A Field Study of Collaborative Work in Network Management: Implications for Interface Design

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A FIELD STUDY OF COLLABORATIVE WORK IN NETWORK MANAGEMENT: IMPLICATIONS FOR INTERFACE DESIGN

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To inform the design of interfaces in real-time network management, a field study of telecommunication engineers was conducted at a corporate network operating centre. Eighty hours of direct observations, spanning ten different shifts, were carried out. This study focused on the nature of collaboration between network managers and stakeholders who were internal and external to their organization, how they communicated with one another, and how network managers distributed responsibilities and information. The characteristics of network management, and thus the collaboration, differ substantially in some ways from other complex work domains. This work helped to identify novel opportunities for enhancing and redesigning current interfaces to provide better support for communication and coordination in network operating environments.

INTRODUCTION

Network management is a "highly distributed, highly shared, and high speed" complex work domain that has only recently attracted the attention of cognitive engineers (Burns et al., 2000). Burns et al. (2000) were the first to identify and address the cognitive demands associated with network management via work domain analyses and the design of ecological interfaces. However, the work to date has not addressed the issue of real-time collaboration between various stakeholders in and around a network operating center – an issue that is critical to timely and successful problem solving in this domain. The field study presented here specifically examined the forms and characteristics of collaborative work in network management, contrasts these findings with what has been learned in other domains that have been studied extensively by cognitive engineers (e.g., process control, air traffic control, space missions), and identifies challenges and opportunities for interface design to support collaborative work.

Similar to previously studied domains, telecommunication and computing networks are characterized by large problem spaces, potential for disturbances, and highly dynamic behaviour. However, networks also have highly dynamic underlying structure (with daily additions and replacements of components), and are highly distributed both physically (as measured by the number and remoteness of locations where components are found) and functionally (as measured by the number and variety of stakeholders who design, supply, manage, use, and change the networks).

METHOD

The network operating centre (NOC) that was studied serviced both internal and external clients. It managed a wide variety of technologies (e.g., router-based, fibre optic, microwave, and traditional voice networks) that connected about 20,000 network elements distributed across 400 sites. During high workload periods, the centre was staffed by six network managers, each performing a different job function. For this study, eighty hours of direct observations, spanning ten different shifts, were carried out by two observers. A total of eight different network managers, with various levels of experience, were observed. The observations spanned both high and low workload periods.

RESULTS

Collaboration within the NOC

Within the NOC, responsibility was distributed by the <u>time horizon</u> for decision making: Junior team members were responsible for short-term incident management (i.e., responding to incoming alarms, performing initial analyses) and change management (i.e., coordinating in real-time the addition, removal, or replacement of network elements). Senior team members were responsible for long-term problem management (i.e., investigating and resolving persistent or complex problems that required days or months of attention) and change review (i.e., validating plans for changes scheduled for the next few days). Responsibility was <u>not</u> distributed by a <u>part-whole decomposition</u> (e.g., flight controllers in space shuttle mission control who monitor power, thermal, communication, and other subsystems) (Watts et al., 1996), by a <u>means-end hierarchy</u> (e.g., managers who overlook high-level system functions versus operators who overlook low-level component states in nuclear power or petrochemical processing) (Mumaw et al., 1995; Jamieson & Vicente, in press), or by <u>spatial boundaries</u> (e.g., air traffic controllers who overlook adjacent airspaces) (Bentley et al., 1992).

Collaboration beyond the NOC

Within the company, network managers were found to coordinate in real-time with users (who experienced network problems), technical experts (who had designed the networks or analyzed similar problems), field staff (who acted as the network managers' "eyes" and "hands" as they investigated or corrected problems), and change managers (who mapped out the plans to add, remove, or replace network elements and coordinated in advance with stakeholders). Outside the company, network managers coordinated with users, service providers, and equipment suppliers. Figure 1 depicts the collaboration that occurs between the NOC and other stakeholders when managing an unexpected problem, and Figure 2 depicts the collaboration when managing an expected change.

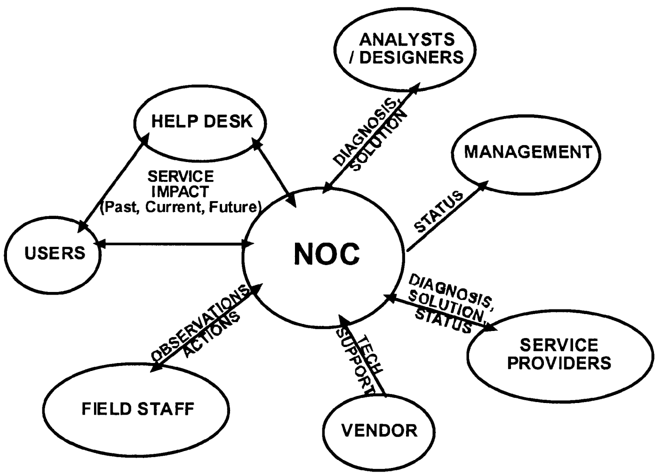

Figure 1: Collaboration in Incident/Problem Management

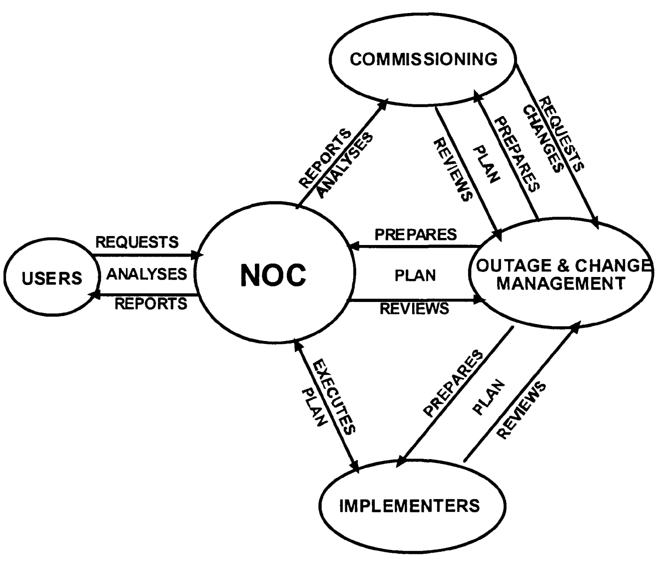

Figure 2: Collaboration in Change Management

These stakeholders had overlapping but different views of the networks, and different scopes of authority and responsibility. In fact, from the perspective of a network manager, there were often "black boxes" within the work domain that he/she managed: While the NOC we studied controlled routers at two company sites, an external service provider controlled the "black box" that connected these end routers. Likewise, from the perspective of a network manager who worked for the company's Help Desk, he/she controlled various local area networks (LANs), but the NOC controlled a "black box" (i.e., a wide area network) that connected these LANs. Therefore, the NOC was simultaneously a supplier and a consumer of network services, and there was a tangled web of supplier-consumer relationships that existed between this NOC and other NOC-type facilities internal or external to the company. Since the NOC and its collaborators belonged to different groups in an organization or to different organizations altogether, they could have very different priorities and constraints as they worked together on a problem. Depending on the nature of the problem, external collaboration could play a larger role than internal collaboration in real-time network management. The existence of "black boxes" within the work domain being controlled, and the need for real-time collaboration with numerous internal and external stakeholders distinguish network management from other complex work domains that have received much attention from interface designers (e.g., nuclear power, petrochemical processing, medicine).

Means and Patterns of Communication

A frequently updated database of service requests and change requests was the most frequently used means of communication within the NOC. Service requests pertained to unexpected disturbances to the networks, and change requests pertained to planned reconfigurations of the networks. Each request had a log that was updated every time a network manager got new data on the problem/change, performed activities to investigate or resolve the problem (in the case of service requests), performed activities to execute or verify the reconfiguration (in the case of change requests), or communicated (face-to-face, by phone, by email or any other means) with another person about the problem/change. Although this database was essentially an asynchronous communication tool, each service/change request was a relatively complete and timely record of all problem-solving and coordinative activities conducted to date on a particular issue. With this database, even if a network engineer had not been directly involved in a particular issue, he/she still had ready access to all pertinent information for responding to queries or updates from anyone at any time. Face-to-face conversations did occur within the NOC, but they were used to supplement information already (or soon to be) logged into the database.

Considering that network managers were co-located within the NOC, their reliance on the database rather than face-to-face conversations for communication with their co-workers was surprising. However, the database tool offered two key advantages: 1) the same information could be transferred within and across shifts, and 2) the information recipient did not have to be interrupted from their current activities.

The telephone (i.e., a synchronous medium) was the most frequently used means of communication between the NOC and its external collaborators. The NOC received about 85 phone calls per day, and the numbers of incoming and outgoing phone calls were comparable. It was common for network managers (or their collaborators) to go "off-line", to obtain more data or to confer with others, before "getting back" to the other party. Pagers and voice mails were often used to coordinate phone calls as some collaborators frequently stepped away from their workstations. Email was sometimes used to exchange detailed information (e.g., test results, analyses, plans) or formal information (e.g., requests for actions or important updates).

In contrast to relatively "closed" domains (e.g., power plants, space shuttles), network management involves frequent and intensive collaboration with external stakeholders, and an emphasis on external rather than internal collaboration. These characteristics liken network management to domains such as air traffic control or emergency dispatch.

Current Interfaces

Network managers used three main types of interfaces for monitoring: 1) alarm lists, 2) map displays, 3) element managers. Like the operators of other large-scale systems (e.g., nuclear power plants, petrochemical plants, space systems), network managers found it impractical to monitor directly and continuously the state of every component. Therefore, they relied on alarms (which indicated the identity of the failed component, its location, and the nature of its failure) to direct their monitoring. Map displays showed any active alarm(s) at network sites: Physical map displays showed the geographic distribution of sites, and functional map displays showed the logical connections between sites. Element managers were specialized applications that polled and sent commands to specific classes of network devices. When "element managers" received alarms from devices, they passed the information onto "enterprise managers" such as alarm lists and map displays. Under normal conditions, element managers ran in the background, but network managers could bring them up and use them directly to investigate specific problems if needed.

In process control, operators tend to use one "enterprise manager" (e.g., a control room suite); in aviation or medicine, practitioners tend to use various "element managers" (e.g., the Flight Management System and the Traffic Alert and Collision Avoidance System in the cockpit; infusion pumps and patient monitors in the operating room). In contrast, network managers use both enterprise managers and element managers. Enterprise managers tend to be more useful for fault detection, since they integrate information from diverse sources, provide "snapshots" of the state of the work domain, and show some high-level relationships (e.g., simultaneous failures at adjacent sites, consecutive failures at one site). Element managers tend to be more useful for fault diagnosis, since they report the detailed behaviour of a component over an extended period.

DISCUSSION

Implications for Interface Design

When disturbances occur, current interfaces provide poor support for orientation and navigation in the problem space. They do not distinguish between network elements that service different clients, and network services or equipment that are provided by different suppliers. The NOC is, however, committed to different service level agreements (SLAs) with different clients, and in each case, there are different stakeholders to inform and different expectations for problem resolution. The NOC also receives different levels of support from different service and equipment providers, and in each case, there can be different technical experts to consult and different expectations for problem resolution.

Unfortunately, the current interface design hides these meaningful distinctions and makes it difficult for network managers to orient themselves in the problem space (i.e., to recognize the significance of a failed device in the present system context). For example, the network managers must have the expertise, time and attention to utilize various electronic and paper-based tools around the NOC to answer questions like 1) what function(s) the device served for which client(s) and 2) which other devices it worked with. The first question pertains to service impact assessment, and the results need to be communicated to management and clients. The second question pertains to fault diagnosis; its investigation may require coordination with internal or external technical experts, and its answer needs to be communicated to clients, designers, implementers, and/or suppliers.

The current interface also makes it difficult to navigate through the problem space (i.e., to identify the path from the present state to a recovered state). For example, the network managers need to know what (if any) alternative means are available to reinstate service, how the failure impacts overall work domain health and redundancy, and what short or long-term diagnostic or therapeutic actions are necessary. Often, the answers to these questions require consultation with field staff and/or technical experts.

Since the current interfaces (especially the "enterprise managers") include data from many sources and the relationships between each piece of data are not apparent, network managers must find their way through massive quantities of (potentially irrelevant) data as they diagnose specific problems, assess service impacts, and communicate with their collaborators. One promising direction for interface design is to parse the work domain by either: 1) client or 2) type of network product (e.g., WANs, LANs, voice), and to develop separate abstraction hierarchy representations (Rasmussen, 1985) of each "mini-" work domain. A client-oriented partition is intended to support service impact assessments, prioritization according to SLAs, and timely communication with users. A product-oriented partition is intended to support problem diagnosis (by focusing on how pieces of technology work together), and timely communication with technical experts who can aid in analysis and problem correction.

In a NOC or any other collaborative work setting, workers may be provided with the same or different views of the work domain. For example, all network managers in a NOC may be shown a view of the work domain as partitioned by client, or they may all be shown a view of the work domain as partitioned by product. Alternatively, some network managers may be shown a client-oriented partition while others are shown a product-oriented partition. Yet another option is to provide each network manager with a client-oriented view as well as a product-oriented view, and these views may be made accessible in parallel and/or in series.

In collaborative work domains, decisions about interface design are closely tied to decisions about distribution of responsibility. For instance, if all network managers in a NOC are responsible for communicating with clients and with suppliers (as was observed in this particular study), it may be useful for everyone to have access to both a client-oriented partition and a product-oriented partition of the work domain. However, if some network managers are to specialize in customer relationship management while others are to specialize in problem diagnosis and resolution, then it may be more useful for the former group to view a client-oriented partition of the work domain and the latter group to view a product-oriented partition of the work domain. It is important to note that the distribution of responsibility in a collaborative work domain affects each worker's monitoring needs as well as the communication needs between workers. And whether workers can access the same view of a work domain may be a factor in how effectively they can communicate with one another.

Recall that network management is a volatile work domain: the networks themselves are constantly changing, as are the customers and the suppliers. Companies update their interface design (i.e., through in-house development and/or acquisitions) and their organizational design much more frequently and quickly than in traditional process control domains. Therefore, there appear to be opportunities for innovative interface design to enable positive changes in organizational design (e.g., the distribution of responsibility among workers) and not just vice versa.

Implications for Future Studies of Collaborative Work

Besides informing interface design to support collaborative work in network management, this field study also led to useful insights for future studies of "collaboration in the wild". These insights pertain to the questions of who collaborates, why they collaborate and how they collaborate in a complex work domain.

First, the collaborating workers may belong to the same or different teams, or even to different departments or organizations. Within-team collaboration tends to involve shared goals and priorities and access to shared information, while across-team collaboration tends to involve interacting goals and priorities and access to partial information. A given work domain may be dominated by within-team collaboration or across-team collaboration. And when both forms of collaboration can be found in the same work domain, each form of collaboration may take place on a different time scale (e.g., synchronous versus asynchronous), involve different team members (e.g., junior versus senior staff), and/or make use of different technological support (e.g., telephone versus email).

Second, why workers collaborate can be explained by how responsibility has been distributed among these workers. There appear to be five main ways in which responsibility can be distributed in a complex work domain:

1. part-whole distribution
   (e.g., different workers are assigned to different subsystems)
2. means-end distribution
   (e.g., "supervisors" overlook high-level functions of the system, and "subordinates" control physical components and processes that implement these functions)
3. spatial distribution
   (e.g., different workers are assigned to different geographical regions)
4. distribution by temporal span
   (e.g., some workers are responsible for short-term (tactical) decision making, and other workers are responsible for long-term (strategic) decision making)
5. distribution by temporal sequence
   (e.g., different workers are assigned to different steps or phases of the decision making process)

Even within the same operational setting, there may be different "reasons" for collaboration between different sets of workers (e.g., team leads versus trainees, planners versus executors, control centre staff versus field staff). Therefore, collaborative work even just in network management can have many different manifestations.

Third, how workers collaborate can be described in terms of their spatial proximity, temporal proximity, and means of communication (Schmidt, 1991). In terms of spatial proximity, the collaborating workers may be proximate (e.g., fellow network managers sitting together in a NOC) or remote (e.g., a network manager sitting in a NOC and a technician out in the field). In terms of temporal proximity, the workers may communicate synchronously or asynchronously. And their means of communication may be direct (e.g., face to face) or mediated (e.g., by phone, by email, by a shared database, etc.).

By systematically answering the questions of who collaborates, why they collaborate, and how they collaborate in a given work domain, we hope to identify meaningful differences between instances of collaborative work that may have superficial similarities (e.g., because they occur in the same domain). We also hope to identify meaningful parallels between instances of collaborative work that may have superficial differences. The goal is to facilitate effective comparisons and to promote technology transfer (e.g., interface designs) when (and only when) it is appropriate.

CONCLUSION

In this study, many forms of collaborative work occurred within the network operating centre. Within the network management team, collaboration occurred because responsibility has been distributed by temporal span. The team members were co-located, but their communication was mostly asynchronous and mediated by a database of service and change requests. Across-team collaboration occurred between network managers within the NOC and field staff, customers, and suppliers. These collaborators were remote, but their communication with the NOC was mostly synchronous and mediated by the telephone.

Two possible directions for interface design to support collaborative work in network management were to partition the work domain by client and by type of product, and to develop interfaces based on each partitioned work domain. Decisions also need to be made about whether the collaborating workers will be given the same or different views of the work domain, and whether each worker will be given access to multiple views. The interaction between organizational design and interface design warrants careful analysis, especially in a rapidly changing work domain such as network management.

Any lesson(s) learned about the nature of collaborative work and the design of support for collaborative work may be generalizable to other work domains. However, any hypothesis about generalizability should be based on an assessment of who collaborates, why they collaborate, and how they collaborate in the test and target work settings.

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