Communication Of Intent In Military Command and Control Systems

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Abstract

Military command and control (C2) is a type of distributed supervisory control system. These systems are characterized by remote supervisors who work through multiple local actors to control a dynamic process. The agents can be separated by both space and time but still must coordinate their activities to achieve the goals of the system. Coordination normally occurs through the use of predetermined plans and procedures. However, these plans and procedures can be underspecified and brittle when a local actor is confronted with an unanticipated situation. In these instances, the local actor must adapt the plan in a manner consistent with the intent of the remote supervisor. Remote supervisors guide the adaptation by imparting their presence to local actors prior to controlling the process.

This research investigated the communication of intent in military C2 systems by using a mixed-fidelity simulation. U.S. Army battalion commanders and subordinate company commanders developed operations orders using their standard planning procedures. Anomalies were developed that forced them to rely on the senior commander's intent rather than the written plan. Battalion and company commanders were asked to determine what action they would take in response to the anomaly. The responses of the battalion commanders were used to evaluate the responses of the company commanders. Results of the simulation indicated that even though military C2 systems have a specified method to communicate intent, company commanders were able to match their battalion commander's intent in only 34% of the thirty-two episodes. Explanations for the results are discussed and methods to improve performance are suggested.

1. Introduction

Military command and control (C2), air traffic control, and nuclear power plant control rooms are examples of distributed supervisory control systems. Distributed supervisory control systems are hierarchical and cooperative. They include remote supervisors who work through intelligent local actors to control some process. A remote supervisor typically provides plans and procedures to multiple local actors. These plans and procedures often are inadequate to cope with the unanticipated variability of local situations (Woods and Roth, 1988). As a result, local actors must adapt the plans and procedures to the situation based on their understanding of the remote supervisor's intent. The research reported here investigated how remote supervisors (senior commanders), separated by both time and space from local actors (subordinate commanders), impart their presence by communicating intent to coordinate and adapt underspecified plans and procedures.

Normally, plans and procedures are developed by designers before the system is implemented or by remote supervisors who have an incomplete (or inaccurate) view of the local situation. These plans and procedures often do not aid local actors in their process control tasks if they follow them rotely. In a field study of a human-intelligent machine system, Roth, Bennett, and Woods (1987) learned that correct problem-solving paths deviated from the predetermined plans and procedures in 78% of the cases. Deviations were found to be the norm because domain experts and designers are unable to anticipate all possible local conditions. The plans and procedures were underspecified, requiring technicians to "supply knowledge and act outside of the scope and direction" of the expert system (Roth, et. al., 1987).

Woods, O'Brien, and Hanes (1987) also found in their studies of nuclear power plants that "good operations require more than rote rule following." They identified two types of errors that occurred when "events demanded a relatively variable sequence of component actions and extensive feedback from the environment in order to adapt to unpredictable constraints or disturbances."

- "Type A problems where rote rule following persisted in the face of changing circumstances that demanded adaptable responses."

- "Type B problems where adaptation to unanticipated conditions was attempted without the complete knowledge or guidance needed to manage resources successfully to meet recovery goals."

Local actors either failed to adapt plans and procedures to local conditions or they adapted plans and procedures without considering the intent of the remote supervisor.

Suchman (1987) supports the concept of local actors adapting plans and procedures. She states that "instructions must be interpreted with respect to a collection of actions and circumstances that they never fully specify." Local actors cannot blindly follow predetermined plans and procedures issued by remote supervisors or by system designers without regard for local conditions.

Local actors need a framework or a context for adapting their plans and procedures when responding to novel situations. They must understand the supervisor's intent underlying the plans and procedures. The dictionary describes *intent* as "a purpose; object; aim" (Webster's New World Dictionary, 1970). Another dictionary (Webster's II New Riverside University Dictionary, 1994) describes *intention* as "an aim that guides an action." In communicating intent, the remote supervisor explains the goals of the system (object or aim) and the reason for pursuing the goals (purpose). This description provides a framework for adapting the existing plans and procedures to respond to novel situations. Intent is the means by which the remote supervisor imparts his or her *presence* to local actors. This sense of presence assists local actors in responding the same way the supervisor would if the supervisor were able to view the situation through the eyes of the local actors.

There is an inherent tradeoff for the remote supervisor in establishing the framework for adaptation. Supervisors must determine the latitude or flexibility they will give actors to adapt plans and procedures to local situations. Supervisors who establish centralized control inhibit local actors. These supervisors show little regard for the impact of local situational factors. At the other extreme are supervisors who give local actors complete autonomy. In the latter case, remote supervisors are 'out of the loop' and the response across multiple local actors may be coordinated and synchronized only by coincidence. In fact, the system may actually move away from its goals or end state. Somewhere between these extremes are systems in which local actors are able to modify and implement procedures to achieve the supervisor's intent based on an analysis of local conditions and a sense of the supervisor's presence.

2. A Model Of Distributed Supervisory Control Systems

Military C2 systems, nuclear power plants, air traffic control networks, and many industries exhibit some form of distributed supervisory control. Although these domains are very different in their specific objectives, there are distinct similarities in the underlying structures and functions used to achieve their objectives or end states. In spite of their ubiquitous nature, little has been written about the characteristics of these systems. Any model of distributed supervisory control that could be applied across diverse domains must address the following scheme:

A ***remote supervisor*** uses a ***communications process*** to provide ***local actors*** with ***plans and procedures*** and to impart his/her ***presence***. The ***degree of control*** established by the remote supervisor influences the ability of the local actors to adapt to unanticipated conditions based on the ***actors' assessments of their local environments***.

2.1 Remote Supervisor

Advances in communication and automation no longer require supervisors and actors to be at the same location. Supervisors can be separated by both space and time from their subordinates. Such technology affords greater span of control but has its pitfalls. Supervisors who attempt to function as local actors will quickly lose sight of high-level organizational goals. They cannot continuously monitor all processes, filter the information, and determine the appropriate course of action for each local actor. They must remain detached from the details of the local actors' environments so they can evaluate the system's progress relative to the high-level goals.

Prior to controlling a process, the remote supervisors and local actors may engage in cooperative activities, including planning, training, and rehearsals. During periods of low activity in controlling a process, the need to exchange information among the supervisor and actors is minimal. When an unanticipated, time-sensitive event occurs, a remote supervisor must rely on local actors to provide him/her the information needed to assess the situation and to formulate a plan at the very time that the actors are most busy. Woods (1994) describes this ebb and flow of activity as characteristic of systems in which cognitive activity is distributed across multiple agents. If the supervisor's intent is effectively communicated prior to an unanticipated event, actors are more likely to make proper decisions with respect to overall system goals. Supervisors will not become mired in one local situation and lose sight of the system's goals. Thus, during peak periods, actors are able to devote more cognitive resources to controlling the local situation and less to the task of updating the supervisor.

2.2 Local Actors

A remote supervisor and local actors have different perspectives of the environment. Local actors operate at the sharp end (Reason, 1990) where they interact directly with the process being controlled. They have privileged access to a narrow portion of the system. Remote supervisors operate at the blunt end and can only influence the control process indirectly through policies, plans and procedures, and the allocation of resources.

Local actors have specific goals and are able to continuously monitor local changes in system status. These local conditions, in turn, affect how the actors respond to the plans and procedures of their remote supervisors. For example, if the local actors cannot communicate with the remote supervisor, actors must rely on the plans and procedures provided them. If local situations are such that the plans are no longer valid, actors must modify and implement the plans on their own. Even then, however, local actors cannot act independently. They must reconcile their actions with their supervisor's intent and coordinate their activities with other local actors. Failure to coordinate their activities with other agents could result in system failure.

2.3 Communications Process

The methods used to communicate between the remote supervisor and the local actors include voice, text, and graphics. Exchanges can occur face to face or electronically. Functions of the communications process include:

- Distributing plans and procedures;
- Specifying the degree of control;
- Imparting presence;
- Updating agents on status of system.

A remote supervisor will communicate plans and procedures to local actors but the actor is not expected to implement them until some future point in time when the system is most likely in a different state, one which might not have been anticipated by the supervisor. (For example, at Time T, when the System is in State S1, implement Procedure P. However, in Time T, the system is in State S2 and Procedure P may not apply). The content of the communication may consist of nothing more than the procedure itself, or it may contain additional information, including system goals, rationale, constraints, and other considerations (Klein, 1993). It is vital that the local actors understand the intent so when local conditions are different than those envisioned by the remote supervisor, the actors (if given the latitude) can take action that will move the system closer to its goal state.

2.4 Plans and Procedures

Distributed supervisory control system functions are based on plans and procedures (or guidelines). Plans and procedures are often developed by designers in conjunction with domain experts long before a system is operational. By their very nature, they are brittle. The plans and procedures specify what actors should do and how they should do it for each state of the system. However, designers and experts are not able to predict every situation, system state, or set of interactions for which plans and procedures should be developed.

Plans and procedures are also developed just prior to beginning (or even during) the control process. These situation-specific plans and procedures require supervisors to have an accurate view of the control process. Since supervisors cannot directly observe the process, local actors must devote both time and cognitive resources to updating the supervisors' knowledge of the local situation when time is critical and cognitive resources may be committed to near-capacity.

2.5 Degree of Control

There is an inherent tradeoff for the remote supervisor in establishing the framework for adaptation. Supervisors must determine the latitude or flexibility they will give actors to adapt plans and procedures to local situations. Ashby (1956) wrote that "only variety can destroy variety." If in some game, D can make 10 moves, but R can only make one move, then the variety in the outcomes will be as large as the variety in D's possible moves. If, however, R can make two moves rather than one, then the variety of outcomes is reduced by as much as one-half. The remote supervisor determines the number of "moves" available to the local actors vis-à-vis the environment by the degree of flexibility afforded to the actors.

Remote supervisors establish the degree of control they exert on local actors through plans and procedures. Specific, detailed plans and procedures establish centralized control and reduce the flexibility of actors to adapt to unanticipated variety in the local environment. Generalized plans and procedures increase the flexibility of local actors but decrease the likelihood that there will be a coordinated response across the system.

3. Military C2 as a Type of Distributed Supervisory Control

In the domain of military command and control, senior commanders (remote supervisors) and their staffs engage in a deliberate, self-paced decision-making process to formulate a plan for future operations. The plan is then communicated to subordinate commanders (local actors) for implementation. In this domain, the system includes an intelligent, uncooperative, unpredictable enemy that attempts to exploit weaknesses in the plans of the friendly forces. Detailed battle plans do not remain viable much past the onset of hostilities. When confronted with unanticipated events, subordinate commanders must initiate an event-driven decision-making process. Their task is to identify and achieve the senior commander's higher-order objective even if the specified mission can no longer be accomplished. Subordinate commanders must rely on the senior commander's statement of intent to bound the space of acceptable solutions.

In most distributed supervisory control systems, intent is communicated passively. It is implied in the procedures and difficult to discern. However, in the domain of military command and control, senior commanders work diligently to develop a statement of intent that is communicated to subordinate commanders prior to starting a tactical operation. Such explicit statements of intent ought to increase the likelihood that local actors will make decisions in accordance with the goals of the remote supervisor. Favorable research results in a military C2 system could be extended to improve local actor compliance with remote supervisors in other domains.

The present study used active duty, infantry and armor battalions to investigate how intent guides the event-driven decision-making process so that the senior commander's higher-order objectives are achieved. In a mixed-fidelity simulation (see Figure 1), four army battalion commanders and their staffs developed tactical operation orders based on

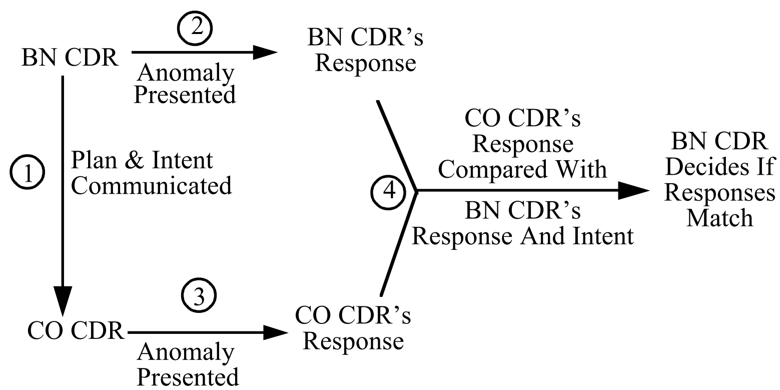

Figure 1. Sequence of events for tactical simulation.

a brigade (next higher echelon) operation order they were provided. The battalion commanders and their staffs disseminated the orders, which included statements of intent, to subordinate company commanders. These company commanders (four per battalion) developed their own operation orders and briefed them back to the battalion commanders.

An investigator then reviewed copies of the battalion and company operation orders. Two types of anomalies were created for each battalion. In the first anomaly, the unit was blocked from completing its specific mission but could still achieve the higher-order objectives of the battalion commander. In the second anomaly, the unit had unexpected success relative to the specific mission and had to decide what to do next. In both cases, the intent statement of the battalion commanders provided sufficient information to aid the company commanders in responding to the anomalies.

The battalion commanders were presented with both anomalies. They were asked how they expected the subordinate company commanders to respond to the anomalies. Their answer became the basis for evaluating the responses of their subordinate company commanders. The anomalies were then presented to the company commanders. While being videotaped, the company commanders used a think-aloud protocol as they considered how to respond to the anomalies. The battalion commanders watched the video tapes and judged the responses of their subordinates relative to their own responses. Finally, former battalion commanders, serving as neutral observers, watched the video tapes. The neutral observers provided valuable commentary on the intent process within each of the battalions.

4. Results of Simulation

Four battalions, each with four company commanders were given two anomalies, generating thirty-two problem-solving episodes. General information extracted from the verbal protocols included the following:

- a summary of the company commander's response.
- the judgment of the battalion commander on whether or not the company commander's response matched his intent.
- the basis for the company commander's response.
- references by the company commander to coordinate his actions.
- references by the company commander to any element of the plan.
- length of the protocol.

Battalion commanders judged that the company commander's responses matched their intent in only seventeen of the of thirty-two episodes (53%). In three episodes, however, the responses matched only by coincidence. The company commanders chose to remain in place not because they understood the battalion commander's intent but because they misinterpreted the information available to them. In three other episodes, although the battalion commanders judged the decision of the company commanders to match their own, they were, in fact, substantially different. Battalion commanders considered them a match because the company commanders were "thinking along the right lines." If these six episodes are considered mismatches, then the responses matched in only eleven of thirty-two episodes (34%).

During the detailed analysis of the think-aloud protocols, six distinct categories of utterances were identified. These categories were used to parse the protocols and to identify the type of information used by the company commanders to respond to the anomalies. The six categories are:

- Need for more information
- System status
- Reference to procedures
- Reference to intent
- Course of action
- Coordination activities

Company commanders who were successful in matching their battalion commander's intent initially determined the system status (i.e., the disposition of friendly and enemy forces). They made specific references to procedures and the intent statement in the battalion operation order. They also acknowledged that they had to coordinate their activities with commanders of adjacent units prior to taking any action.

Unsuccessful company commanders generally did not refer to the battalion commander's statement of intent. In addition, unsuccessful commanders also exhibited several other behaviors. Some commanders exhibited flawed domain knowledge. For example, one commander's incorrect knowledge of tactics and time/distance factors caused him to initiate a system response that could not have been completed in the time available. A few commanders had a low tolerance for situational uncertainty. They decided not to act until they were given more information to reduce their uncertainty. In some instances, commanders misassessed the information available to them. Even though they were given information on the status of the environment (i.e., enemy units), they did not incorporate it into their mental model of the system. Some commanders also exhibited a rigid adherence to procedures in spite of situational information that indicated they were facing a novel, unanticipated situation. When a major, unanticipated event occurred on an adjacent part of the battlefield, these commanders would not deviate from their assigned mission, even though the event jeopardized the higher-order goals of the system.

5. Implications of Results for Distributed Supervisory Control Systems

Results of this study suggest several areas that can be explored to improve communication of intent, and, therefore, the performance of distributed supervisory control systems confronted with unanticipated variability.

5.1 Path vs. State Solutions

Rich and Knight (1991) believe that solutions to problems can be either paths or states. Military doctrine suggests that intent should focus on state solutions yet, in practice, solutions are often paths. The doctrine states that intent is designed to "focus subordinates on what has to be accomplished in order to achieve success, even when the plan and concept of the operation no longer apply…" (FM 100-5, 1993). In implementing the doctrine, commanders are taught that their intent statements ought to include these components: purpose, method, and end state. In this study, the method sections were often very specific. In a sense, they established a canonical path through a Problem Space (see Figure 2). The method tells Local Actor 1 to proceed from Start State to State 2, State 3, and, finally, the End State. An actor may progress unimpeded through the Problem Space. Or, in the case of Local Actor 1, there may be an obstacle that prevents the system from reaching the End State as planned. However, the event (or breakdown) that blocked mission accomplishment was not unexpected so there is a contingency plan that can be implemented. So even though a breakdown occurs, Local Actor 1 follows a pre-planned path through the Problem Space.

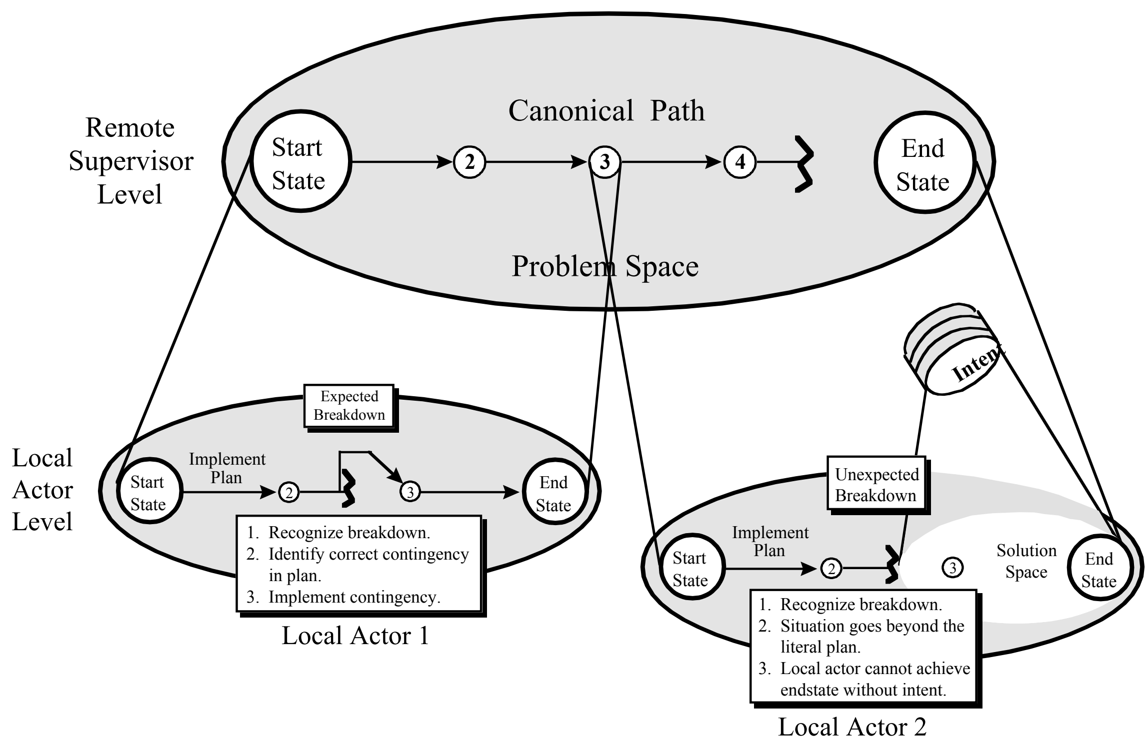

Figure 2. Path vs. State Solutions.

For Local Actor 2, however, the event that occurs between State 2 and State 3 is unanticipated. Very specific intent statements offer no help. There is no alternative, pre-planned path through the Problem Space to the End State. In order to move through the Problem Space to the End State, the intent statement should illuminate and bound a Solution Space. Actors should be free to move through the Solution Space based on their analysis of the local situation. The intent, then, should guide the local actor's adaptation process.

5.2 Ambiguity of Natural Language

The ambiguity of natural language also presents an obstacle to distributed supervisory control systems when confronted with unanticipated variability. Misunderstandings arise when remote supervisors and local actors do not share a common understanding because they are separated by both space and time. Suchman (1987) states that many expressions "rely upon their situation for significance." In describing distributed decision making systems, Fischoff & Johnson (1990) state that "people need to translate their thoughts into some language before those can be shared with others. Their ability to use the language sets an upper limit on the system's coordination of decision making, as does the system's procedures for information sharing." They also state "that terms will unwittingly be used differently" by agents in the system.

These difficulties are compounded in distributed supervisory control systems because intent is communicated from remote supervisor to local actor at Time 1 and in Context A, but often is not interpreted and implemented until Time 2 and in Context B. Remote supervisors should make every attempt to ensure that local actors clearly understand the intent. Embedding the intent in hypothetical contexts is one method that can be used to check the understanding of the local actors.

5.3 Flexibility vs. Synchronization

Highly-coupled, technologically-laden systems call for flexible yet synchronized responses to anomalous, unanticipated situations. In distributed supervisory control systems, a remote supervisor oversees multiple actors, each controlling a local process. It is not enough for local actors to implement the correct procedure. The procedure must be initiated at the correct time and place relative to the actions of the other agents in the system. Decisions made and implemented in isolation can interact in unexpected ways and actually prevent the system from reaching its goals.

5.4 Imparting Presence

Remote supervisors have no other means to control a process except through the actions of local actors. Plans and procedures are too brittle to effectively guide the decision making processes of these actors. The plans and procedures must be tailored to the local situation. A remote supervisor with high-level system knowledge and a clear understanding of system goals would effectively adapt the plans and procedures based on local conditions. Remote supervisors, however, must remain in a position where they can retain a comprehensive view of the entire system. Since they cannot be physically present with the local actor, they need to impart their presence to guide the adaptation of plans and procedures.

When remote supervisors impart their presence, they are equipping local actors with the strategic-level goals, constraints, and tradeoffs of the system. Presence empowers a local actor to make decisions similar to those that the supervisor would make if the supervisor were at the actor's location. Communicating intent is the primary means by which remote supervisors impart their presence.

6. Conclusion

Van Creveld (1985) states "Confronted with a task and having less information available than is needed to perform that task, an organization may react in either of two ways. One is to increase the information-processing capacity, the other to design the organization, and indeed the task itself, in such a way as to enable it to operate on the basis of less information. These approaches are exhaustive; no others are conceivable."

Those who design distributed supervisory control systems must choose one of the two alternatives proposed by Van Creveld. Advocates of technology-based solutions will undoubtedly seek to increase the information-processing capacity of an organization. The logic is that if they increase the ability to process information, they will reduce the amount of uncertainty. Less uncertainty will result in better (and probably more centralized) control of the system.

Uncertainty, however, is not so much a function of information-processing capacity as it is the ability of the designer to predict and identify all conceivable states of the system. But as stated earlier, highly-coupled, complex, distributed systems will often confront remote supervisors and local actors with unanticipated states. Designing distributed supervisory control systems with the ability to function with less information requires that local actors have a variety of responses at their disposal and the authority to implement them at their discretion. The process of imparting supervisor presence through the communication of intent is essential and worthy of further investigation.

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