

IDENTIFYING BREAKDOWNS IN TEAM SITUATIONAL AWARENESS IN A COMPLEX SYNTHETIC ENVIRONMENT TO SUPPORT MULTI-FOCUSED RESEARCH AND DEVELOPMENT

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ABSTRACT

Currently in the U.S. Army, staff level team performance is being examined to determine how to achieve more with fewer team members through organizational changes, task changes and new supporting technology. The key goal of such research and development is to create smaller organizations that are able to react quickly, efficiently, and effectively by virtue of their shared awareness. This type of multi-focus, rapid prototyping in a complex, field-like context requires that researchers devise or adapt methods to capture useful information to inform multiple, simultaneous development efforts. The purpose of this paper is to describe a specific data collection and analysis method, Breakdown Analysis, that we adapted to separate out the effects of new organizational configurations and new technology, as well as to detect the influence of the simulated future environment on performance. The setting for observation was the operation of a future fire support organization in a complex, synthetic environment involving several scenarios. We focused data collection to determine how well Breakdown Analysis could inform our picture of the staff's situational awareness (SA). Our findings were that breakdowns in all levels of SA could be documented, and probable reasons for the breakdowns could be diagnosed using the methodology. The methodology was also unobtrusive, which met the requirements of the experiment. These findings allowed us to recommend developments in task definition, information technology design, training, and organization that would better support SA on all levels, and thus, team performance.

Keywords: Breakdown Analysis; team performance; collaboration; decision support systems, situation awareness.

INTRODUCTION

Problem Statement

Currently in the U.S. Army, team performance is being examined at the staff level in terms of how to achieve more with fewer team members through organizational changes, task changes and new supporting technology. The key goal of such research and development is to create smaller organizations that are able to react quickly, efficiently, and effectively by virtue of their shared awareness. Development of new information technology, roles and organizational configurations are

often approached simultaneously in test-bed type environments that simulate the complex, natural environment envisioned in the future. This type of multi-focus, rapid prototyping of new organizations, roles and technology in one complex, field-like context requires that researchers devise or adapt methods to capture useful information. The purpose of this paper is to describe the second iteration of one such test-bed environment and the use of Breakdown Analysis to separate out the effects on performance of new organizational configurations, new technology, as well as to detect the influence of the simulated future environment.

We began development of the methodology during the Future Fires Command and Control (F2C2) Concept Experimentation Program 1 (CEP1) (Childs & Ross, 2000). F2C2 CEP 1 was conducted to examine the effects on performance of a prototype collaborative technology, the Future Fires Decision Support System (F2DSS), simultaneously with new organization structures and roles for the field artillery battalion staff in a high combat environment envisioned for the year 2005. The challenges to measurement included a number of factors being varied simultaneously, work that is increasingly cognitive as well as collaborative, a faster-paced environment than current operations, and simultaneous technology development to support both individual and collaborative work.

The data collection methods used during CEP 1 included questionnaires, interviews, focus groups, and Breakdown Analysis. Of these methods, Breakdown Analysis (Scrivener, Urquijo, & Palmen, 1993) appeared to be the most adaptable to our current purpose. Breakdown Analysis was originally developed to support the development of collaborative technology by permitting systematic observation of tool use in a natural setting. Scrivener, et al. (1993) points out that a system is usable only if the user can work on tasks while remaining unaware of the system. Interruptions into the cognitive flow of the tasks due to the user or users becoming aware of the technology are called breakdowns. Breakdown Analysis was developed to sort out which performance problems were based on poor technology design and which stemmed from other sources such as lack of task or team knowledge. Because Breakdown Analysis can be used to reveal problems in individual task performance, collaboration, and technology usage, and even the adequacy of the test-bed environment, it was considered an ideal tool for F2C2 experiments.

The Setting

The Fires Effects Coordination Cell (FECC) is a new organizational element at the brigade level. The FECC's mission is to perform full-spectrum effects management. Effects are generally defined as any intervention, lethal or non-lethal carried out in the unit's area of responsibility to influence the course of action and support goal attainment by the maneuver force. This new organizational element was supported in the test-bed by a prototype decision support system (F2DSS) which included collaborative, distributed, and formatted information displays. The F2DSS was designed to support information needs for each organizational position. Centralized effects management at the FECC represents a change from current methods of providing responsive fire support. For CEP 2, participants were required to merge existing fire support tasks with tasks associated with tactical fire direction and control. Traditionally, tactical fire control and direction have been decentralized to field artillery battalion tactical operations centers (FA BN TOCs) and performed by fire direction personnel. The FECC's mission critical tasks required close, continuous interaction with the supported brigade combat team (BCT).

The organization of the FECC had to facilitate synchronization of effects with the BCT maneuver forces and enable adaptation of plans to rapidly changing tactical situations. The FECC was staffed with 12 personnel who performed effects management tasks using voice and digital communications

systems that simulated live tactical data processors. The core FECC organization consisted of three functions: 1) Lethal Effects Management, 2) Targeting and Intelligence, and 3) Non-lethal Effects Management. These functions were supported by the Operations and Plans element of the BCT, which integrated FECC efforts and facilitated transition and support to future operations.

Breakdown Analysis as a Situational Awareness Measurement Method

Situational Awareness has been defined as a three-step process involving, 1) detecting or perceiving elements in the environment, 2) processing or comprehending the current situation, and 3) acting on the information or projecting the future status of the situation (see for example, Endsley, 1998). This definition is in accordance with Endsley's model of SA in the decision making process (Endsley, 1995).

Recent work has pursued the refinement of SA measures for use in the design of new systems in an operational environment (Endsley, 1998; Endsley & Jones, 1999; Endsley, et al., 2000.) Endsley (1998) documents an effort to develop a measure of SA within the context of an Air Operations Center to support test and evaluation of new systems. Four major categories of SA measures were considered in the development: process measures (indirect); direct measures; behavior measures (indirect); and performance measures (indirect). Endsley considered studying the communications between operators to be in the indirect, process category. Simulation manipulation is also considered a process measure, and is not recommended during test and evaluation as probes may artificially distort the SA process. Behavioral measures include such things as communication frequency—better SA being associated with less verbal communication—or time to verbal response from query. Performance measures include such things as kill ratio and mission accomplishment. Endsley supports the use of direct measures of operator SA and workload during test and evaluation, which are often subjective reports from participants. Endsley et al., (2000) concentrated on adapting SA measures for the infantry to support the individual soldier to the brigade level in order to inform information technology development. The report concludes that there is a need for a good deal of research to adapt SA measures to infantry operations if they are to support design of future technology, but a good foundation exists for this endeavor.

Heffner (2000) reviewed current methods being used to measure situation awareness and established strengths and weaknesses of the methods for use in pilot SA. These methods included the China Lake Situational Awareness (CLSA), SA Subjective Workload Dominance Technique (SA-SWORD), SA Global Assessment Technique (SAGAT), Crew SA, Snapshots, and SA Probes. While each of the existing methods for measuring SA has desirable characteristics, none was completely suitable for our purpose. We were looking for an objective measure of SA, rather than a “user-centered” subjective measure. The SAGAT is objective in that it relies on a comparison of real and perceived truth. Crew SA, Snapshots, and SA Probes are objective in that they rely on observer information. They require that the action is stopped at random times or that conversations be held with the participants during their performance, however, this impedes the flow of the experiment, which was not desirable by the customer. The customer (the Depth & Simultaneous Attack Battle Lab) had designed an environment that closely simulated operations. Neither conversations with observers during operations nor stopping the action were seen as a natural part of the flow of operations. We agreed with this approach in that it supported our attempts to design a more ecological or “use-centered”, as opposed to “user-centered” methodology, and our desire to avoid verbal reports of past actions and verbal reports of ongoing action. Both of these verbal report

approaches can be subject to bias which can lead to design recommendations that support what users believe they want rather than what they show they will use.

While most approaches consider the technology or the user-technology coupling as the system, we defined the system as including 1) the users (soldier in the loop), 2) the tasks (Effects Coordinator; Plans & Operations; Lethal Effects management; Targeting & Intelligence; and Non-Lethal Effects Management), 3) the tool (F2DSS), and 4) the environment (test-bed). Our approach to data collection stems from an ecological or “use-centered approach” as described by Flach, Vicente, Tanabe, Monta, and Rasmussen (1998). This view regards the human or the team in the loop as an adaptive, meaning processing part of the system as opposed to an information processing system with limited capacity – a view that emphasizes designing systems to be manageable. We were focused on supporting the design of an organization and an information technology system that supports the production of meaning in order to create a basis for adaptive behavior in a complex, fast-paced environment. We were not only measuring the effect of the F2DSS on situational awareness and collaboration, but were also trying to identify the most efficient organization arrangement for the FECC including workload effects.

Breakdown Analysis avoids the self-report and reconstruction of events that are prone to bias, and provides a structured approach to direct observation of the whole system of user, environment, and technology. It is specifically designed to analyze the use of software systems designed for two or more people, but the method also creates a framework to observe all breakdowns in task performance, not just those attributable to the software system. Because Breakdown Analysis reveals problems in individual task performance, collaboration, and technology usage, and even the adequacy of the testbed environment used, it was considered an ideal tool for collecting data during the F2C2 experiment. Breakdown Analysis is executed in three phases: 1) notation and classification of the breakdown (i.e., user-tool; user-user; user-task; user-environment); 2) determination of the probable cause for the breakdown (diagnosis); and 3) what to do to fix it (remedy).

FINDINGS

Our application of Breakdown Analysis involved three observers taking notes for two-hour blocks for six days as the FECC progressed through three scenario types. The notes were translated into an analysis matrix and each breakdown was categorized as one of four types, 1) user-task, 2) user-tool, 3) user-environment, or 4) user-user. The breakdowns within the four categories were 1.1) User does not understand task, 1.2) User does not have necessary knowledge to accomplish task, 2.1) Tool failure, 2.2) User does not understand tool, 2.3) Tool is inadequate for job, 3.1) User becomes aware of environment, 4.1) Insufficient information, 4.2) Message unclear, and 4.3) Message not received.

Examples of each level of SA identified through Breakdown Analysis are shown here. The corresponding diagnosis based on the content of the conversation, and suggested recommendations are also presented. 1) Breakdown in first level of SA, detecting or perceiving elements in the environment – Eagle 6 to Venom 6, “Is that a location grid?” Venom 6 to Eagle 6, “No, I can’t read the whole number on my screen. It’s what I can see of a target number.” This breakdown was classified an user-tool breakdown, specifically a 2.2 and 2.3. Eagle 6 could not identify the type of number appearing on the screen and the tool, F2DSS, did not allow Eagle 6 or Venom 6 to view the number in its entirety. Recommendations were made to improve operator control of the graphic user interface. 2) Breakdown in second level of SA, processing or comprehending the current situation – Eagle 3 to Venom 3, “Someone is putting in personnel targets and someone is shooting it. Can you confirm what’s happening?” Eagle 3 to Warrior 3, “Are you firing targets? Targets are invalid.

Trying to find out what's happening." This breakdown was classified as user-task and user-user, specifically a 1.2 and 4.1. Eagle 6 became aware that fire missions were not being processed through proper channels. He notified Venom 6 and Warrior 6 and halted the firing of targets. Recommendations were made to increase information sharing so that each participant was aware of the extent of their individual responsibilities. 3) Breakdown in third level of SA, acting on the information or projecting the future status of the situation – Eagle 32 to Eagle 3, "Ammo control plan?" Eagle 3 to Eagle 32, "We need to work with them so they don't exceed 50%." Eagle 32 – Eagle 3, "What do we have left that can shoot?" Breakdowns were classified as user-tool, specifically 2.3. Eagle 32 and Eagle 3 were attempting to project the future status of the ammunition supply but had difficulty doing so because the F2DSS would not allow them to view the necessary information. Recommendations were made to simplify the presentation of the supply status so that users could quickly view ammunition levels.

Our measure of workload, the NASA-TLX, administered daily and showed a wide variation in the workload of individual team members. It was difficult in this setting to see the relationship between SA and workload, because numerous difficulties in the technology dominated the breakdowns for the majority of the experiment causing high levels of frustration ratings in the TLX. The large role of technology-centered breakdowns did not allow us to see SA performance that the staff was probably capable of given more a more fully functional decision support system. Therefore, variations in workload could not be compared well to variations in SA performance. This conclusion is based on interviews with the staff members that generally indicated that the F2DSS was well designed, but had not been well developed. A more robust development of the design would have surely resulted in very different data in the areas of SA and workload.

DISCUSSION

The Breakdown Analysis method was found to meet our expectations as a measurement tool. The method produced fine-grained observations suitable for use by the organizational designers as well as the information technology designers. The method supported categorization and prioritization of findings that had previously not been possible in the synthetic settings, which helped the engineers sort through the numerous recommendations coming out of the experiment. Shortcomings that impeded basic perception (level 1 of SA) could be categorized as important for immediate remedy, so that levels 2 and 3 could have an opportunity to occur. For example, shortcomings that led to misinterpretations or poor predictions could also be addressed. As noted above, we believed that although the overall purpose of the multiple developments was not to improve SA, a focus on this basic building block of decision making would provide a framework for focusing development to support better team performance. This approach is recommended for rapid prototyping efforts, as opposed to focusing on a variety of process and outcome measures that may prove overwhelming to the designers and developers.

We believe that we should continue to pursue a relationship between workload measures and breakdowns in SA in the test-bed environment, but that this relationship will not be evident until the elements being tested are more mature. Further work to improve the use of the Breakdown Analysis method includes the need to develop a more sophisticated analysis display that could help us to determine not only the types of breakdowns occurring in SA, but help more clearly link those breakdowns to technology, team or task skills, or organizational design. We are also currently expanding our work into the area of peacekeeping operations and will be examining the use of Breakdown Analysis in operational settings to understand the nature of SA in these slower paced,

more ambiguous settings. Of interest is how the individual and the team build understanding of cues that may occur over a period of months instead of minutes or hours to allow for proactive visualization when most have been trained to assess more fast-paced environments. Breakdown Analysis as a method of SA measurement, while still immature, holds promise as a truly use-centered method that can be employed in natural environments to support the design of organizations, roles and systems that support adaptive performance. However, the method must be placed more firmly within the framework of process versus direct measures to determine exactly what is being measured.

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