

A MODEL OF COMMUNICATION IN SUPPORT OF DISTRIBUTED ANOMALY RESPONSE AND REPLANNING

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This paper proposes a descriptive model of the contents of communication among distributed practitioners engaged in the cognitive work of anomaly response and replanning. The model was checked by a re-analysis of data on coordinative activities in response to an anomaly in a past space shuttle mission, and through a new analysis of log-based communication among flight controllers during normal space station operations. The model was found to be useful for supporting the discovery of patterns in communication among practitioners in complex work domains by providing a "coding scheme" that transforms domain-specific data into domain-independent protocols. The results of these model-based analyses have important implications for the design of computer-supported cooperative work.

INTRODUCTION

Anomaly response and replanning in complex work domains present difficult challenges to practitioners because they must maintain the integrity of a faulty underlying process while modifying plans in action in the face of time pressure, uncertainty, high consequences of failure and multiple interacting goals (Woods, 1994). Much of the research in this area has focused on preventing breakdowns in human-machine coordination (Malin et al, 1991).

This paper addresses the study of human-human coordination, which is important for two main reasons: First, successful human-human coordination serves as a model of competence upon which the design of human-machine coordination can be based. In particular, understanding the content and structure of information exchanged during coordinative activities between people can help designers make decisions about the types of information which need to be captured by automated systems and about mechanisms for communicating this information to human collaborators. Second, the responsibilities for anomaly response, replanning and even normal operations in most complex work domains are distributed across multiple human agents who must coordinate across functions, time and physical distance to achieve their shared high-level goals. Therefore, understanding the content and structure of information communicated between these people can guide the design of tools specifically intended to aid human-human coordination.

The descriptive model of communication presented in this paper integrates findings from previous studies of human-human coordinative processes in the high-performing complex work domain of space mission control. These studies focused on the processes involved in functionally distributed anomaly response (Watts-Perotti & Woods, 1997), the updating of incoming personnel during escalating situations (Patterson & Woods, 2000), and how voice loops function as cooperative aids in mission control (Patterson, Watts-Perotti & Woods, 1999). Specifically, these studies helped to identify classes of information that are exchanged among coordinating mission control practitioners, and the contexts for these information exchanges (i.e., the uses for different information classes and their relationships). By using this model to re-analyze a past case of anomaly response and replanning, and to analyze space station operations, we discovered important patterns in the coordinative processes among human agents that need to be considered and supported in the design of computer-based tools for cooperative work environments.

MODEL OVERVIEW

Figure 1 shows the communication that support anomaly response. Initially, a practitioner is monitoring his/her data screens. He/she then notices a pattern of change in the data values suggesting that an off-nominal event has occurred. That is, the practitioner integrates the available data into an event which he/she recognizes as anomalous relative to expectations. At this time, this practitioner may start to coordinate with others by asking for corroborating evidence for the occurrence of this event. If he/she decides that the event really constitutes a disturbance in the monitored process, it will become necessary to start investigating the sources of this disturbance and its impacts on other processes and goals. That is, recognition of the anomalous event will spawn diagnostic and predictive analyses, to be carried out by various practitioners depending on their expertise, the tools at their disposal, and whether they are involved in other conflicting tasks. These practitioners will bring together results of these analyses, discuss them, and coordinate with one another to develop a common team stance (i.e., an

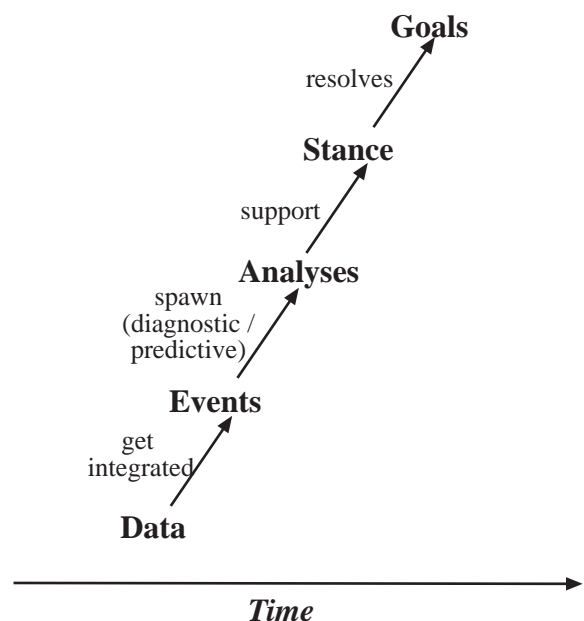


Figure 1: Communication in Support of Anomaly Response

agreed-upon position and rationale) towards alternatives on how the anomaly should be managed. That is, the results of diagnostic and predictive analyses provide support for the team's stance.

In most decision-making situations, choosing between the available alternatives is difficult because there are multiple goals which interact and tradeoff against one another. Different teams of practitioners, with their own scopes of authority and responsibility, will not prioritize the various goals in the same manner. That is why the stance presented by different teams will likely differ, and the teams will need to defend their stance and engage in debates. However, each team's stance does reflect how that team has chosen to resolve their own goal conflicts at a given point in time.

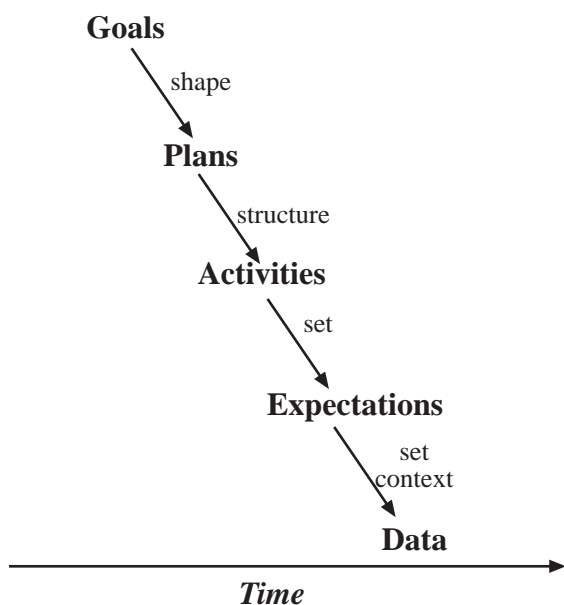


Figure 2: Communication in Support of Replanning

Figure 2 illustrates a different scenario of coordination between practitioners in support of dynamic replanning. Whenever there are disturbances to the monitored process, or disruptions to plans, practitioners will be faced with the need to replan future activities, to ensure that their safety, production and other goals can continue to be met. Since the activities of different practitioners in a complex work domain are interdependent, practitioners will need to first consider their own goal priorities, then coordinate to come up with a mutually satisfactory plan to schedule future activities and develop means to handle contingencies. Whichever plan ends up being approved by the various stakeholders will be shaped by the goals that these practitioners have brought to bear on the planning process. The approved plan then provides a structure for the activities that different practitioners will now coordinate or synchronize to perform. An activity performed by any practitioner on the monitored process will influence system behavior. Therefore, by being aware or informed of one another's activities, practitioners can set expectations for monitoring. These expectations set the context for the interpretation of data values that are monitored by the practitioners.

Overall we distinguish among eight types of information that one (set of) practitioners can communicate to another, including: Base Data Values, Events, Analyses, Stance, Goals, Plans, Activities, and Expectations (see Figure 3). These information types, or contents of communication, are represented as "nodes". The relationships between these information types (i.e., the processes by which practitioners, either individually or cooperatively, transform one type of information into another type to be communicated) are represented as "links" between nodes. Notice that all coordinative processes take place over time (as shown along the x-axis), and that the processing of different types of information can be influenced by causal constraints in the technical system and/or intentional constraints of the human practitioners (as shown along the y-axis). In anomaly response, there tends to be a lot of "data-driven" communication (depicted as "upward" links in the model) as practitioners try to understand and respond to changes in system behavior. When replanning, there tends to be "goal-driven" communication (depicted as "downward" links in the model) as practitioners try to ensure that their goals are being addressed as plans are modified to handle changing circumstances such as disruptions, impasses or opportunities.

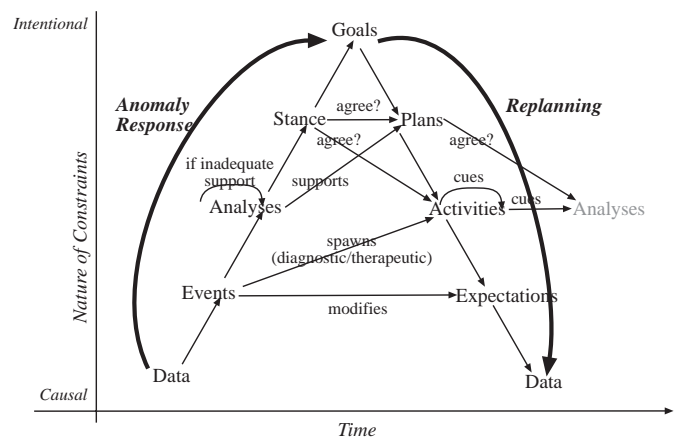


Figure 3: Integrated View of Functions in Distributed Anomaly response and Re-Planning

Links occur across the structure of the model. For example, upon recognition of an anomalous event, practitioners may immediately perform a diagnostic or therapeutic activity on the underlying process (i.e., Event cues Activity). As another example, the results of an analysis may feed immediately into refining the details of a plan, especially if all the stakeholders have already agreed on following that basic plan (i.e., Analysis supports Plan).

By tracing out how practitioners move from communicating about one type of information to another in various operational scenarios, researchers can trace how cognitive processes are coordinated across teams of practitioners. The results will take the form of cycles moving from monitoring plans in progress to recognizing and managing disruptions to those plans, and modifying the plans to take the reverberations from the disruption into account. In this process the base level is events as integration of the data stream across past events, future expectations relative to the goals, stance, and activities of different groups involved.

SUPPORT FROM A SPACE SHUTTLE ANOMALY

In the study of functionally distributed anomaly response, Watts-Perotti and Woods' (1997) constructed "distributed activity protocols" that described coordination among flight controllers and engineers who managed an anomalous hydraulic system leak during the STS-76 space shuttle mission. The proposed model was used to re-code these "distributed activity protocols", to see whether the model fit and could capture the contents of communication and the processes of coordination that transpired between these mission control practitioners.

Table 1 shows the results of applying the proposed model as a "coding scheme" to formalize the information that was exchanged within and between the flight control (i.e., operations) team and the engineering team over the course of three coordinative meetings. These meetings addressed the issue of whether to use the faulty auxiliary power unit (APU) or the circulation pump to carry out a plan to prepare for entry -- FCS checkout plan. Figure 5 is a graphical representation of the same protocol shown in Table 1. Rather than representing the mindset of all practitioners involved as a single "group" mind, Figure 5 traces out the mindset of individual (teams of) practitioners and how they communicate with one another to carry out coordinated activities.

Who	Comm Type	Details
Ops	Plans	- prepared plans for FCS checkout using circ pump rather than APU
Both	Plans	- <u>disagreement</u> between Ops and Eng re: use of circ pump rather than APU - Issue unresolved - hence, need more ANALYSES
Eng	Anal	- analyzed info gained from different power sources (APU vs. circ pump)
Both	Plans	- continued <u>disagreement</u> re: use of circ pump rather than APU - Ops proposed an addition (of procedure 303) to the plan to use circ pump rather than APU - <u>suspended judgement</u> (rather than disagreement) on new plan - still, need more ANALYSIS
Eng	Anal	- determined how much info will be lost if not use APU
Both	Plan	- agreement on NOT to use APU - Issue resolved!!

Table 1: Communication in Support of the Revision of FCS Checkout Plans

Evidence for all eight types of information included in the proposed model was found in the communication among flight control practitioners in this STS-76 case. This re-analysis revealed several generic patterns:

- Practitioners communicated about events (for which base data provided support);
- Communications among on-console operators tended to be closely tied to the events that occurred and their implications for action (i.e., activities);
- Communications among off-console practitioners emphasized analyses, stance, and plans;
- Different practitioners played different coordinative roles which changed what was seen as informative in communications.

ANALYSIS OF SPACE STATION LOGS

Re-analysis of the STS-76 case focused on synchronous communication across functional teams in an anomaly response scenario. In the second stage of our exploration of the proposed model's utility for understanding communications in support of distributed cognitive work., we analyzed asynchronous communications within functional teams (in the form of shift logs) during normal operations.

A total of 2093 log entry records created by six different flight controllers within the same discipline (i.e., Station Duty Officer/Communications and Tracking Officer) were analyzed. These log entries spanned thirty six consecutive shifts over the course of two weeks. Again, proposed model was used to "code" the contents of these logs.

Findings from this study of shift logs essentially agreed with and extended findings from the STS-76 study:

- Practitioners made few references to base data values and goals in their log-based communications (just as in STS-76's coordinative meetings);
- On-console operators placed a great emphasis on events and activities in their communications;
- Expectations also played a substantial role in their communications - in particular, the operators emphasized the comparison of events to expectations;
- In normal operations, there is a key set of relationships between events, activities and expectations that are critical to successful monitoring and control - that is, events set the context for activities, activities generate expectations, these expectations are either met or violated depending on how events (which were the preconditions for activities) develop over time.
- Besides distinguishing between the "processing" and "reporting" of information, evidence for a much richer set of coordinative roles were found (e.g, information provider, recipient, requestor, verifier, etc.);
- Different coordinative roles were possible depending on the type of information (e.g., events, stance, plans, etc.) being communicated.

DISCUSSION

The two analyses of communication among flight controllers facilitated insight into what constitute useful

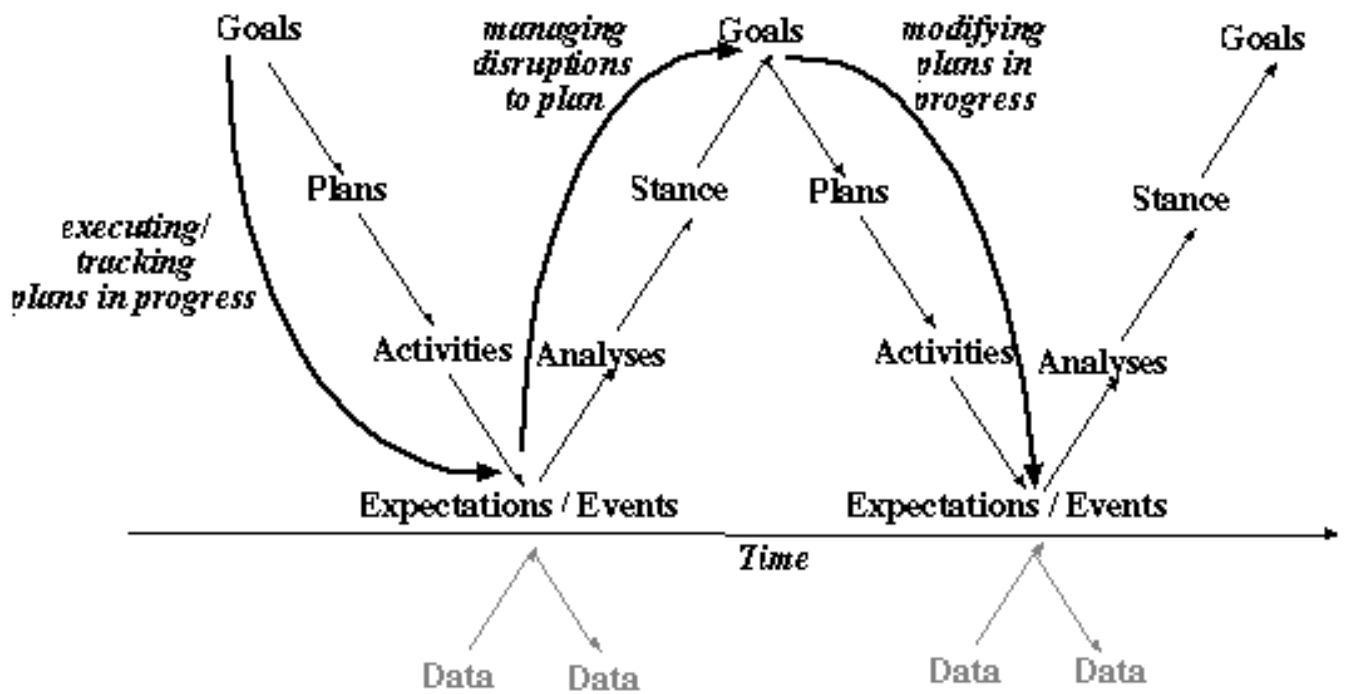


Figure 4: Co-Ladder Framework as a Unified Model of Communication in Support of Distributed Cognitive Work

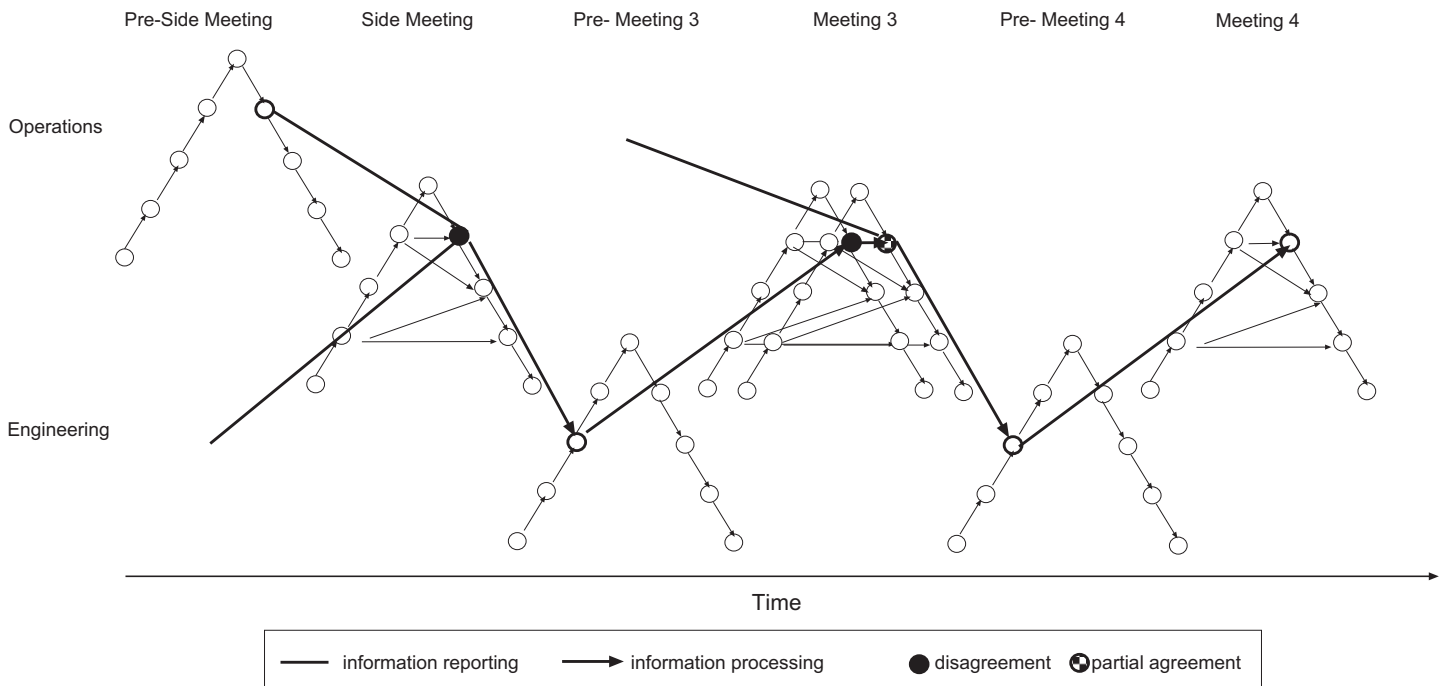


Figure 5: Communication about Revisions to FCS Checkout Plans

strategies for supporting cooperative work in the mission control environment. These results helped in the design of an electronic logging tool for space station flight controllers (Chow et al., 1999).

In general, the following issues should be addressed in the design of tools to support coordination among space mission controllers:

- Automated display and/or recording of base data values will have little utility for practitioners, unless mechanisms are provided to support the recognition and monitoring of events (i.e., meaningful changes or patterns of changes in data over time) (Christoffersen, 1999);
- Support should be provided for the generation, revision, and comparison of expectations to events;
- Support should be provided for relating events (which may constitute activities' pre-conditions or post-conditions) to activities. In addition to supporting activity recording, support should be provided for looking ahead to future activities.
- Especially for off-console operators, supporting only the communication of data, events and activities is inadequate. Support should be provided for the communication of the results and implications of analyses, the teams' stance on significant issues (i.e., their position and rationale), and the status of plans being followed or modified;
- Public and private "annotation" capability is important because different practitioners, depending on their own scopes of responsibility and authority, will play different coordinative roles even as they communicate about the same piece of information. Therefore, they need to be supported in determining and recognizing the significance of any piece of information to their own particular purposes.

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REFERENCES

- Chow, R. (2000). Communication during Distributed Anomaly Response and Replanning. . Institute for Ergonomics/Cognitive Systems Engineering Laboratory Report, ERGO-CSEL 00-TR-03, The Ohio State University, Columbus OH, October, 2000.
- Chow, R., Christoffersen, K., O'Neill, J., and Wales, R. (1999). SDO Logging and Handover Tool: Preliminary Design Concepts. NASA JSC.
- Christoffersen, K. (1999). Event representations: Communicating change information in supervisory control. In Proceedings of the Human Factors and Ergonomics Society, 43rd Annual Meeting, Houston, TX.
- Malin, J., Schreckenghost, D., Woods, D., Potter, S., Johannesen, L., & Holloway, M. (1991). Making Intelligent Systems Team Players No. TR-104738). NASA Johnson Space Center.
- Patterson, E. S., Watts-Perotti, J., & Woods, D. D. (1999). Voice loops as coordination aids in space shuttle mission control. Computer-Supported Cooperative Work, 8, 353–371.
- Patterson, E. S., & Woods, D. D. (2000). Shift Changes, Updates, and the On-Call Model in Space Shuttle Mission Control. Computer-Supported Cooperative Work, in press.
- Watts-Perotti, J., & Woods, D. D. (1997). A Cognitive Analysis of Functionally-Distributed Anomaly Response in Space Shuttle Mission Control No. CSEL Report 1997-TR-02). Cognitive Systems Engineering Laboratory.
- Woods, D. D. (1994). Cognitive Demands and Activities in Dynamic Fault Management: Abductive Reasoning and Disturbance Management. In N. Stanton (Eds.), Human Factors of Alarm Design London: Taylor & Francis.
- This paper appeared in Proceedings of the 44nd Annual Meeting of the Human Factors and Ergonomics Society/IEA2000, July, 2000.