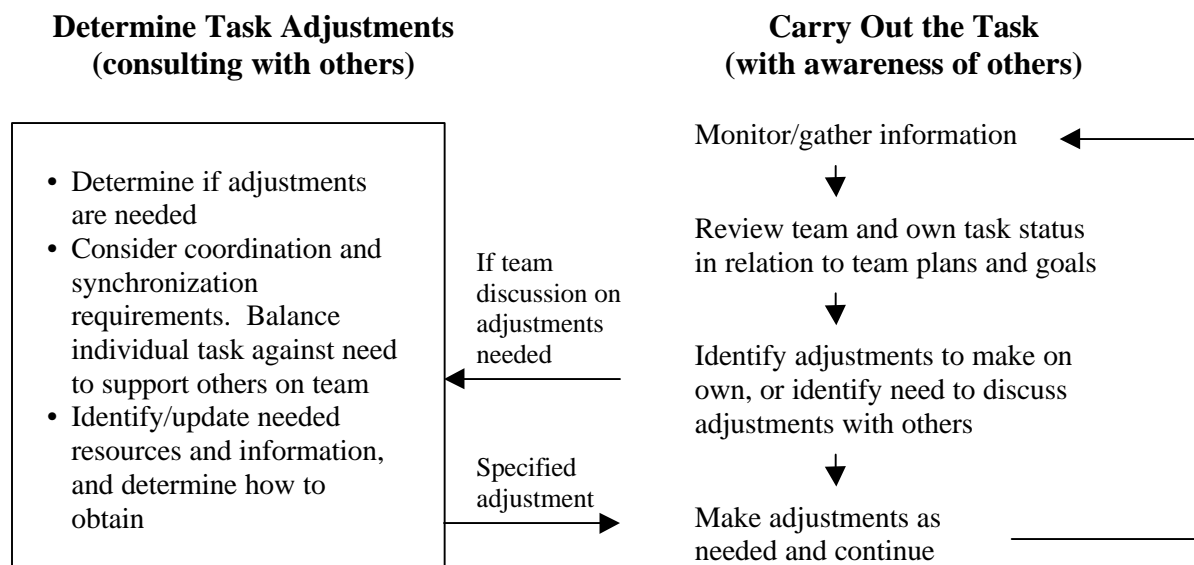Make adjustments as needed and continue

Figure 2. Individual's Processes in Coordinated Team Activities

In this process, each team member monitors the situation and gathers information to review situation, task, and team status. If there is a problem, then he considers the need for adjustments, and decides whether he can make the adjustments on his own or if he needs to discuss them with others. Examples of adjustments include modifying team coordination and synchronization requirements, rebalancing the emphasis placed on various tasks, deciding a task is no longer needed, or changing information or resource requirements.

Once the adjustments are determined, he continues his work, pacing it and coordinating with others as called for in the adjusted team plan.

3.2 Team Knowledge and Understandings

To work together as a team, team members need to know about their tasks and team. This includes both process knowledge—how to do tasks and work together—and declarative knowledge—facts and conclusions. It also includes "meta-knowledge," people's assessments of the adequacy of their own and other's knowledge. Table 1 summarizes some of task, team, and meta-knowledge and understandings most important to effective collaboration and teamwork.

1. Knowledge about the plan, tasks, and goals
   a. Methods/strategy for achieving mission success
   b. Plan, schedule, contingencies, tasks, task relationships
   c. Tasks, priorities, deadlines and constraints of dependent tasks
   d. Perspectives needed to address problem
   e. Need for various types of problem data
   f. Risks from parochialism

2. Knowledge about the situation
   a. Plan and mission progress and status
   b. Current and predicted future need for contingencies
   c. Likelihood of a situation arising in which a team member will need help
   d. Impact of misinterpreted information

3. Knowledge about team members
   a. Criteria other team members use when deciding what to do
   b. Methods for helping other team members understand the situation, goals and action requests
   c. Possible ways a team member may misinterpret information
   d. How well team members (including ones self) are performing
   e. Types of situations where team members will likely need help

4. Knowledge about team methods
   a. Criteria for determining that a team member (including ones self) needs help
   b. Methods for obtaining or providing help
   c. Criteria for selecting among competing tasks, including supporting others
   d. Agreed team-assigned meaning of conventions
   e. Stylized response to conventions

5. Meta-knowledge
   a. Adequacy of knowledge about the physical situation and of ability of team member to interpret situation cues
   b. Assessment of own ability to carry out various tasks
   c. Assessment of other team members' abilities to carry out their tasks under various circumstances

Table 1. Primary knowledge drivers for effective collaboration

3.3 *The Importance of Knowledge Alignment*

Successful teamwork requires that all team members' understandings of the goals, situation, plan, and the team are similar enough so that they can support one another effectively and avoid conflicts. When team members have conflicting views, then coordination and synchronization problems can arise. For example, team members with differing understandings of team goals may be unable to agree on what should be done. If they do not know they have different understandings of goals, then they might not know the reasons for their disagreement, and so may never be able to reach consensus.

Table 2 summarizes six different states of alignment in team member knowledge and understanding, and the extent to which they support or hinder effective teamwork.

Impact on Effective Teamwork	Knowledge/Understanding Disposition Within Team
Supports teamwork	• Team members have compatible understandings, with no conflicts • Different team members know different things, but all team members know who to ask to get needed information
Acceptable to teamwork	• The team members conflict in some of their understandings, but know that they differ
Impedes teamwork	• Team members conflict in some of their understandings, and they don't know they differ • No one on the team has the needed understanding, and no one knows how to obtain it • Some team members have the needed understanding, but do not know it's relevant so don't share. The other team members don't know that anyone else knows, and so do not ask

Table 2. Impact of Alternative Alignments of Team Member Knowledge and Understandings

4. Collaboration Dynamics

The nature of the interactions among set up and adjustment, group problem solving, coordinated action, knowledge, and understandings depend on the nature of the team and task. All teams have a set up phase, but individual teams may differ on how frequently they adjust their process during their mission. Teams also differ in the relative emphasis they place on group problem solving vs. coordinated action. Some teams focus primarily on the former (e.g., a planning team) and others on the latter (e.g., sports teams). Some other teams, however, engage significantly in both coordinated action and group problem solving (e.g., nurses, fire fighters, military teams executing a plan).

Group problem solving teams. These are the teams that produce an intellectual product. Team members brainstorm and prioritize. They critique and enrich each other's ideas and work. One

team member may stimulate an insight in another, who in turn sparks new thoughts throughout the team. In this kind of joint problem solving team, each suggestion modifies the individual and shared understandings, so that these understandings evolve as the dialog continues. Because team knowledge at any point in time is the result of the team dialog up to that point, the state of that knowledge represents team progress in problem solving tasks.

This collaborative give and take can be fine or coarse grained. When fine-grained, team members make very frequent small contributions to the intellectual product. When coarse-grained, team members may exchange ideas or critique each other infrequently. For example, in group planning each team member may write a separate section of the plan, posting it in a common repository for comment and refinement by others.

Some group problem solving teams monitor their group processes to determine the need for adjustments. They may decide, for example, to add a new team member with a needed area of expertise. As another example, they may change the structure of the dialog process to encourage greater participation from less vocal team members.

Coordinated action teams. In their purest form, these teams carry out pre-planned actions based on a common understanding of team goals and mission, a common understanding of the situation, and a common set of rehearsed actions that team members understand are to be applied under various predetermined circumstances. In such teams, there may be very little, if any, explicit dialog or group problem solving. Rather, each individual team member sizes up the situation, perceives opportunities and risks, and adapts his behavior to seize opportunities or minimize risks for the team in accordance with the pre-planned actions. The team behaviors emerge from the team member's individual adaptations. These continual adjustments have sometimes been called "self-synchronization." They enable very fluid, responsive, adaptable teams.

Like the group problem solving teams, the behavior of the coordinated action teams can be understood in terms of the relationship between individual team member understandings and team behaviors. Understandings directly impact the actions that team members will take, which then change the situation, producing yet another set of understandings and actions. Like the group problem solving teams, this interplay can have a very high level of granularity. The granularity can be sufficiently high, in fact, for the interactions and adjustments to be viewed as continuous.

Hybrid teams. These teams engage in both group problem solving and synchronized action. Like the coordinated action teams, team members coordinate through reference to a common plan, which they continually monitor to determine needed adjustments. However, when these teams encounter circumstances that their plan cannot accommodate, they may reenter the group problem solving mode in order to revise their plan.

Like the other two modes, the shared understandings can represent the state of the team. These understandings generate actions, either to act or to discuss a problem solution. These actions in turn generate new understandings.

5. **Collaboration and Coordination Shortfalls**

5.1   Knowledge and Teamwork

For each of the three types of teams, the quality, completeness, and alignment of team member understandings have a major impact on the effectiveness of the team. Teams with high quality understandings can do well. Conversely, teams whose understandings have gaps, errors, and inconsistencies are vulnerable to serious collaboration and coordination shortfalls. As suggested by Figure 3, these errors can build on each other. Gaps, errors, and inconsistencies cause poor team performance, which in turn amplifies the gaps, errors, and inconsistencies.

Group Problem Solving		**Coordinated Action**

- Process omissions or skimping
- Good ideas omitted
- Poor ideas preserved
- Disconnects
- Clashes

Individual and Team Understandings

- Gaps
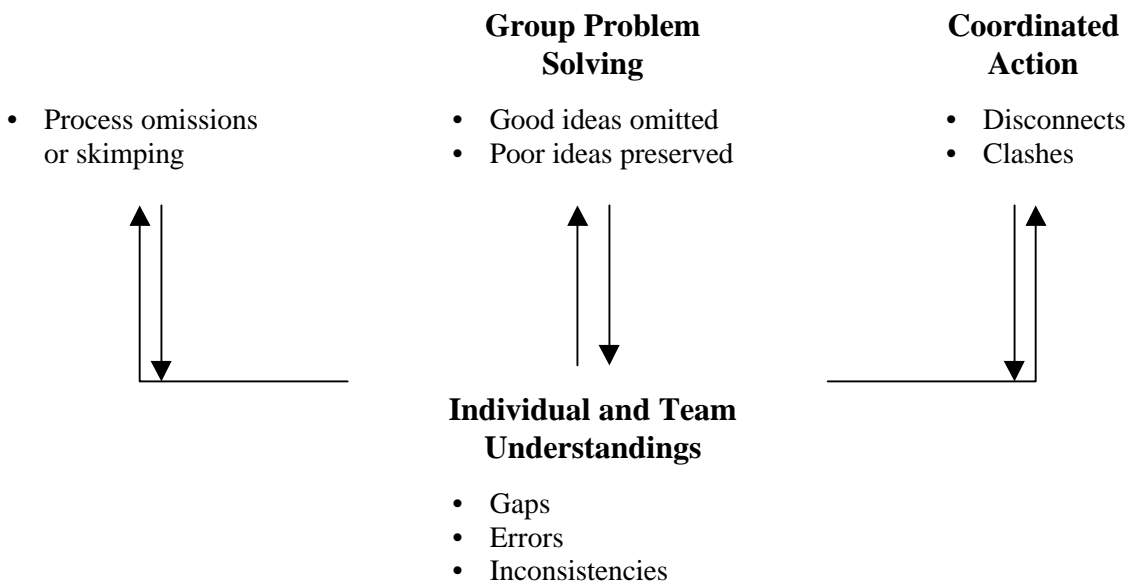- Errors
- Inconsistencies

Figure 3. Mutual Reinforcement of Teamwork Problems and Shortfalls in Team Understandings

These problems manifest themselves in many ways. For example, one team member may ask another to do something, which that person then carries out in an unexpected or counterproductive way. Or team members may fail to report significant events to the people who need to know; or some people may become so absorbed in their assigned tasks that they let other team members down.

5.2   The Seven Underlying Causes of Poor Collaboration and Teamwork

Although there is an enormous range of specific problems that teams may experience when working together, there are a relatively small number of basic underlying causes of these problems. By focusing on the underlying causes and the associated knowledge gaps, errors, and inconsistencies, team members can identify remedies targeted on these causes.

In the case studies examined when developing this cognitive description of collaboration and coordination, just seven underlying causes were able to account for all of the reported problems. These causes are 1) misunderstood decision rationale; 2) misunderstood coordination

convention, 3) understanding misalignment, 4) goal-task conflict, 5) process misunderstanding 6) expertise hole, and 7) group tunnel vision. The following summarizes each of these deficiencies and the associated inadequacies of the knowledge listed in Table 1.

1. **Misunderstood decision rationale.** Here, team members misunderstand an action request. This problem manifests itself in two ways. In the first way, one team member asks another to take an action, that team member misunderstands the reason for request and what the requestor actually wanted, and then either fails to take the action or takes one that does not support the requestor's needs. In the second way, one team member tries to persuade another to take an action, but does not know the criteria that matters to the person being asked to take the action, fails to relate to those criteria, and so fails to convince that person to take the action.

   Knowledge most important for avoiding misunderstood decision rationale is the understanding of other team members' action criteria, and methods for framing the request in those terms.

2. **Misunderstood coordination convention**. Teams often agree in advance to interpret specific actions or words in a particular way to mean something other than what those actions or words usually mean. When a team member forgets that a convention is being used, he may respond assuming the action and words have their usual meanings. The person who forgets the convention may fail to take a needed action, may take an incorrect one, or may cause others to do so. Teams can avoid this problem by knowing what the team's coordinating conventions are.

3. **Understanding misalignment**. Here team members have different understandings about the situation, plan, or actions to be taken, and do not know that they have different understandings. Team members that understand the plan or situation differently may fail to support one another, fail to coordinate, or get in each other's way.

4. **Goal/task conflict**. Team members sometimes have tasks that support multiple team and individual goals. If a team member fails to properly balance these goals, he may fail to accomplish his tasks or may fail to support the team adequately.

   Critical knowledge for avoiding goal/task conflicts are: 1) the team's methods/strategy for achieving mission success; 2) the plan and mission progress and status; 3) criteria for selecting among competing tasks, including supporting others; 4) tasks, priorities, deadlines and constraints of dependent tasks, and 5) how well team members (including self) are performing

5. **Process misunderstanding**. All team members must understand the part of the team's work plan relevant to them. They must understand what they are to do and how they are to interact with others under various circumstances. If they do not understand these processes, they may fail to take a needed action, take one that is not fully effective, or make requests that others cannot satisfy.

   Knowledge that reduces the probability of this problem includes: 1) methods/strategy for achieving mission success; 2) plan, schedule, contingencies, tasks, task relationships; 3)

tasks, priorities, deadlines and constraints of team members with dependent tasks; and 4) current and predicted future need for contingencies

6. **Expertise hole**. Expertise is often distributed among team members, with different members being responsible for expertise in different areas. An expertise hole occurs when circumstances arise that a team member has insufficient expertise to handle and the team fails to provide the needed expertise back-up.

   To reduce the chances of this problem, team members need to know: 1) criteria for determining that a team member (including ones self) needs help; 2) how well team members (including self) are performing; 3) types of situations where team members will likely need help; 4) likelihood of a situation arising for which a team member will need help; and 5) how to obtain or provide help.

7. **Group tunnel vision**. This problem arises when teams fail to consider a full range of situation interpretations, alternatives, or alternative evaluation criteria. It can lead to the team's taking poor quality actions or producing an inadequate product.

   Knowledge important for avoiding this problem includes: 1) perspectives needed to address problem; 2) need for various types of problem data; and 3) risks from parochialism

6. Summary of Guidelines Based on this Description of Collaboration and Teamwork

The guidelines for effective collaboration and coordination help people diagnose and fix teamwork problems. The guidelines are based on the view of teamwork described in this paper, and on the "knowledge gap-trigger-safety net" model of how potential teamwork problems become actual ones. The guidelines themselves are organized in terms of the seven underlying causes described in Section 5. For each of these causes, the guidelines describe the nature of cause, diagnostic metrics for measuring risks and symptoms, and problem remedies.

At the time of the 2002 ICCRTS conference, EBR had prepared an initial draft of the guidelines [Evidence Based Research, 2002]. Over the next twelve months, Evidence Based Research, will validate the guidelines drawing on, as appropriate, formal experimentation, consensus of expert opinion, history of operational success, literature citing experiments that validated similar guidelines, and case analyses.

6.1   The Knowledge Gap-Trigger-Safety Net Model of Collaboration Problems

Gaps, errors, and misalignments in knowledge and understanding leave a team vulnerable to the seven causes of collaboration problems. They represent potential problems. To become real problems that impede team performance, the team also needs some bad luck and some bad teamwork. Figure 4 summarizes this knowledge gap-trigger-safety net failure view of collaboration problems.

Knowledge vulnerabilities are the gaps, errors, and misalignments in team knowledge that leave teams vulnerable to the seven causes of collaboration problems. Problems in any of the knowledge drivers in Table 1 can be knowledge vulnerabilities. Note that inadequacies in

knowledge and understanding not only generate these initial problem vulnerabilities, but can also contribute to later safety net failures.

Triggers are the "bad luck." They are the stressors that cause the knowledge inadequacy to matter. If a team member's knowledge is weak in some areas, that weakness doesn't matter if no circumstances arise that call for that knowledge. The triggers can arise from the environment, from the team, or from the problem. Examples are equipment breakdowns, a team member illness, or a stronger than expected adversary. Generally, while teams can hedge for these stressors so that they can handle them if they arise, unlike the knowledge vulnerability and safety net failures, teams usually can do nothing to stop them.

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│                 │      │                 │      │                 │
│   Knowledge     │ ───▶ │    Trigger      │ ───▶ │   Safety Net    │
│  Vulnerability  │      │                 │      │    Failure      │
│                 │      │                 │      │                 │
└─────────────────┘      └─────────────────┘      └─────────────────┘
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• gaps, errors, and   • Environment, team,   • Inadequate team
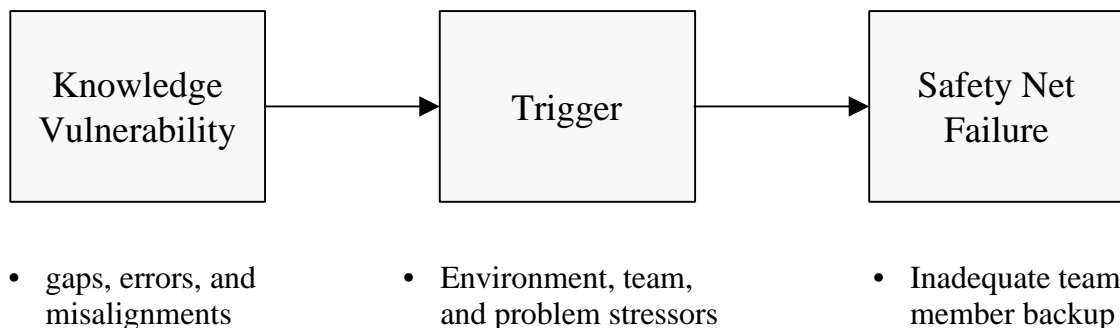 misalignments   and problem stressors   member backup

Figure 4: Knowledge Gap-Trigger-Safety Net Instigation of Collaboration Problems

The safety net failure is the failure of the team to back up people needing help. It stops potential problems before they become serious. Every team puts in place methods for team members to help each other in emergencies. These methods are the team safety net. The safety net can fail if its need was not anticipated and so was never set up, if the team members do not know how to carry out the safety need processes, if the team members do not recognize when they need to carry them out, or if the team is physically unable to do so.

6.2   *Metrics and Remedies*

The guidelines' diagnostic metrics are questionnaires that list risk factors and symptoms for each of the underlying causes of collaboration problems. The metric—level of risk or likelihood of occurrence, is the number of items on the list that apply to the team.

The guidelines discuss two kinds of remedies: 1) revisiting the team set up procedures and 2) employment of critical collaboration tool services. In both cases, the guidelines recognize the burden of following recommended set up processes or of employing needed collaboration tools. The guideline's attitude in both cases is that teams when they form should initially use their best judgment on both procedures and tools, and that if circumstances later imply the need to revisit procedures or to introduce new tools, then the team should do so.

Recommendations on revisiting set up procedures are directly linked to team risk factors. Every risk factor questionnaire includes several risks associates with skimping on recommended set up processes [Katzenbach, 1993]. Should they overall risk for a problem be high, then the team may wish to revisit those particular processes in order to reduce this overall risk.

Recommendations about tool use are linked both to risk factors and to knowledge vulnerabilities. For each of the seven causes of teamwork problems, the guidelines describe tool services that either reduce the risk factors associated with the problems or that support the acquisition of the knowledge needed to avoid the problem. These tool services transcend communication tools such as VTC, e-mail, and bulletin boards. They also include tools to find information and expertise, tools to help view and understand the team and situation, tools to structure and share information and manage knowledge, and tools to help organize meetings.

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