USING PATHFINDER TO GENERATE COMMUNICATION NETWORKS IN A COGNITIVE TASK ANALYSIS

Steven M. Shope[1], Janie A. DeJoode[1], Nancy J. Cooke[2], and Harry Pedersen[1]

1 - U.S. Positioning Group, LLC
Mesa, AZ

2 - Arizona State University East
Air Force Research Laboratory
Mesa, AZ

As part of a cognitive task analysis performed in the initial design stage of developing an Unmanned Aerial Vehicle (UAV) operations center, we used Pathfinder to generate communication networks based on four subject matter experts' (SMEs') understanding of the typical communications that occur in different task scenarios (i.e., a strike operation versus a non-strike operation). SMEs provided ratings on three dimensions of communication for each pair of ten team members. Dimensions were 1) importance, 2) volume, and 3) diversity of communications. We developed two methods for merging the ratings of importance and volume into a single network in order to simultaneously represent both dimensions. This application of Pathfinder has allowed us to 1) quantify the extent to which the SMEs conceptualize communications in the same way and 2) generate surrogate communication networks when it is impossible to monitor actual communications.

INTRODUCTION

Command-and-control (C^2) environments in military and civilian sectors are inherently complex. The demands imposed by C^2 tasks and the technology used to perform those tasks have resulted in C^2 systems composed of a complex team of teams. The overarching goal of our efforts is to improve the process by which C^2 entities are designed, monitored, and assessed. We performed a cognitive task analysis in the context of a UAV C^2 cell called DUOC (Deployable UAV Operations Cell) that is currently in the initial design stage of development. The DUOC will act as a layer of command-and-control that mediates interactions between the Air Operations Center (AOC) and the UAV ground control stations (GCSs). The results of this effort are relevant for design and AOC staffing decisions, but in addition we assume that the processes and methodologies used to elicit information about and represent the C^2 task at the system level are generalizable to other C^2 entities. Thus, this paper will describe one of the many methodologies we used to elicit knowledge in our cognitive task analysis of the DUOC.

According to Cooke, et al. (2000), effective communication in teams is paramount in dynamic environments where resources, such as knowledge and information, and actions must be shared and coordinated. Furthermore, Kiekel et al. (2001) suggest that communication patterns are predictive of performance. In addition, communication can be thought of as cognitive processing at the team or system level (Kiekel, et al., 2001). For these reasons, we have chosen to elicit from subject matter experts, the communications that they envisioned occurring among the DUOC team in its fully functioning state. Specifically, our goal was to compute communication networks that depicted three dimensions of DUOC communications. The dimensions were 1) importance, 2) volume, and 3) diversity of communications. We used the Pathfinder psychological scaling technique (Schvaneveldt, 1990) to compute the communication networks. As Cooke (1990) points out, psychological scaling techniques such as Pathfinder can be used to circumvent the problems associated with the difficulty experts have in verbalizing their knowledge.

Typically, Pathfinder is used to analyze the semantic relatedness of concepts in a particular domain, to assess how knowledge is organized, and to highlight differences in the knowledge structures of novices and experts (Schvaneveldt, 1990). Durso and Coggins (1990) identify uses of graph theoretic constructs to represent the frequency of communications among or within organizations and they highlight past uses of graph structures that account for communication patterns within groups. Furthermore, Durso and Coggins speculate that Pathfinder could be used to test the effect of various communication patterns on task performance. Kiekel, et al. (2001) have in fact applied Pathfinder to the analysis of communication flow among team members and have identified network patterns predictive of performance.

In this study we elicit experts' understandings of typical communications that may occur among team members within and external to the DUOC. These judgments serve as a surrogate for monitoring actual communications.

A surrogate is necessary in this case because the DUOC is an envisioned world. However, we assume that these surrogate representations are good descriptions of the envisioned world. Our assumptions are based on the fact that our subject matter experts are not only the DUOC system architects, but they also have experience in UAV operations and other military operations environments, including combat operation environments.

DUOC Task

The DUOC is an initiative of the UAV Battlelab (UAVB) at Eglin Air Force Base and is currently in the initial design stage of development. The UAVB's concept of operations defines the DUOC as a tool for managing, monitoring, and supporting multiple numbers and types of UAVs conducting a variety of mission types over the battlefield at the tactical level. The current internal design of the DUOC has seven core functional positions. The seven team members will be highly interdependent not only with one another, but also with outside entities, such as the AOC and the GCSs. The seven core positions include a Tactical UAV Coordinator (i.e., the leader), a Weather Officer, two Imagery Analysts, an Intelligence Officer, an Administrative Officer, and a Target Officer.

METHOD

Participants

Four subject matter experts (SMEs), from the UAVB participated. One of the SMEs is the primary DUOC initiative manager and architect. All SMEs have extensive experience in UAV operations.

Procedure

Each SME provided ratings on three dimensions of communications: 1) the *importance* of a communication link, 2) the *volume* of communication on a given link, and 3) the *diversity* of communications (topics) on a given link. We defined a communication link as any physical mode of communication, such as internet, radio, telephone, text messaging, and face-to-face.

For each dimension, ratings were given for each pair of entities internal and external to the DUOC. Ratings, which were randomly presented, were made twice for each pair, once in each direction. Specifically, there were 7 entities internal to the DUOC, as previously noted, and 3 entities external to the DUOC: AOC, GCS, and a generic outside entity (e.g., a back-up imagery analysis team). Furthermore, SMEs rated these dimensions of communications in the context of two types of missions. The first context was a mission involving only intelligence, surveillance, and reconnaissance (ISR). The second context, an ISR-strike mission, includes ISR activities as well as an objective of attacking targets with UAV-carried munitions. See Figure 1 for an example rating.

Materials

There were six DUOC communications ratings packets, one packet for each dimension of communications in an ISR and ISR-strike context. Each packet contained 90 ratings.

RESULTS

Networks for each of the six sets of ratings from each SME were generated (e.g., see Figure 2). For each of the six networks, we calculated the proportion of shared links among pairs of the individual SME networks. This proportion, or similarity value, identifies how similar the networks are for pairs of SMEs. For example, how similar are the SMEs' ratings of the importance of the communication link between each pair of entities in the context of an ISR mission? On average, the proportion of shared links among SME's networks was .42. Although many of the similarity values that went into the average were significantly greater than what would be expected by chance, we view .42 as relatively low and consequently chose not to average ratings across SMEs. In this paper, we present the results of one individual SME (i.e., DUOC architect).

Figure 2 shows a Pathfinder network based on the DUOC architect's ratings.

Scenario: In an **ISR-Strike** mission, what is the ***importance*** of the following communication link (i.e., would the mission be compromised if the link was lost)?

Example 1. Please shade the circle of your rating. **The communication link…**
From GCS to Coordinator is of

No Importance O	**Low Importance** O O ● O O **High Importance**

Figure 1. Example rating.

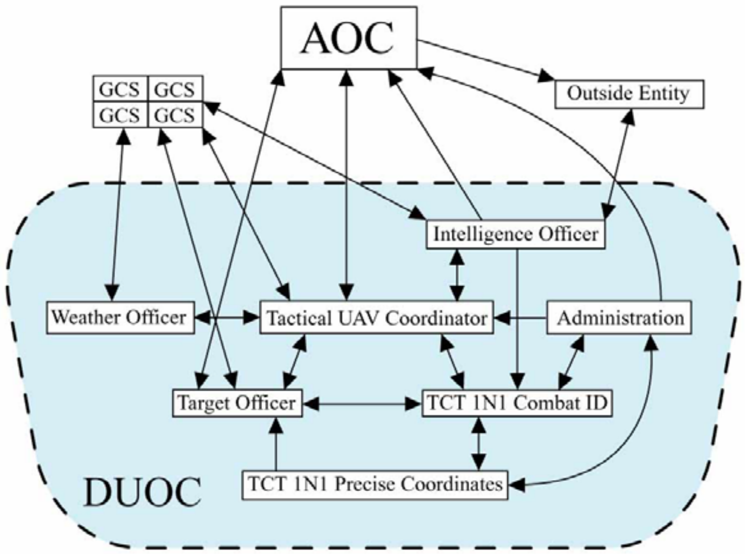

Figure 2. A Pathfinder network depicting one SME's ratings of the *importance* of communication links among DUOC and other entities in an ISR-Strike mission.

Each node represents an entity internal or external to the DUOC. For this particular set of ratings, the links represent the importance of the communications links among the entities in the context of an ISR-strike mission. For example, a loop of important links emerged among the Combat ID Officer, Precise Coordinates Officer, and Target Officer, whose respective responsibilities are to identify a target, locate a target's position, and determine the strike plan. Furthermore, because the identity and position of a target are often packaged together, this prevents the need for a direct link between the Precise Coordinates Officer and Tactical UAV Coordinator (TC). Instead, this information is relayed to the TC via the Combat ID Officer. Because the Pathfinder procedure only adds a link if there is no other path of equal or greater importance, the links present are those that the SME viewed as important. In other words, absence of a link between two entities indicates that the SME viewed that communication link as not critical or not important. Note that each link is bidirectional, where two entities can be linked in both directions, one direction, or not at all.

Each group of networks (importance, volume, and diversity) provided valuable information about DUOC communications. However, we developed two methods for combining the *importance* and *volume* ratings into one network. The purpose of merging the two types of ratings was twofold: 1) to differentiate the links between entities with highly important communications that are very frequent (e.g., "Target has been photographed") versus those with highly important communications that are very infrequent (e.g., "UAV has crashed"), and 2) to filter out the links between entities with very frequent, unimportant communications (such as "Roger that"). Due to space limitations, we deem it most important to present our findings of those entities that share *important* and *voluminous* communications; therefore, our analyses of the *diversity* ratings are not reported here.

The first method involved developing a parameter that integrated the original *importance* and *volume* ratings to represent a new set of communication ratings. The parameter is: (original *importance* rating)^2 × original volume rating. These new integrated ratings were then submitted to Pathfinder. Communications rated as unimportant (whether low or high in volume) are given little weight (e.g., see Table 1). An example of a network created from this new set of integrated ratings is presented in Figure 3. As expected, Figures 2 and 3 share many common links. However, as can be seen in the latter, where volume is taken into consideration, several of the links have been eliminated. For example, a link no longer exists from the GCS to the Weather Officer (and visa versa) in Figure 3. This suggests that the communications on that link were rated as moderately important, but very infrequent. Figure 3 also illustrates the critical role of the TC as an entity heavily involved with communications across links that are crucial to the mission success.

Table 1
Examples of New Integrated Ratings

Importance	Volume	Calculation	New Rating
Low = 1	Low = 1	$(1)^2 * 1$	1
Low = 1	High = 5	$(1)^2 * 5$	5
High = 5	Low = 1	$(5)^2 * 1$	25
High = 5	High = 5	$(5)^2 * 5$	125

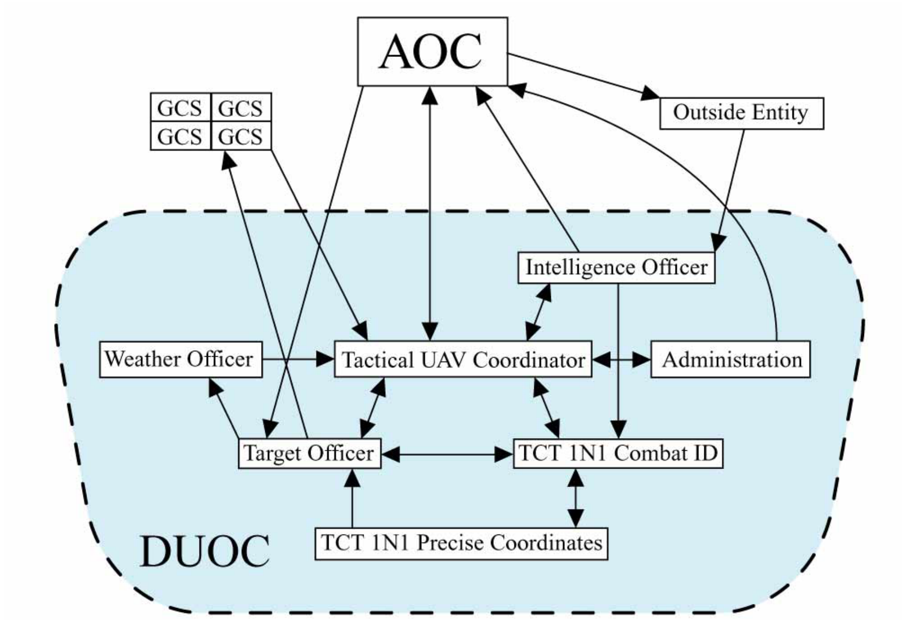

Figure 3. A Pathfinder network of one SME's ratings based on the combined ratings of *importance* of links and *volume* of communication among DUOC and other entities in an ISR-Strike mission.

The second method we used to create a single network provides a graphical solution to combining the *importance* and *volume* of communications and is not based on Pathfinder analysis of a new data set. To combine the networks, we used the original Pathfinder network generated for the *importance* of communications as a starting point and weighted the links in that network with the original ratings given for the *volume* of communications. The links in the resulting network are identical to the links in Figure 2 (i.e., all links are important) but here those links are weighted by the degree to which they carry voluminous communications. Figure 4 illustrates this method, depicting the communication strength of each channel (or link), where higher numbers indicate more important and frequent communications.

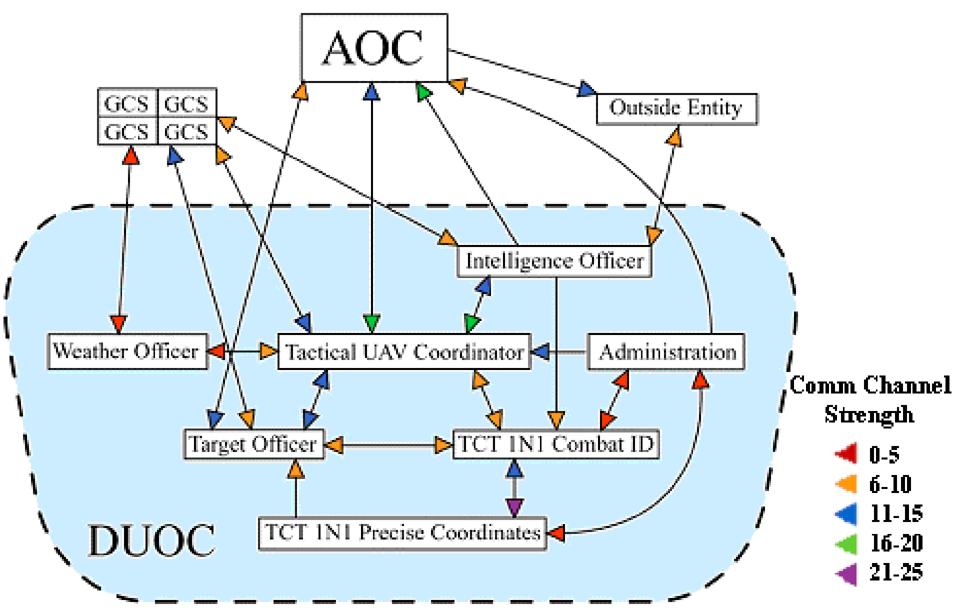

Figure 4. The original *importance* Pathfinder network weighted by the ratings of the *volume* of communication among DUOC and other entities in an ISR-Strike mission.

Due to space limitations, we highlight only a few of the interesting features of these pathfinder networks. In each pathfinder network, the TC (i.e., DUOC leader) is a hub for important communication links and frequent communications. Furthermore, as seen in Figure 4, the number of links connecting the TC to other entities and the strong communication channels leading to the TC suggest that this DUOC member is coordinating the push and pull of information, gathering information and distributing subsets of that information to the appropriate entities. Finally, these networks introduce important questions to pose to SMEs. For instance, is there a particular member of the GCS that is primarily involved in the communications with the DUOC? Is there an entity in the AOC that should be re-located to the DUOC to minimize the number of links between the two entities?

DISCUSSION

We have developed a method for constructing surrogate communication networks based on subject-matter experts' understandings of the typical communications that may occur among and within a C^2 cell that does not yet exist. Our approach utilized Pathfinder in a non-traditional way by constructing communication networks based on SME's ratings of how 1) important, 2) voluminous, and 3) diverse communications are envisioned to be.

Although the similarity among SME's networks was moderate, due to the level of our SMEs' experience, we assume the surrogate communications networks we have constructed provide a reasonable description of the communications in the envisioned C^2 structure. However, these communications networks do not necessarily reflect what is ideal. That is, the preliminary design of the DUOC and its communication networks, as well as the SMEs' conceptualizations of this design is not necessarily ideal. Nevertheless, the networks, and the differences in the manner by which experts conceptualize the system, can highlight problems or issues in the current or conceptualized system.

For example, the networks can highlight problems with the distribution of tasks and workload, as evidenced by a high number of importance and volume links for a single individual. The potential problems identified through the surrogate communications networks will guide our future interviews with SMEs and ultimately facilitate the initial design of the operations cell.

The critical features of this method we have developed for constructing surrogate communication networks are as follows. First, the method can be implemented in virtually any domain where multiple communication links exist. Furthermore, minimal effort is required to adapt this method to various tasks. Finally, although surrogate communication networks serve as a useful tool at any stage of a system's design, they are especially valuable during the initial design of an envisioned world, as they provide a starting point for designers to iterate upon.

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