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An Information Flow Analysis of a Distributed Information System for Space Medical Support

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Abstract

In this study, we applied the methodology grounded in human-centered distributed cognition principles to the information flow analysis of a highly intensive, distributed and complex environment - the Biomedical Engineer (BME) console system at NASA Johnson Space Center. This system contains disparate human and artificial agents and artifacts. Users and tasks of this system were analyzed. An ethnographic study and a detailed communication pattern analysis were conducted to gain deeper insight and better understanding of the information flow patterns and the organizational memory of the current BME console system. From this study, we identified some major problems and offered recommendations to improve the efficiency and effectiveness of this system. We believe that this analysis methodology can be used in other distributed information systems, such as a healthcare environment.

Keywords

Information Flow, Communications, Distributed Information Design.

Introduction

The structure, people, culture, and procedures of an organization can all affect the efficiency and effectiveness of knowledge management and information distribution in the organization. Information flow in a social organization is relevant to the issue of productivity, innovation, and the sorting out of useful ideas out of the general chatter of a community. In health care societies, well-designed organizational memory and information flow patterns can improve the quality of health care services. In today's environment, there is a continuous increase in the demand of knowledge-workers. With the increasing acceptance of the importance of intellectual capital for health organizations and business organizations, many information systems have been designed specially to address knowledge management issues.

Some studies in cognitive and social science show that knowledge is deeply conceptual. Remembering is a constructive act, which not only requires active participation but also is influenced by context. [1]. Researchers started to abandon the view of organizational memory as repositories of experience objects, and suggest considering organizational memory as both object and process [2]. A new generation of knowledge management is also being proposed to "grow beyond managing knowledge as a thing to also managing knowledge as a flow" [3].

Distributed cognition principles frames problems in terms of examining a functional system as a cognitive system. Distributed cognition captures the relationship of the system interactions, processes, and knowledge structures. Based on distributed cognition principles, the methodology of Human-Centered Distributed Information Design (HCDID) [4] considers human-centered computing not only at the level of representations but also at the levels of functions, users, and tasks. Our data collection, data analysis, results analysis and recommendation proposal were guided by these principles and methodology.

The Biomedical Engineer (BME) console at NASA is a very complex distributed information system. One of Console BME's (CBME) major work responsibilities is providing space medical related information to support many different but related disciplines. Communications consume a large portion of the CBME's time when they are on console. These communications happen so frequently that the CBMEs have to constantly address them throughout the shift. We believe that studying and analyzing these communication patterns will help us to better understand and redesign the information flow and organizational memory of the whole system. In this study, we used a specific and typical case, the EXAMPLE issues handling scenario, to conduct our analysis.

Domain

The task's domain for this study is the work practice of the CBMEs in the Mission Control Center at NASA Johnson Space Center. The CBMEs work in a complex environment, which contains disparate human and artificial agents and artifacts. The CBMEs are responsible for the technical and operational support in medical related tasks. Their responsibilities include acquiring information from disparate systems using timely, reliable, secure measures and distribute the information to different communities for the execution of various medical related operations of space mission. A large collection of information prorogates through disparate entities and different mediums, such as desktops, laptops, voice loops, telephones, pagers, TV monitors, printers, fax machines, video cassette recorders, and so on.

Environmental conditions in the space station, which are essential to astronaut's health, are more complicated than on earth. One of the CBME's primary tasks is monitoring and processing environmental variables for medical tasks. For this study, close attention is given to the problem-solving scenario concerning the EXAMPLE issues. "EXAMPLE" is an alias for an equipment kit, which is used to monitor radiation doses in the space station in near real time. Some EXAMPLE related activities are periodically scheduled and performed. For example, the EXAMPLE is relocated approximately every five to seven days, summary data is called down weekly and detailed data is downloaded monthly to the ground. Its related issues include mismatch on parts numbers, relocation procedures, data download procedures, etc. These issues are being communicated between the crew in the space and the ground groups of NASA Johnson Space Center across time and space dynamic and amongst human and artificial artifacts.

When handling any medical related issue, the CBMEs are usually involved in the process of acquisition, transmission, distribution, retrieval, and archiving of a large amount of data. The EXAMPLE issues handling scenario is one of the typical work practice scenario in the BME console system. Because of the periodic EXAMPLE activities, the related issues need to be handled every time. Handling one single piece of task related to an EXAMPLE issue, such as checking the power supply, usually takes a significant amount of time, and requires a lot of collaboration among people in different places and from different disciplines. We also chose the EXAMPLE issue handling as a case because one of its procedural problems occurred during the time from which most of our data was collected.

Data Collection and Analysis

The methodology of HCDID [4] was used to guide the data collection, data analysis, results analysis and recommendation proposal. We also conducted time-space analysis and distributed user and task analysis based on the principles of distributed cognition and HCDID methodology.

The CBME's work practice was observed and video recorded during a two-hour handover period. The video captured the handover between an oncoming CBME and an out-going CBME. The captured data from the video was then transcribed and coded in MacShapa [5], which is a Macintosh based Exploratory Sequential Data Analysis software application for both qualitative and quantitative study. From this data, we analyzed the amount of information processed by the CBMEs, the number of different formats and methods through which the information is retrieved, stored, and distributed.

As one of the CBME's major work activities, they continuously log significant events into the log notes while they are on console. In addition to the description of the events, all related issues, concerns, and communications are also logged with accurate time, date and persons involved. One week of the CBME's log notes, which include the logs of the recorded two-hour handover period, were reviewed.

Further information about the CBME's work activities and environment was gathered by interviewing the CBMEs, reviewing the CBME's training manuals and the photo profiles of the BME console.

Results

From the recorded interview with one of the CBMEs, we got a basic understanding of the CBME's daily work activities and how the CBMEs handle issues. The CBME's top three most frequent and important activities are: 1) writing significant events in the CBME's log notes, 2) monitoring voice loops and 3) working issues with the Liaison BME (LBME). The LBME is the intermediary and contact with the engineering group in the Mission Evaluation Room. The CBMEs are involved in numerous interactions and communications with other disciplines when working on issues. When the crew on the space station calls down a problem, the CBMEs handle this problem while at the same time performing other daily activities. For example, when there is an EXAMPLE download problem, a CBME receives the question from the space station Flight Director, and then the CBME contacts the LBME to work through and ultimately resolve this issue.

Interacting and communicating with other disciplines or personnel is the major way for the CBMEs to handle any issues. In addition to the high frequency of occurrence, these communication activities are also carried out through a variety of media, across space and time dimensions, and with many different people from different disciplines. From the data we collected, we analyzed the most frequently used communication mediums in the BME console system. These mediums include voice loop, telephone, face-to-face talk, email, pager, and videoconferencing (See Table 1). We examined the major attributes and dimensions of the communication mediums based on previous literatures [6, 7] combined with the reality of the BME console. These attributes and dimensions include synchronicity, spatial dimension (co-located/remote), channel capacity (multiple/single user addressibility), representation (text/audio/multi-modal), reviewability and distraction source.

The voice loop is an auditory groupware technology and it is an essential coordination support tool for experienced practitioners in space shuttle mission control domain [8]. It supports synchronous communication on multiple channels among groups of people who are spatially distributed. Voice loop conversations are recorded, so they are reviewable. The CBMEs usually monitor multiple channels in parallel, such as the Flight Director, the Flight Surgeon and the Medical Operations. When related activities are on the timeline, the CBMEs will listen in on the crew's voice loop conversations in case any questions are asked. According to one of the CBMEs that we interviewed, within a nine-hour period of time, during which the crew is awake and activities are being performed, the CBMEs spend approximately 60% of their time passively listening to the voice loop and 40% participating in the communications.

Videoconferencing is another means for the CBMEs to communicate with the Flight Surgeon who is located in a different room than the CBMEs. Videoconferencing provides multi-modal (i.e., audio and visual) representations. The information can be synchronously seen, heard and interacted with at more than one location.

Table 1: Communication methods on BME console

Attributes Mediums	Synchronicity	Representation	Channel Capacity	Spatial Dimension	Review -ability	Distraction Source
Voice Loop	Synchronized	Audio	Multiple	Multiple (Remote)	Yes	Yes
Telephone/ Speakerphone	Synchronized	Audio	Single/ Multiple	Multiple (Remote)	No	Yes
Face-to-face	Synchronized	Audio, Visual, Gesture	Multiple	Co-located	No	Yes
E-mail	Asynchronized	Text	Single	Multiple (Remote)	Yes	No
Video Conferencing	Synchronized	Audio, Visual	Multiple	Multiple (Remote)	No	Yes
Pager	Asynchronized	Simple Text	Single	Multiple (Remote)	Yes	Yes

Face-to-face talk is usually used between the CBMEs when they are on console at the same time or during the handover period. Other methods, such as telephone, email and pager, are also very frequently used by the CBMEs. Telephone links provide audio representation, which allows remote person-to-person calls and, if required, conference calls because it has a speaker and an external microphone. Email allows a person-to-person or person-to-group, asynchronous, remote and text-based interaction. Each communication activity through any one of these mediums, except for email, can happen at any time, thus, these communication methods can be a distraction source for the CBMEs..

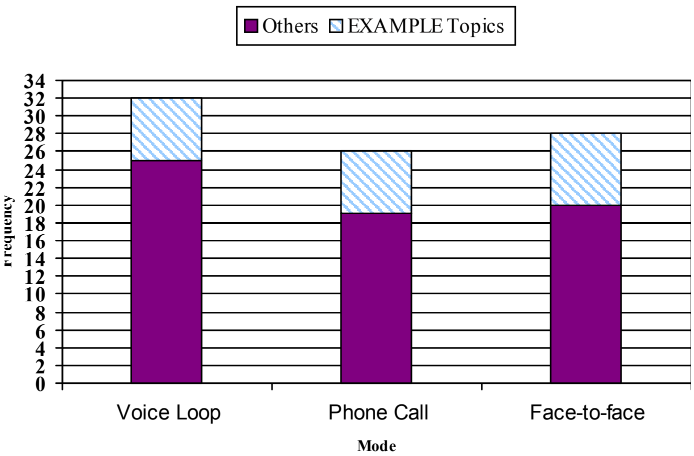

Figure 1 - Communication frequencies within 2-hour handover period

From the videotape of a two-hour handover period, we focused our communication analysis on three of the major mediums - voice loop, telephone and face-to-face talk, because these communication activities are easy to capture in terms of clarity of their content and context. We observed a total of 86 communications of which 32 were voice loop, 26 were phone calls and 28 were face-to-face talk. Of the 86 communications, 22 are EXAMPLE related (See Figure 1). If a communication happened during the process of another work activity, it is considered as an interruption. We observed 32 interruptions out of the total 86 communications during this two-hour period with 9 of these interruptions being EXAMPLE related (See Figure 2). Based on the interview notes and CBME's log notes, the EXAMPLE procedure manual, and the communications from the videotape, we also categorized the EXAMPLE related communications into six topics – data download, relocate, re-timeline, data files, general EXAMPLE issues and specifics (e.g., power, procedure, etc.). One communication may cover more than one topic (See Figure 3). So within the 22 EXAMPLE related communications, 7 are related to data files, 6 are related to general EXAMPLE information, 5 are related to re-timeline issues, 5 are related to EXAMPLE specifics, 4 are related to relocation procedures and 3 are related to download procedures.

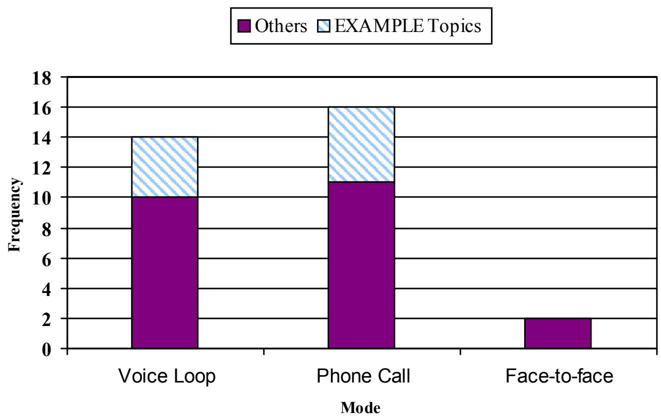

Figure 2 - Interruption frequencies within 2-hour handover period

From the CBME's log notes, we found that the CBMEs are not only asked about information related to medical activities, but also other information, such as a person's contact information. These requests resulted in interruptions of the CBME's normal work activities, and added additional cognitive workloads to an already high cognitive workload. Regarding the EXAMPLE issues, during the 2-hour observed handover period, 30% (3/10) phone/voice loop conversations were logged in the log notes. In a 24-hour period of log notes, which include the observed 2-hour handover period, there are a total of 41 EXAMPLE related log entries, but only 22% (9/41) of these entries contain the word 'EXAMPLE'. Therefore, 78% of the log entries cannot be retrieved when using 'EXAMPLE' as the searching keyword.

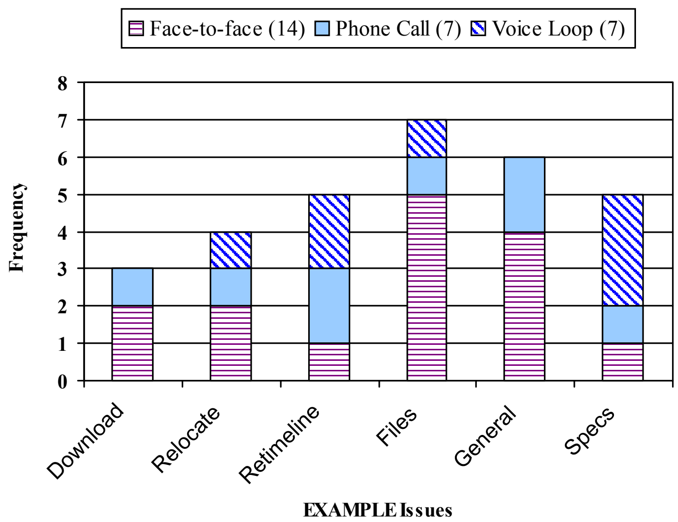

Figure 3 - Communication on EXAMPLE topics within 2-hour handover period

Identified Problems and Recommendations

From the detailed analysis of the features of the different communication mediums, and how, when, for what and how often these mediums have been actually used by the CBMEs, we found that the CBME's work environment contains high-levels of multi-tasking and interruptions. There are numerous information exchange interactions and most of the CBME's activities are event-driven. From the CBME's communication topics and their log notes, we found that the CBMEs function as an information relay station, using one-to-one communications with a large distributed group. For example, when a CBME is asked for information that he cannot immediately provide the answer to, he will search documents or ask someone for the answer. After retrieving the answer, the CBME will then will contact and inform the original person requesting the information. Redundant interactions and interruptions can be reduced by increasing information sharing capability and redirecting one-to-one communication pattern to a group communication pattern. These improvements can be accomplished by capturing knowledge during work, providing information in context, linking related information together and notifying all involved parties of important events.

Analysis of the CBME's communications and handling of requests shows that both local and remote users had difficulty finding and accessing needed information. There is an insufficient access to routine information (e.g., EXAMPLE specifications), so that a request for such information can cause multiple communications through multiple different mediums within a short period of time. The CBME's and other team members repeatedly requested and searched for the same information, each time it was needed. To improve the organizational memory and reduce repetitive information requests and searches, we can organize data in more sharable databases, record answers to frequent requests and make them more accessible, and improve data search and retrieval services.

Event logging in the CBME's log notes is one of the most important work activities of the CBMEs. The CBME's log notes are an important source of information on issue status and requests. From the analysis of the CBME's issue-handling scenarios (i.e., EXAMPLE issues) and their log notes regarding those issues, we found that frequent interruptions and a heavy workload interfered with the CBME's event logging task and had a negative impact on the quality of the log notes. In addition to the need for reducing interruptions, there is also a need for a better system for capturing and documenting the CBME's activities as well as a need for techniques to reduce the CBME's cognitive workload in order to facilitate their typing activities. Based on these needs, we have designed and developed a web-based logging system, which is customized for the BME console domain, and provides menu selection of common text elements, auto text insertion, standard color coding and search. The CBMEs participated in walk-through evaluation of the prototype, and expected these new capabilities to improve the efficiency and accuracy of event logging and information searches.

Conclusion

By looking into the details of the information flow and organizational memory, we got a deeper understanding of the structure and workflow of the BME console system. The problems we found from this study helped us to create a more effective and applicable design criteria for this system. Work efficiency and effectiveness of a distributed information system can be improved by improving its organizational memory and information flow pattern. This is consistent with the results of a previous related study of EXAMPLE by our team [9].

Our study methodology can be applied in the analysis of other distributed information systems, such as those within a healthcare environment. In a healthcare environment, there are numerous communications and collaborations among a variety of departments and personnel, such as doctors, nurses, social workers, lab professionals, clinical researchers, patients and their relatives, and so on. Medical information are also gathered, archived or distributed through many different mediums and formats. An information flow analysis, as described in this paper, can also be applied to any healthcare environment to identify existing problems and to better redesign the information systems to facilitate clinical decision-making and improve healthcare practice.

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