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

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ABSTRACT

A field study of telecom engineers was conducted at a corporate network management centre. 80 hours of direct observations, spanning 10 different shifts, were carried out to inform the design and evaluation of interfaces to support collaborative work in real-time network management. This work led to an understanding of network engineers' job demands, and how they distributed responsibilities functionally and temporally within the team. It also provided insight into how network engineers collaborated with other stakeholders internal and external to their organization. One promising direction for interface design is to begin by parsing the work domain by client or by type of telecom service, and to develop displays that integrate information from multiple levels of abstraction. Interfaces based on a work domain analysis may be especially valuable for supporting collaboration across teams, while computer support based on a control task analysis may be especially valuable for supporting collaboration within teams.

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1. INTRODUCTION

This report describes a field study of network engineers at a corporate Network Operating Centre (NOC). This study was conducted to inform the design of human-computer interfaces to support collaborative work in network management. The main goals of this study were to understand network engineers' job demands, to identify the forms and characteristics of collaborative work in a NOC, and to define the scope of subsequent interface design and evaluation work.

The NOC we studied manages networks for both internal and external clients. As of January 1999, this NOC managed 40 different technologies, and overlooked some 20,000 network nodes distributed across 400 sites. The managed networks change constantly, as new devices are brought online everyday to replace older devices, or to provide new or enhanced telecom services.

Therefore, from a technical perspective, this NOC provided a rich and dynamic setting for naturalistic observations of how engineers manage vast, heterogeneous, and distributed networks in real-time. From a social perspective, the NOC also provided a fertile environment for studying how network engineers collaborate with people within and outside their organization, in a variety of operational scenarios.

In this work, we focused on how network engineers communicate with one another and with their collaborators (e.g., Are the communicating parties co-located or remote? Do they communicate synchronously or asynchronously? Is the communication direct or mediated?); how they distribute and transfer their responsibilities; how they gather, utilize, and distribute information; and how their current tools support or impede their work. Our findings helped us to identify challenges and opportunities for the design of interfaces (and other computer-based tools) that support engineers in managing networks, and in interacting with other stakeholders.

This report begins with a description of our method, followed by an overview of the NOC, its main functions, personnel, tools, and resources. We then describe the factors that contribute to the complexity of the problems faced by network managers. Next, we use the Cognitive Work Analysis (Rasmussen, Pejtersen, & Goodstein, 1994; Vicente, 1999) framework to interpret our observations, to assess the strengths and weaknesses of the current interfaces, and to identify promising directions for enhancements or redesigns. The last section summarizes the broader implications of this study's findings for interface design and evaluation.

2. METHOD

Eighty hours of direct observations, spanning ten different shifts, were conducted by two observers. The observers were trained in human factors engineering and had experience with conducting field research in complex work settings. Their background was not, however, in telecommunications or computer networks.

Eight of the observed shifts occurred during high-tempo, full-staffing periods (i.e., weekdays), and two occurred during low-tempo, reduced-staffing periods (i.e., weeknight and weekend). A total of eight different network engineers were observed. Two engineers were observed more than once, but they performed a different job function during each observed shift. We observed the functions of “Team Leads” as well as non-“Team Leads”, and experienced network engineers as well as trainees.

We sat with the same network engineer at his/her workstation over the course of each observed shift. We took notes on how the engineers used shared displays, individual displays, shift logs, trouble ticket (i.e., problem) logs, other artifacts and documentation as they engaged in problem-solving activities. We also took notes on when, why, how, and with whom they communicated and coordinated. Our data collection and analysis focused on the cognitive and collaborative activities of network engineers. Whenever we looked at tool use by the network engineers, we focused on the tools’ informational rather than technological value, as the study was intended to guide the design of human-computer interfaces rather than computer-computer interfaces.

3. NOC OVERVIEW

The NOC manages several key types of telecommunication services. For internal clients, it tends to manage microwave and fibre optic networks that connect the company’s production (P) sites, as well as telephone and router networks that connect its business (B) sites. The P networks are specialized, and are used to control the company’s unique and remotely located production equipment. (In the interest of generalization to other NOCs, this report will contain minimal references to the management of P networks.) The B networks are more generic, and are used to support voice and data communication between company sites, or between company sites and external sites. The NOC also manages fibre optic networks that service sites belonging to external clients (X). The primary responsibility of the NOC is to keep all current in-service (P, B and X) networks up and running and to respond effectively to any service-affecting alarms.

3.1 Functional Distribution of Responsibility

In general, a team of three network engineers is responsible for the P networks, and a team of three other network engineers is responsible for B networks. However, members of the two teams are cross-trained, and can support one another when necessary (e.g., very early / late in the day or during lunch when the centre is not staffed at full strength, or when one team is especially overwhelmed).

Figure 1 depicts the physical layout of the NOC, how the two teams and their shared displays are located relative to one another. There are extra workstations in the NOC to accommodate trainees (who may add to the total number of network engineers working within the centre) and/or analysts, designers or implementers who need a temporary workstation within the centre to make observations or to make changes to automation and other tools.

Each team is responsible for three main functions: 1) incident management, 2) change management, and 3) problem management. Incident management involves keeping abreast of the status of the network, responding to new alarms in real-time, and doing initial analyses to determine if the alarm is legitimate and/or service-affecting. If the alarm is legitimate, incident management also involves assigning a person or a group (e.g., a team member, a field support staff, an analyst, a designer, or an implementer within the company, or an external service provider) to track and/or resolve the alarm.

This assignment should consider factors such as: Who (if anyone) has been monitoring related alarms? Who is at or close to the site of the alarm? How much time and expertise is needed to follow up on the alarm?

Change management involves keeping abreast of changes to the network. This means coordinating, in real-time, the phasing in of new equipment, the phasing out of old equipment, and the maintenance of current equipment. These kinds of changes to the configuration of the network must be reviewed and approved beforehand. The challenge in change management is to distinguish between expected and unexpected perturbations to the system.

Within each team, responsibilities for incident management and change management may be divided or shared by the two team members who are not functioning as the Team Lead. However, problem management tends to be the Team Lead's responsibility. He/she is responsible for in-depth analysis and resolution of complex and/or "chronic" (i.e., persistent / recurring) problems that cannot be fully diagnosed or corrected right away and require attention over a longer term. He/she is essentially responsible for keeping abreast of significant problems in the system. The Team Lead has additional management/administrative responsibilities such as: conducting technical review of changes that have been proposed (for the next few days), informing clients of outages and following up, auditing reports (some of which are automatically generated) on the performance of the NOC staff and the NOC automation, and appraising the performance of his/her team members.

The Team Lead for the B networks also functions as the NOC Administrator. He/she is the shift supervisor, and is responsible for ensuring smooth operation of the entire centre. He assigns severity ratings to any major problem encountered by the NOC, sends out a daily report on NOC operations to management and other key stakeholders, and serves as the main point of contact for external entities.

Towards the end of this study, this NOC is preparing to reduce staff for the B Team. There will soon be two (instead of three) network engineers overlooking the company's voice and data networks. All responsibilities for incident management, change management, and problem management will be shared between the non-Team Lead and the Team Lead who is also working as the NOC Administrator. This staff reduction is made possible by several factors: 1) there has been a de-merger in this company since the NOC was first established , reducing the number of sites monitored, and 2) the technology used to implement the underlying network and the technology used to monitor and control the network have both become more robust with time. This organizational change will allow the NOC engineers to enjoy longer and more frequent rotations outside the centre for special projects in analysis, design and implementation.

3.2 Temporal Distribution of Responsibility

The NOC is not staffed at full-strength at all times. On weekdays, the centre is staffed 18 hours a day from 06:00-24:00. Each shift is 8 hours long, and the team members stagger their start times (at half-hour or one-hour intervals) between 06:00 and 08:30, such that the centre is fullest at prime time, and has gradually decreasing numbers of staff towards the earlier and later hours. On weekday afternoons and evenings (i.e., 16:00-24:00), the NOC is staffed by one network engineer. On weekends, the NOC is staffed by one network engineer for 12 hours a day (i.e., 08:00 to 20:00). After-hours support is provided during the night on weekdays (i.e., 00:00-06:00) and on weekends (i.e., 20:00-08:00), where one network engineer can remotely access all interfaces and tools for monitoring and problem-solving. Whenever a network engineer is by him/herself in the NOC, he/she will be responsible for the B, P and X networks. Teams of NOC engineers rotate in and out of the centre on a monthly basis. The four possible rotations are: 1) daytime P service, 2) daytime B service, 3) nighttime/weekend operations, 4) special projects (e.g., building / updating displays, databases, servers, automation for use in the NOC).

3.3 Sources of Information

3.3.1 Shared Displays

As seen in Figure 1, the NOC engineers have access to a variety of information on large wall-panel displays that can be viewed simultaneously by everyone in the centre. On these displays are: the "Severity Status Monitor", various maps, and alarm lists.

3.3.1.1 Severity Status Monitor

The Severity Status Monitor provides an overview of any high-impact problem currently being tackled by the NOC. It only shows three pieces of information: 1) the telecom service (e.g., protection of remote equipment, voice communication, business data communication) that has been affected by a problem, 2) a severity rating based on time allowable for problem resolution, and 3) a counter that tracks how long the problem has persisted. In essence, the Severity Status Monitor shows any threat to the high-level functions of the system.

3.3.1.2 Physical and Functional Maps

Two map displays provide support for the P networks. The first map shows how all P sites (including those being serviced by analog microwave equipment, digital microwave equipment, and fibre optic equipment) are physically distributed. The second map zooms in on a subset of the sites, only covering the region where the newer (i.e., digital microwave and fibre optic) equipment is concentrated. Both displays are annotated to show whether there is an active alarm, colour-coded for its significance, at any of the sites.

A third map display provides support for the B networks. It shows how all the sites that comprise the company's WAN are functionally distributed. That is, it shows hub sites versus non-hub sites, and the logical connections between them. This display is also annotated to show whether there is an active alarm at any of the sites.

3.3.1.3 Alarm Lists

There are three different alarm lists. The first list contains all alarms from microwave equipment and provides support for the P networks. The second list contains all alarms from fibre optic equipment and provides support for B and X networks. The third list contains all alarms from voice and data network equipment and provides support for the B networks. All alarms appear in chronological order, and are colour-coded according to their significance. Each alarm includes a textual indicator of the alarm location, and a textual message specifying the failed device and the nature of the failure.

3.3.2 Individual Displays

All the shared displays described in 3.3.1 can be brought up at an individual workstation. Naturally, each team tends to bring up displays that are most relevant to their current responsibilities in either the P or B side of operations. One benefit of bringing up a map display at a workstation is additional navigational support: if the user clicks on a site that is showing an alarm, the alarm message will be brought up automatically.

There is one other map display used by the P team that does not show up on the large wall-panel displays. This map shows the functional (rather than physical) relationships between sites that are serviced by microwave and fibre optic networks. This map can show up to four current alarms per site because it uses a larger, sub-divided alarm indicator that can show four different colour codes corresponding to four different alarms at the site.

3.3.3 Enterprise vs. Element Managers

All the shared and individual displays described above can be characterized as tools for “enterprise management”. Enterprise managers pull together, integrate, and present information from a large variety of network devices that serve different functions, that have different physical and logical implementations, and that are manufactured by different suppliers. Enterprise managers can be contrasted with element managers that work only with specific (classes of) devices.

The NOC does use a variety of element managers (e.g., HPOpenview for monitoring router networks, NetHealth for extended monitoring of specific router ports, Visual UpTime for monitoring frame relay networks, etc.) Often, these element managers run “behind the scenes” and send alarms that show up in the enterprise managers only when an anomaly occurs. In normal situations, the NOC engineers do not directly monitor the networks using element managers. In a fault situation, they may bring up an appropriate element manager to focus their monitoring and/or to obtain more detailed information for diagnosis and response planning.

3.3.4 Ticketing / Logging Tools

The NOC engineers require up-to-date information on the status of the networks and on the activities of their teammates and other collaborators to function effectively. The Action Request System (ARS) is the central tool with which the NOC keeps track of their own problem-solving activities, and their communication and coordination with others within and outside the centre. The ARS is used to record, store, and retrieve several key kinds of information (i.e., database records): service requests, change requests, shift summaries, and network elements.

Service requests are also called trouble tickets. For B networks, automation opens up a ticket automatically in response to incoming alarms. A NOC engineer can also open up a ticket manually, for example, if he/she learns of a problem via communication with a collaborator. Each ticket has a unique ID that is used extensively by the NOC team and their collaborators as they communicate about this particular issue. Each ticket also has a “short description” that corresponds to the alarm message. Other useful information can be entered manually, for example: a long description, the problem area, the service impact, the affected customer(s), the assignee(s), and the ticket status (e.g., open, on hold, closed, etc.) An assignee may be another NOC engineer, non-NOC colleagues who work on or off-site (e.g., field staff, other designers, implementers, and/or analysts), or even agents external to the company (e.g., service providers).

Each trouble ticket has a log. Every time a NOC engineer gets new data on a ticket, performs activities to investigate or resolve the ticket, or communicates (face-to-face, by phone, by email or any other means) with another person about the ticket, he/she will type this information into the log. Different NOC engineers, and some internal colleagues with whom they share the use of ARS, can add to the same log at different times. Therefore, the log serves as a complete, chronological, and up-to-date record of system anomalies. These logs are the primary means by which the NOC engineers coordinate their problem-solving activities with their teammates on the same shift, with their teammates on other shifts, and with collaborators external to the NOC.

Change requests concern expected, rather than, unexpected disturbances to the system. There is a change requestor who has asked to put a device into service, remove a device from service, or re-configure an in-service device. Each change request needs to go through a formal review and approval process before it can be executed. The change request record contains details on how the change is to be executed, by whom, in what timeframe, and which stakeholders need to be informed or consulted. The NOC engineers coordinate changes in real-time, log all related activities and communications, and update the status of the change request (e.g., in review, approved, open, completed, etc.) over the course of the change.

Daily shift summaries contain synopses of major problems (if any) that have been carried over from a previous day or that occur today. It also contains useful information such as the availability of key collaborators. Network element records are also kept in the ARS such that the NOC engineers can look up attributes of particular devices in the system. When network elements are added, deleted, or changed, the NOC engineers need to update the corresponding records. All records in the ARS database can be searched by any attribute. Any service (or change) request can be associated with any other service (or change) request.

3.3.5 Other resources

One source of information frequently consulted by the NOC engineers is a web-based directory where the job function and contact information of all company employees and contractors can be found. The web can also be used to access product and technical support information made available by equipment suppliers. Detailed schematics of the managed networks are available in both electronic and paper forms. As changes are made to the networks, corresponding diagrams are updated and re-posted in both media.

3.3.6 Tools for communication

Tools for both synchronous and asynchronous communication abound in the NOC. The telephone (i.e., a synchronous medium) is the most frequently used means of communication between the NOC and its external collaborators (e.g., customers, field staff, suppliers, or colleagues outside the NOC who are involved in analysis, design or implementation). The numbers of incoming and outgoing phone calls are comparable, since it is common for either party to go “off-line” to conduct more observations, tests or analyses, or to confer with others, before “getting back” to the other party. Pagers and voice mails are frequently used to coordinate phone conversations as some collaborators frequently step away from their workstations. Email is sometimes used to exchange detailed information (e.g., results of tests or analyses, plans) or formal information (e.g., requests for actions or important updates).

The ARS (i.e., an asynchronous medium carrying content that can be updated and retrieved very quickly) is the most frequently used means of communication within the NOC. As mentioned in 3.3.4, the NOC engineers constantly update service requests and change requests to maintain a timely and complete record of all problem-solving and coordinative activities conducted to date on a particular issue. This way, even if a NOC engineer has not been directly involved in investigating, tracking or resolving a particular issue, he/she still has ready access to all pertinent information for receiving queries or updates from outside parties at any time. Face-to-face conversations between the NOC engineers do occur, but they are used to supplement information already (or soon to be) logged into the ARS. For example, if the NOC is tackling a major problem, and if one engineer receives a significant update from an outside caller, he/she may share and discuss this update with the team right away. However, any significant information learned in the phone conversation (with the outside caller) or in the face-to-face conversation (with the team) will be logged into ARS. This allows other stakeholders (e.g., NOC engineers currently not on duty, other analysts/designers who are helping to resolve the problem) to access the information at a later time if needed. The log can also be a valuable resource for generating formal reports to management or to other stakeholders.

A face-to-face conversation is also used to supplement the ARS in other situations, for instance: one team member may ask another to clarify some information in the log; one team member may overhear another’s conversation with an outside party, realize that the conversation is relevant to an issue he/she is working on, and ask for a quick update; one team member may solicit advice (or confirmation) from another on how to deal with a particular issue, especially if the solicited member has more experience, or at least more recent experience, with similar issues.

4. THE NOC AS A COMPLEX SOCIOTECHNICAL SYSTEM

4.1 Large Problem Spaces & Disturbances

The NOC we observed manages a system of telecommunication networks that is large (as measured by the number of network nodes), heterogeneous (as measured by the variety of technologies) and highly distributed (as measured by the number of network sites). This makes for a very ***large problem space*** (Vicente, 1999); so large, in fact, that most network engineers agree it is impossible to monitor the system node-by-node. Instead, they rely on incoming alarms, incoming phone calls (from customers, field personnel, etc.), and open “tickets” to guide their monitoring and action. Currently, this NOC receives about 45 alarms per day that are related to the P networks, and about 5 alarms per day that are related to the B networks. The NOC also receives about 85 phone calls per day overall. These alarms and phone calls often relate to ***disturbances*** (Vicente,

1999) in the system, some of which are unanticipated, and some of which are caused by planned work to add, remove, or repair equipment. Since changes are being made on an ongoing basis, the size of the problem space and the potential for disturbances (that reflect changes if not breakdowns) remain high.

4.2 Social Aspects

The ***social*** nature of work in and around the NOC also adds to its complexity (Vicente, 1999). For the overall system to function properly, the NOC engineers need to coordinate with one another and with various personnel within and outside the organization. Figure 2 shows these collaborators:

- users (i.e., customers) who experience problems;
- intermediaries (e.g., help desk staff) who relate an end user's problem;
- field personnel who detect, help to investigate, and/or resolve problems;
- second-level support personnel (e.g., analysts, designers, implementers, or vendors) who can help to diagnose or resolve problems;
- change requestors who want to add, remove, or repair equipment and may disturb the system in this process;
- change planners who map out a change, assess the impact on service during and after the change, consult with and inform stakeholders (including the NOC who coordinates the change in real-time);
- field personnel or off-site designers/implementers who help to execute the change;
- suppliers (i.e., service providers) who provide the company with telecommunication services (e.g., frame relay networks, phone lines) that connect many sites within the company's networks.

Figure 3 depicts a set of interesting nested relationships that exist between the NOC, its customers and suppliers. Consider one possible incident/problem management scenario: If an end user has difficulty accessing a remote site in the company, he/she may first contact the Help Desk who manages the local area network. The Help Desk is, in essence, a service provider to the end user. If the Help Desk determines that the problem is not caused by the local area network, it may contact the NOC who manages the wide area network. The NOC is, in essence, a service provider to the Help Desk. If the NOC determines that the problem is not caused by end equipment (e.g., routers) at its two WAN sites, it may contact its service provider who manages the frame relay network connecting the sites. If the frame relay provider cannot find a problem with their networks, it may contact its own service provider who supplies the physical circuits that carry their frame relay data packets. Effective communication must occur between this chain of customers and suppliers to facilitate timely problem diagnosis and resolution.

Besides customers and suppliers, the NOC also interacts with other stakeholders when coping with unexpected disturbances to the networks. Figure 4 illustrates the variety of interactions that can occur between the NOC and other people internal and external to their organization during incident management or problem management.

Figure 5 depicts various interactions that can occur between the NOC and its collaborators in one possible change management scenario: A user experiences a network performance problem. He/she suspects inadequate bandwidth and sends a request (directly or indirectly) to the NOC to track his/her bandwidth utilization over an extended time period. The tracking period is over, and the NOC reports its findings to the user and to the "Commissioning" department who can authorize a bandwidth upgrade if necessary. The "Commissioning" department agrees to a bandwidth upgrade and places a request for this change to the "Outage and Change Management" (O&CM) department. O&CM (i.e., the "change planners") develops a detailed plan, and sends it to various stakeholders (including the NOC) for review and approval. On the day of the approved change, the NOC coordinates with the change implementers to execute the change. The NOC also logs progress and results. The change request is then sent back to O&CM for any further verification, notifications, and closure. It is possible, however, for a change management scenario to involve only a subset of the interactions illustrated in Figure 5. Alternatively, a change management scenario may involve an even larger set of interactions.

The NOC and each of these collaborators do not share the same goals and priorities. Most do not belong to the same organization, or they do not follow the same "chain of command" within the organization. Since they operate under different reward systems and different constraints, what one group sees as an optimal path will often be far from optimal for another. Often, one group's field of view has minimal overlap with another's, so it would be difficult to judge what is best for everyone even if that was the ultimate goal. Therefore, much communication, coordination, and negotiation needs to take place.

4.3 Distributed Aspects

The NOC engineers and their collaborators are also geographically ***distributed*** (Vicente, 1999) at different urban, suburban, or rural sites over an extensive area. Some collaborators are permanently stationed at one site (e.g., specific clients, the customer support centres for specific service providers), while other collaborators are mobile (e.g., field personnel). Sometimes, field personnel are located at the problem sites; at other times, they need to be dispatched to the problem sites, some of which are so remote that it may take many hours of travel to reach. At each site, there are multiple workers who come on and off shifts, on and off vacation, etc. Remote coordination becomes even more difficult since its success is partially dependent on the success of each site's local coordination.

In some ways, telecommunication networks are more social and more distributed than other complex work environments such as: medicine, aviation, or nuclear power generation. In these "traditional" complex work domains, it seems possible to draw a clear boundary around the system being controlled by the operators, to separate what is internal to the system, from what is external to it. However, "within" the networks being monitored and controlled by the NOC are many "black boxes" that the NOC has neither the ability nor the responsibility to monitor or control.

For example, as mentioned in 4.2, the end equipment (i.e., routers) at two of the company's WAN sites are managed by the NOC. But the NOC has no knowledge of what hardware and software their service provider (e.g., of frame relay networks) has in place between the routers at the two company sites. If a problem occurs such that data fail to be transmitted between the two routers, it could be a failure of the routers, or it could be a failure at any point in between. The NOC may conduct some local tests to help rule out the possibility of their end equipment failure. Beyond that, any diagnosis and compensatory action will have to come from their service provider. Likewise, a WAN that is administered by the NOC can be used to connect multiple LANs. And LAN administrators and the NOC engineers have to work together to resolve certain kinds of problems. Hence, there is a high degree of mutual dependence between these distributed collaborators. Each of them offers a unique and indispensable perspective in problem diagnosis and resolution.

4.4 Mediated Interaction

Interaction between the NOC engineers and the network components they oversee is ***mediated*** by people (e.g., field personnel) and/or by technology (Vicente, 1999). First, because most of the network components are remote, the NOC engineers must rely on field personnel to be their "eyes" and "hands" to detect and correct problem states that are straightforward to deal with if one is on-site (e.g., a wire that has been disconnected or cut). Second, a network's dynamic behaviour (e.g., the flow of data packets) is generally not directly perceivable. Therefore, the NOC engineers must rely on various simple (e.g., a command line to "ping" a single device to make sure that it is accessible) or sophisticated technologies (e.g., HP Openview which provides a GUI for expanding or collapsing large groups of devices, showing their connections, and displaying real-time performance data) to get information on the networks' behaviour. In fact, the NOC engineers' interaction with network components is mediated by two layers of technology: 1) "element managers" that poll specific (classes of) devices and generate alarms, and 2) "enterprise managers" that integrate information from multiple element managers, correlate, group, filter, organize, and display these alarms to the engineers (cf., Section 3.3.3). One interesting property of telecommunication networks is that "polling" comes at a cost. That is, sending signals back and forth on a link to obtain information about the link (or a node attached to that link) increases traffic and affects performance along that link.

4.5 Significance of a Cognitive Work Analysis

In summary, a network management center such as the one observed constitutes a complex sociotechnical system because of its large problem spaces and potential for disturbances, its social nature, its distributed nature, and its mediated interactions. For this type of system, a framework "Cognitive Work Analysis" has been developed to identify requirements – both technological and organizational – that need to be satisfied for a device (e.g., a human-computer interface) to support work effectively. (Rasmussen et al, 1994; Vicente, 1999) A Cognitive Work Analysis (CWA) distinguishes between five different aspects of work, and models each aspect independently to inform different types of system design interventions:

1) the work domain (i.e., the system being controlled),
2) the control tasks (i.e., the goals that need to be achieved),
3) the strategies (i.e., the processes by which control tasks can be achieved),

4) the social organization and cooperation (i.e., the relationship between actors),
5) the worker compentencies (i.e., the skills, rules and knowledge workers need to fulfill particular roles effectively). (Rasmussen et al, 1994; Vicente, 1999)

In the rest of this report, we will use the CWA framework to interpret our field study data, to assess how the current interfaces provide support for each of these five aspects of work, and to identify opportunities for strengthening support where it is currently lacking or limited.

5. WORK DOMAIN ANALYSIS

In the first phase of a Cognitive Work Analysis, a modelling tool called the Abstraction Hierarchy (AH) is used to represent the structure of the work domain in a way that highlights its goal-relevant properties. An AH representation uses multiple levels of abstraction to represent each work domain. Each of these levels provides a different description for the very same system. At a given point in time, a worker can observe the work domain at any level of abstraction. These levels are linked by structural means-ends relationships. To see the link to a higher level is to see the system in functional terms (i.e., the "ends" to be achieved). To see the connection to a lower level is to see the system in physical terms (i.e., the "means" to an end). (Rasmussen et al, 1994; Vicente, 1999)

Burns et al. (2000) have used the AH to model a generic computing network, using five levels of abstraction (listed below from highest to lowest) to describe the work domain structure:

- ***functional purpose*** - speed, capacity, and accuracy of information in transfer;
- ***abstract function*** - conservation of information between sources and sinks;
- ***generalized functions*** - traffic routing and security processes;
- ***physical functions*** - capabilities of network devices, transport or security protocols;
- ***physical form*** - physical location and appearance of network devices.

In the next two sections, we will explore: 1) how the above AH (for a generic computing network) may be instantiated for a particular network management environment, to serve as the basis for interface design to support collaboration; and 2) how the AH can guide the evaluation of current interfaces in the NOC environment and the identification of information requirements for future interfaces.

5.1 Defining System Boundaries

There appear to be several reasonable approaches (see Figure 6) to conducting a work domain analysis for the specific NOC we observed. We can develop one AH for:

(1) each major client (e.g., internal, external client A, external client B, etc.);

(2) each major type of telecom service (e.g., voice, WANs, LANs, wireless, etc.);

(3) the entire NOC.

It is important to note that "client" and "service type" represent orthogonal dimensions in this work domain. Any client may use any service type, and a client may use a subset or all of the available service types.

5.1.1 Approach 1: Client-Oriented Interfaces

The Service Level Agreement (SLA) between a NOC and its client generally specifies the "speed, capacity, and accuracy of information in transfer" at which the client's networks need to be maintained. Therefore, if we partition the work domain by client, and develop a "mini" AH for each client, the ***functional purpose*** for each AH should be determined by the corresponding SLA. We can then develop one interface based on each of these client-oriented AHs. Then, when a fault situation arises, it should be relatively straightforward to associate a specific interface with specific stakeholders who need to be informed and/or consulted. And if the interface makes explicit the means-ends links between the violated ***functional purpose*** and the violated ***abstract functions*** (i.e., information flows between sources and sinks, information conservation and loss), it should support a comprehensive and accurate assessment of the service impact, which can then be communicated to the client. Furthermore, by following links to the ***generalized functions*** (i.e., traffic routing, security processes) and ***physical functions*** (i.e., capacity of network interface cards, wires, routers, etc.), the interface should help the worker(s) to develop a feasible and effective response plan, and to communicate this plan to the client in a timely manner. Finally, by following the links to ***physical form*** (i.e., physical location and appearance of the components), the interface should help the worker(s) to dispatch field personnel quickly and appropriately, and to provide them with useful directions on how to carry out the local repairs. Therefore, it appears that approach (1) may be very useful for supporting collaboration between the NOC engineers and their clients, and between the NOC engineers and their field support personnel.

5.1.2 Approach 2: Service-Oriented Interfaces

If we partition the work domain by type of telecom service, and develop an AH for each service type, the portions of the work domain represented by the different AHs should be quite loosely coupled: the telephone network should behave quite independently of the fibre optic network, and the wireless network should behave quite independently of the router network. We can develop one interface for each of these service-oriented AHs. Then, when a fault situation arises, it should be relatively straightforward to relate alarms in a specific interface to specific experts (e.g., vendors or implementers) on that telecom service who can assist in diagnosing and resolving the problem. It should also be straightforward to identify which service provider (e.g., supplier of frame relay service for the switching of data packets, or supplier of telephone lines) needs to be informed, and possibly "pressured" for a speedy resolution to the problem. Therefore, it appears that approach (2) may be especially useful for supporting collaboration with technical experts and service providers.

5.1.3 Approach 3: An All-Inclusive Interface

It also seems reasonable not to partition the work domain, to develop one AH for all the networks being managed by a NOC, and to build one interface based on this "all-inclusive" AH. The NOC engineers will still need to be able to distinguish between clients and types of telecom services as they carry out their problem-solving and coordinative activities. However, these distinctions will be implicit rather than explicit in the interface design. With this approach, when a fault situation arises, it may be rather difficult to identify quickly and accurately who should be contacted and the potential value of establishing such a contact. Each level of the AH will be very densely populated, so an interface design based on such an AH may make it difficult to wade through irrelevant information, and to zoom in on key information as the NOC engineers try to communicate with their collaborators about specific issues.

5.2 Showing Abstraction Levels

5.2.1 Current Interfaces

Information at various levels of the AH can currently be found in the NOC. To assess the absolute and relative availability of information at each level of abstraction, we will examine the information content and form of two important and shared displays used in the NOC: the Severity Status Monitor and the Functional Map Display for Business Services (see also Section 3.3.1).

The Severity Status Monitor (see also Section 3.3.1.1) shows the ***functional purpose*** for multiple AHs, each of which corresponds to one telecom service being managed by the NOC (cf., Section 5.1.2). This display consists of a simple two-column table. For each row, the left cell contains the name of a telecom service (i.e., voice, fibre optics, microwaves for P services, WAN for B services, etc.). If this service is operating normally, the right cell is empty, and the entire row is green (for "Ok"). If there is a severity associated with this service, the right cell will display the time elapsed since the onset of this severity, and the entire row will be colour-coded accordingly (e.g., red="severity 1", orange="severity 2", etc.). The severities are assigned manually, but the NOC does have pre-defined rules for assigning severity ratings. In general, the NOC works to eliminate "reds" and "oranges" as quickly as possible. In this sense, this Severity Status Monitor can be considered as a coarse "performance target view" (Burns et al., 2000) that shows whether key targets (i.e., **functional purposes**) are being met or violated. The information content of the Severity Status Monitor is summarized in Figure 7.

The functional map display for B services (see also Section 3.3.1.2) shows ***physical function*** information, with strong connections to some ***physical form*** information and weak connections to some ***abstract function*** information. In the center of this display is a "cloud-shaped" graphic that represents the frame relay network (supplied by an external service provider) that connects multiple company hub sites. Connected to the frame relay "cloud" are oval-shaped icons, each denoting one hub router. These icons are grouped spatially and labeled according to the hub site at which the router is located (i.e., "coarse" ***physical form*** information). If the router is behaving normally, its icon shows up as green; if there is an alarm for the router, its icon shows up as red or orange or another colour that corresponds to the current alarm level (i.e., physical function information).

Detailed views for some hub routers are shown to the side of the display. For each detailed "hub router" view, there are multiple square-shaped icons, each denoting one router at a remote site that is connected to the hub router. If the remote router is behaving normally, its icon shows up as green; otherwise, it shows up as the colour of its current level of alarm (i.e., more ***physical function*** information). Within the hub router views, icons for remote routers are grouped by blocks that correspond to physical bundling of the wire connections at the hub end (i.e., more ***physical form*** information).

In other words, ***physical function*** (i.e., capabilities of routers) can be seen as single icons on this display, while ***physical form*** (i.e., locations of routers) can be seen as how the icon is located on screen relative to other icons. (Burns et al., 2000) ***Abstract functions*** (i.e., information flows from sources to sinks) can be seen as pairs of two icons that correspond to hub and/or remote routers. If both icons are green, then the ***abstract function*** (i.e., conservation of information flow) is fulfilled. If either icon is displaying an alarm, then the ***abstract function*** is violated (i.e., no conservation of information flow). It is not, however, possible to map a single ***abstract function*** onto a single interface element. Figure 8 summarizes the information content of this functional map display.

5.2.2 Opportunities for Enhancements

First, ***generalized function*** (i.e., traffic routing, security processes) information is not available on any of the shared displays currently used in the NOC (Burns et al, 2000), although it can be accessed by other tools such as individual element managers. Overall, information at different levels of the abstraction hierarchy tends to be distributed over different tools and displays. Even when multiple levels of information are available within a tool, only a subset of information at each level tends to be shown. For example, on the functional map display described above, physical form information is shown so coarsely that it cannot be used, on its own, to support coordination between the NOC engineer and field personnel. Means-ends relationships are not usually apparent, and some displays may show only one level of abstraction, or show multiple "non-adjacent" levels of abstraction. Since the current interfaces do not provide a comprehensive or integrated view of the work domain structure, it may be very difficult to maintain a complete and accurate mental model of the physical and functional relationships between components, subsystems, and systems being monitored and controlled. Therefore, one promising direction for interface design for this environment is to integrate work domain information at multiple levels of abstraction. (Burns, 2000)

6. CONTROL TASK ANALYSIS

The Decision Ladder (see Figure 9) is an important modelling tool used for a Control Task Analysis (i.e., phase 2 of a Cognitive Work Analysis). (Rasmussen et al, 1994; Vicente, 1999) The Decision Ladder is a template consisting of information processing activities and states of knowledge onto which a worker's cognitive processes can be mapped. An information processing activity allows a worker to update his/her state of knowledge. Alternatively, a worker can make "associative leaps" from one state of knowledge to another.

The NOC engineers constantly engage in information processing activities such as: ***detecting*** a need for action (e.g., when cued by an incoming alarm), ***observing*** information and data (e.g., watching out for corroborating alarms), ***identifying*** system states (e.g., distinguishing between real and false alarms), ***evaluating*** performance criteria (e.g., ensuring a timely response to high-priority problems or clients),

interpreting consequences (e.g., assessing the service impact of a disturbance or a change), ***defining*** tasks (e.g., identifying diagnostic or compensatory interventions that should be carried out) and ***formulating*** procedures (e.g., figuring out who needs to be informed, consulted, and involved in carrying out tests or corrective actions, and the sequence of actions required) (Rasmussen et al, 1994; Vicente, 1999). Along the way, they update their states of knowledge and record them in the Action Request System (ARS) in the form of service requests and changes requests. In this way, the ARS serves as a key tool within the NOC that provides support to network engineers as they perform various “control tasks”.

As mentioned in Section 3.3.4, the log associated with each service request is a rich repository of information that corresponds to various states of knowledge included in the Decision Ladder, for example: past and incoming alarms are essentially ***alerts***; corroborating information provided by other stakeholders are essentially ***sets of observations*** or ***system states***; tests or actions that have been initiated or requested are ***tasks***, the test or action plans are ***procedures***, and the test and action results of are additional ***sets of observations*** and/or ***system states;*** predictions of service impacts of changes may be a ***goal states***. Information that is communicated between the various stakeholders may also be ***ambiguity*** and/or ***ultimate goals***.

The ARS is a shared external memory for the entire NOC team. It contains abundant information on what information-processing activities can or should be carried out in a given set of circumstances, and what connections can (or cannot) be established between specific states of knowledge. In other words, the ARS provides important information to the network engineers to support them in performing control tasks in real-time. However, currently, information in the ARS does not seem to get used often or effectively once a service/change request has been “closed”. If support can be provided for effectively retrieving and exploring information from the ARS to bring to bear on current situations, decision-making in familiar situations may be made even more efficient. Decision-making in unfamiliar situations may also be improved if the NOC engineers can learn from past experience to rule out meaningless alternatives, to consider meaningful alternatives that may not have come to mind easily, to avoid “re-inventing” the wheel, and to pursue first those alternatives that are low-cost and high-gain. In other words, there appears to be opportunities for enhancing the ARS such that it provides better support to the network engineers for performing “control tasks” over longer time spans.

7. STRATEGIES ANALYSIS

A Strategies Analysis (i.e., phase 3 of a Cognitive Work Analysis) identifies information requirements for choosing an appropriate process for achieving a control task. For example, there appears to be many different strategies for ***interpreting*** the consequences of a problem or a task, ***defining*** (diagnostic or corrective) tasks, and ***formulating*** (diagnostic or corrective) procedures (Rasmussen et al., 1994; Vicente, 1999). The advantages and disadvantages of each strategy may not be apparent, especially to novices. In fact, a NOC engineer-in-training may have difficulty identifying:

- what questions to ask a collaborator who may be in a position to supply valuable information that the NOC does not have and cannot access directly;
- what information to give to a collaborator who may be eager to understand the cause and impact of the current problem, and what can be and is being done about it;
- what tests to conduct within the NOC to gather valuable (as opposed to entirely redundant) information on the nature of the problem;
- what tests can or should be requested from a collaborator that will provide worthwhile information;
- what corrective action can be conducted within the NOC to mitigate or eliminate a problem; and
- what corrective action can be requested from a collaborator that will mitigate or eliminate the problem.

Since the strategies that can and should be pursued depends on constraints in the work domain and in the control tasks, it seems reasonable that an interface design guided by a set of thorough work domain and control tasks analyses will support the selection of appropriate strategies in diverse circumstances. Specifically, work domain analyses that distinguish clearly between the scopes of responsibility and authority of different stakeholders may help the NOC engineer to ask appropriate questions and make appropriate requests to the right people. Also, means-end links in the abstraction hierarchy may help the NOC engineer to map out fully and reliably potential impacts of planned or unplanned disturbances to the system, and to identify viable paths for effecting a desired change. Control task analyses may help the NOC engineers to update their situation assessments by prompting them to conduct information-processing activities that can help to advance their states of knowledge. Accurate and up-to-date situation assessments can be very valuable in supporting communication and coordination with other parties who have different, though possibly overlapping, views of the process, and who have different goals and priorities.

8. SOCIAL ORGANIZATION AND COOPERATION ANALYSIS

8.1 Human-Human Cooperation

8.1.1 Building on the Abstraction Hierarchy

Cooperation between the NOC and external groups has received much attention in the previous sections. Therefore, we will focus on cooperation within the NOC in this section. The NOC does not distribute responsibilities amongst its members by assigning specific AHs to each member. For instance, if we consider approach (1) in 5.1 to develop one AH for each major client, one NOC engineer is not assigned to servicing internal clients while another NOC engineer is assigned to servicing external clients. Alternatively, if we consider approach (2) in 5.1 to develop one AH for each major telecom service, one NOC engineer is not assigned to the voice network while another is assigned to the fibre optic network.

In addition, the NOC does not distribute responsibilities amongst members along the means-end dimension (e.g., functional purpose vs. physical form) or the part-whole dimension (e.g., by components or subsystems) of the work domain. (Rasmussen et al., 1994; Vicente, 1999) For instance, if multiple engineers are working on a voice mail problem, responsibility for overseeing the high-level ***functional purpose*** (e.g., communicating with clients regarding service impact) and responsibility for examining the failed system at the ***physical function*** and ***physical form*** levels (e.g., consulting network drawings) are not automatically assigned to different members of the team. Of course, at any given time, one engineer may be focusing more on one level of abstraction than another, while another engineer may be focusing on a different level. However, in the process of situation assessment, diagnosis, and response planning, each engineer is free to re-direct his/her attention upwards and downwards in the abstraction hierarchy. With respect to the part-whole dimension, each engineer is not confined to specific subsystem(s) within the larger work domain. By staying away from a fixed allocation of responsibilities along the means-end or part-whole dimensions, the NOC can adapt in real-time to unanticipated disturbances, by having some engineers adopt a broader, higher-level view over normal aspects of the work domain, while other engineers take a narrower, deeper look at abnormal aspects of the work domain as needed.

It is possible, however, to use the AH to describe the focus of a given engineer's attention in real-time. For example, activities of the current "incident manager" who acknowledges and responds to alarms can be characterized as primarily "data-driven" (i.e., upward movement in the AH), while the activities of the current "change manager" who tracks and coordinates change requests can be characterized as primarily "goal-driven" (i.e., downward movement in the AH). However, for each person to do his/her job easily, they must continuously direct their attention across abstraction levels.

8.1.2 Building on the Decision Ladder

The NOC does, to some extent, distribute responsibilities amongst its members by allocating (at least) the "first pass" at some information-processing activities to specific members. For instance, the incident manager is primarily responsible for ***detecting*** the need for action, ***observing*** information and data, and ***identifying*** system state. If associative leaps are possible between the ***system state*** and a ***goal state***, a ***task*** or a ***procedure***, the incident manager will begin to proceed down the "right leg" of the Decision Ladder (refer to Figure 9). (Rasmussen et al., 1994; Vicente, 1999) However, if the information-processing activities along the "right leg" start to demand too much time and attention, the responsibility for these activities may be distributed to other members, as the incident manager continues to focus on real-time, alarm-based system monitoring.

On the other hand, the change manager generally starts with a ***task***, and proceeds to tracking and updating the ***procedure*** that has been formulated previously in real-time. He/she either ***executes*** or monitors the execution of the procedure and is on guard for any ***activation*** that signals a need for action (e.g., unexpected alarms that get triggered while a change is being implemented). That is, the change manager tends to work down the "right leg" of the Decision Ladder.

Finally, the problem manager is primarily responsible for information-processing activities such as: ***interpreting*** consequences (e.g., when he/she conducts a technical review of proposed changes or when he/she considers alternative actions aimed at resolving a chronic problem); ***evaluating*** performance criteria (e.g., when he/she audits performance reports on the team or the automation); ***defining*** tasks (e.g., that will generate useful diagnostic data or alleviate the negative impact of a current problem); and ***formulating*** procedures (e.g., for a series of actions requiring the coordination of multiple parties that will eventually resolve a long-term problem).

8.2 Human-Automation Cooperation

In contrast to aviation or process control, where automation is primarily used to carry out activities along the “right leg” (i.e., action-oriented side) of the Decision Ladder, automation in the NOC is primarily used to perform or support activities along the “left leg” (i.e., perception-oriented side) of the Decision Ladder. For example, the NOC observed currently uses automation to poll devices on a regular basis, to filter alarms, to correlate alarms to assess problem severity, to initiate service requests based on alarms, and to report on performance by the team and by the automation itself.

Specifically, to evaluate the team’s performance, automation reports on the percentage of service requests that get acknowledged on time, the percentage of phone calls that get answered “hot” rather than by voice mail, the timeliness of daily report distribution, etc. To evaluate the automation’s own performance, automation reports on its ability to initiate service requests based on incoming alarms (i.e., the goal is filter out all false alarms, so that a service request should be cut for all remaining alarms).

Automation does play a small role in performing activities along the “right leg” of the Decision Ladder. For instance, it initiates well-defined, relatively safe actions such as attempting to re-boot a device when a failure occurs, or attempting to “dial-in” to a device when the original connection path (e.g., via the frame relay network) goes down.

9. WORKER COMPETENCIES ANALYSIS

Worker Competencies Analysis (i.e., final phase of a Cognitive Work Analysis) identifies information requirements that support workers in their ***skill-based behaviou***r (SBB) which is the most cognitively efficient, their ***rule-based behaviour*** (RBB), and ***knowledge-based behaviour*** (KBB) which is the most cognitively demanding. Although the NOC makes use of many interfaces (mostly showing alarms) that communicate some important information via perceptually salient cues such as colours, these interfaces afford little action possibility and cannot be used to close the perception-action loop. In other words, these interfaces are not made up of ***time-space signals*** and cannot be used as the basis of skill-based behaviour. (Rasmussen et al., 1994; Vicente, 1999)

On the other hand, RBB is prevalent in the NOC. For instance, if an alarm indicates that a network node is “down”, the engineers tend to follow a simple rule to “ping” the device right away to verify the legitimacy of the alarm in a fast, and non-labour intensive manner. The “ping” will generate a combination of two (binary) data values that, based on another set of simple rules, allows the engineers to rule out a substantial portion of the problem space in identifying the alarm’s root cause. RBB appears to be employed by both experienced and new engineers within the NOC.

Interestingly, although KBB contributes significantly to the diagnosis and resolution of complex problems within the NOC, it appears to be the exclusive domain of experienced engineers. This finding seems somewhat surprising since KBB tends to be invoked when people are faced with unfamiliar and unanticipated situations where they have no established rules to guide them, and they must resort to reasoning from “first principles”. Therefore, one would expect that experienced engineers will need to use KBB less, and novice engineers will need to use KBB more. However, the need for KBB must not be equated solely with the ability to engage in KBB. KBB relies on a mental model, but since the current tools in the NOC provides little support for developing a comprehensive and accurate mental model of the work domain, a novice engineer’s mental model is likely to be incomplete, and his/her ability to engage in KBB may be severely compromised. On the other hand, they do have the support of more senior staff (usually the problem manager on the team) to tackle complex, long-term, and persistent problems whose diagnosis and resolution is far from straightforward. Therefore, the problem manager who has developed a richer mental model based on significant experience can step in to use KBB for his/her problem-solving. He/she will need to engage in KBB since problems that get passed onto him/her for resolution tend to be challenging because they are unfamiliar and/or unanticipated. Over time, as the novice engineers observe their mentors’ KBB, they will also develop a mental model that can support their own KBB.

10. IMPLICATIONS FOR INTERFACE DESIGN AND EVALUATION

In conclusion, network management centres such as the NOC we described constitute complex sociotechnical systems that are appropriate for Cognitive Work Analyses. To support collaborative work in this type of environment, a work domain analysis and a control task analysis seem to play different roles: a work domain analysis seems particularly important for guiding the design of tools to support collaboration between the network managers and their collaborators outside of the center (e.g., clients, suppliers, field support staff, technical experts), whereas a control task analysis seems particularly important for guiding the design of tools to support collaboration between network managers within the center (e.g., between incident managers, change managers, and problem managers).

Using the abstraction hierarchy as the basis for organizing team information seems to be especially valuable for developing and updating one’s awareness of a single anomaly being diagnosed and resolved. Using decision ladders as the basis for organizing team information may be valuable for recognizing patterns and trends across multiple anomalies that occur over long time periods, though the abstraction hierarchy should be valuable to this end as well. In fact, a database that relates information that at different levels of abstraction, and states of knowledge that result from different information processing activities may provide a very powerful basis for the development of a corporate memory to facilitate long-term organizational learning.

We hypothesize that by making work domain and control task constraints explicit in an interface, network managers can develop larger repertoires of strategies for interpreting system behaviour and planning response actions. They may also start to develop a more complete and accurate mental model, at an earlier stage of their career within the network management center, such that they can start to engage in knowledge-based behaviour more effectively to tackle complex problems.

10.1 Testbed Design

In terms of interface evaluation, it seems important for the testbed to include: 1) a variety of technologies that cannot be managed with a single element manager; 2) the presence of "black boxes" within the system that cannot be directly monitored and controlled by the users of the interface; 3) the possibility of introducing "unanticipated" disturbances into the system, as well as 4) the possibility of introducing "planned" reconfigurations of the system that also disturb system behaviour.

10.2 Scenario Design

With respect to test scenarios, two possible sets of roles that can be assigned to a team of two workers are: 1) an incident manager (who is primarily concerned with data-driven monitoring) and a change manager (who is primarily concerned with goal-driven monitoring); or 2) a junior engineer and a senior engineer (whom the junior can consult in case of particular persistent or complex problems). Alternatively, we can choose to examine collaborative activities between a network manager and 1) his/her client, and 2) his/her service provider.

10.3 Measurement of Interface Effect

A variety of performance and process measures should be used to assess the impact of any interface design: Besides detection times and trial completion times, we may ask subjects to compose notifications to stakeholders detailing their assessment of the cause of a problem, the service impact of a problem, and the planned response actions. These notifications can be required at various time points during a trial, and the contents of these notifications can be coded for completeness and accuracy.

10.4 Limitations

Although this field study has led to significant insights for the design and evaluation of interfaces to support collaborative work in network management, there are some potential limitations on the generalizability of its findings beyond the NOC that we observed: 1) there are large variations in the number of elements managed by NOCs, ranging from less than 500 to over 30,000; 2) there are large variations in the number of staff engaged in NOC activities, ranging from less than 5 full-time equivalents to over 100; and 3) there are large variations in the number and types of clients served by NOCs. (Blum & Kaplan, 2000) The NOC we observed monitors quite an extensive network (i.e., with about 20,000 network elements), employs relatively few staff (i.e., with 6 network engineers working at high-workload periods), and primarily serves internal clients. The likelihood of seeing the same cognitive and collaborative processes in a different network management environment will depend on the degree of similarity between our field study site and the target site.

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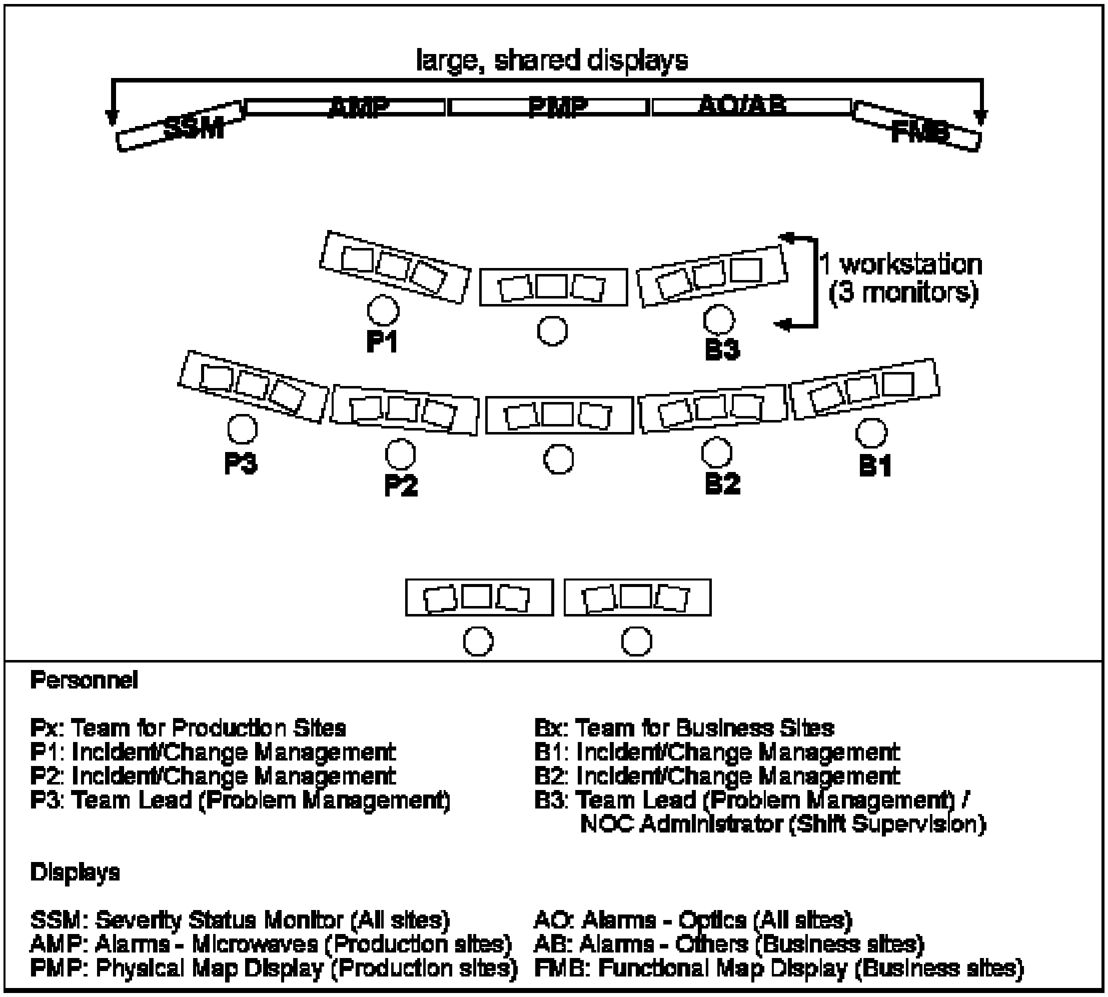

Figure 1: Physical Layout of the NOC – Personnel & Displays

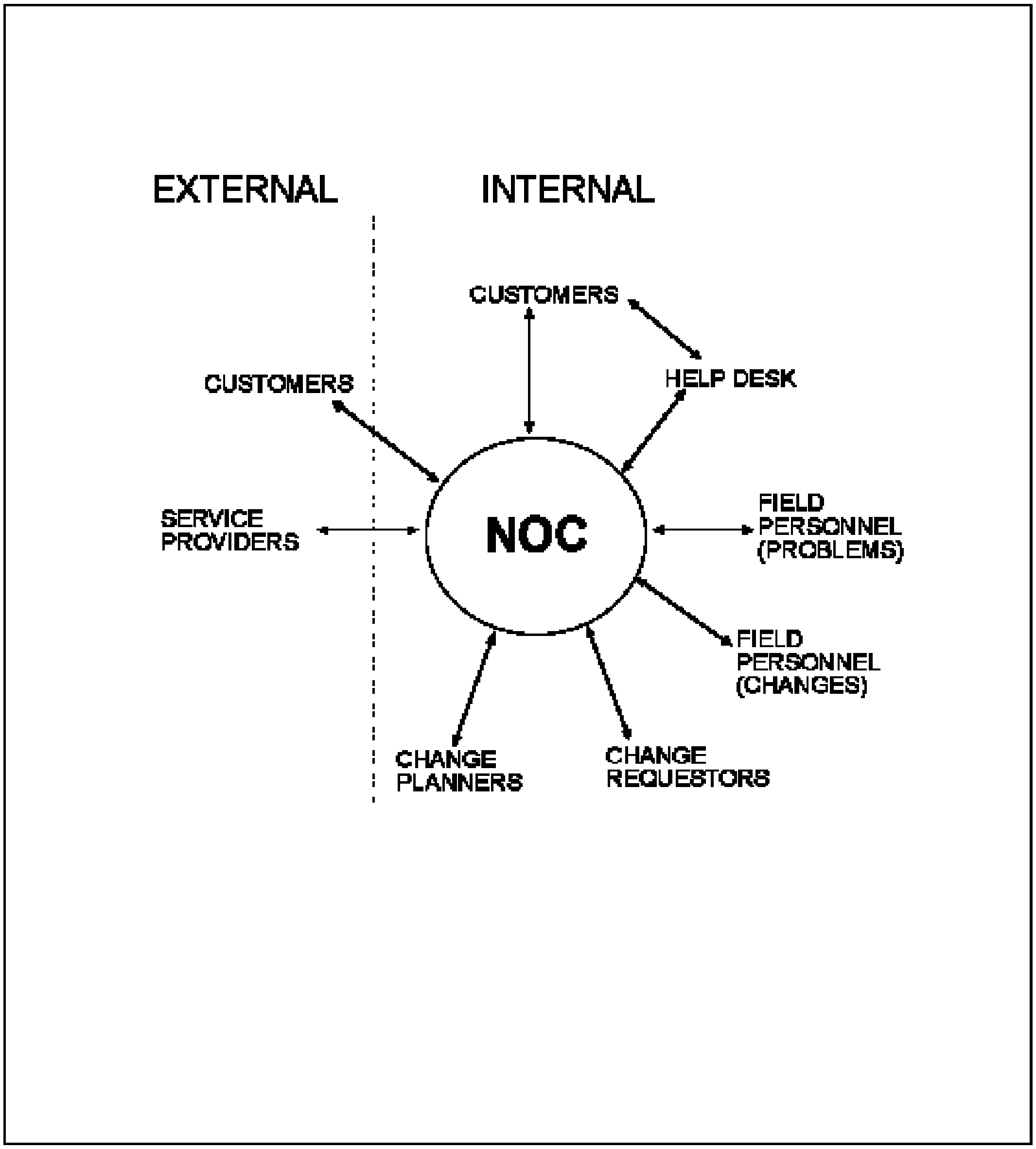

Figure 2: The NOC's Collaborators

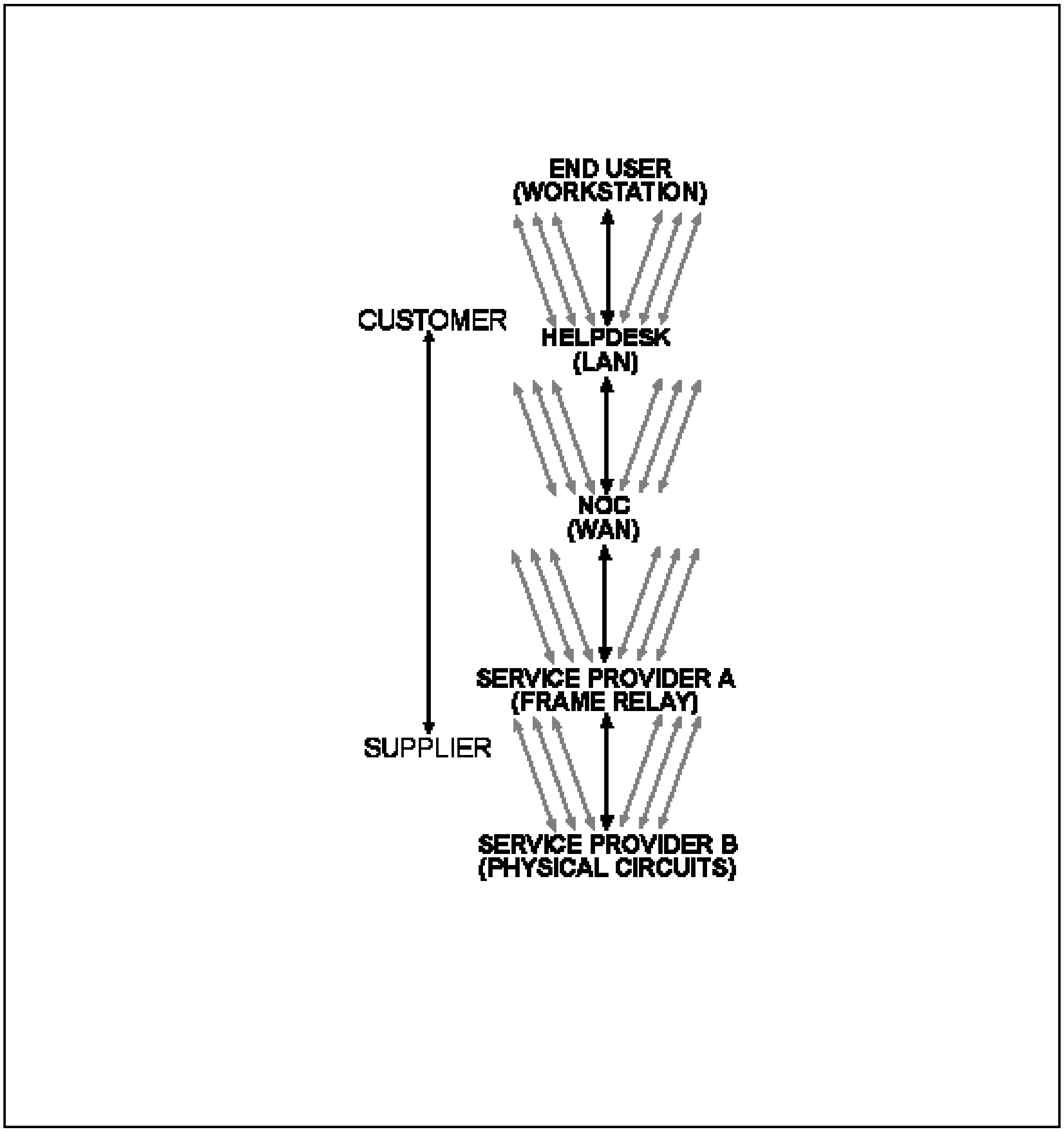

Figure 3: Customer-Supplier Relationships around the NOC

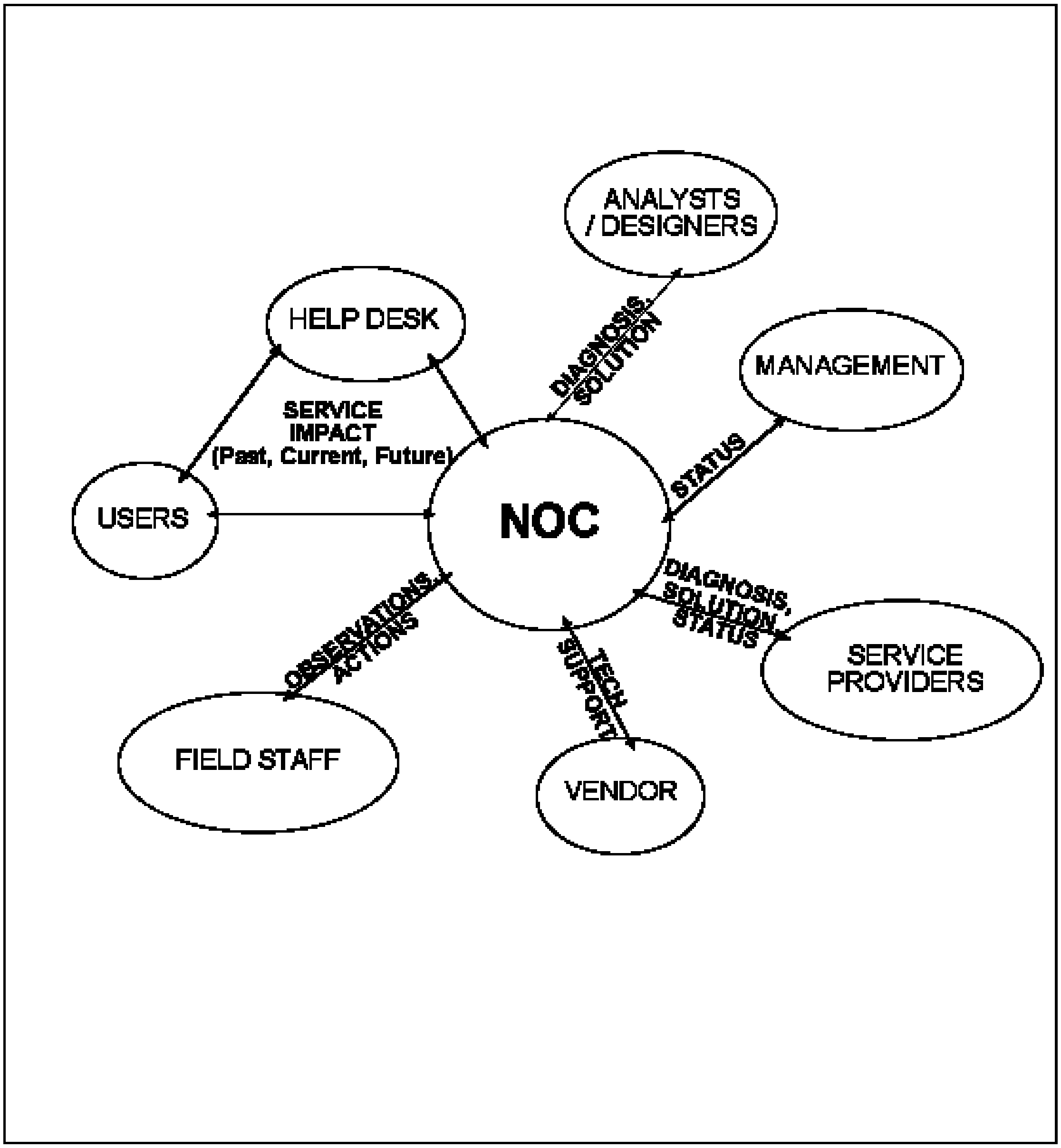

Figure 4: Collaboration in Incident/Problem Management

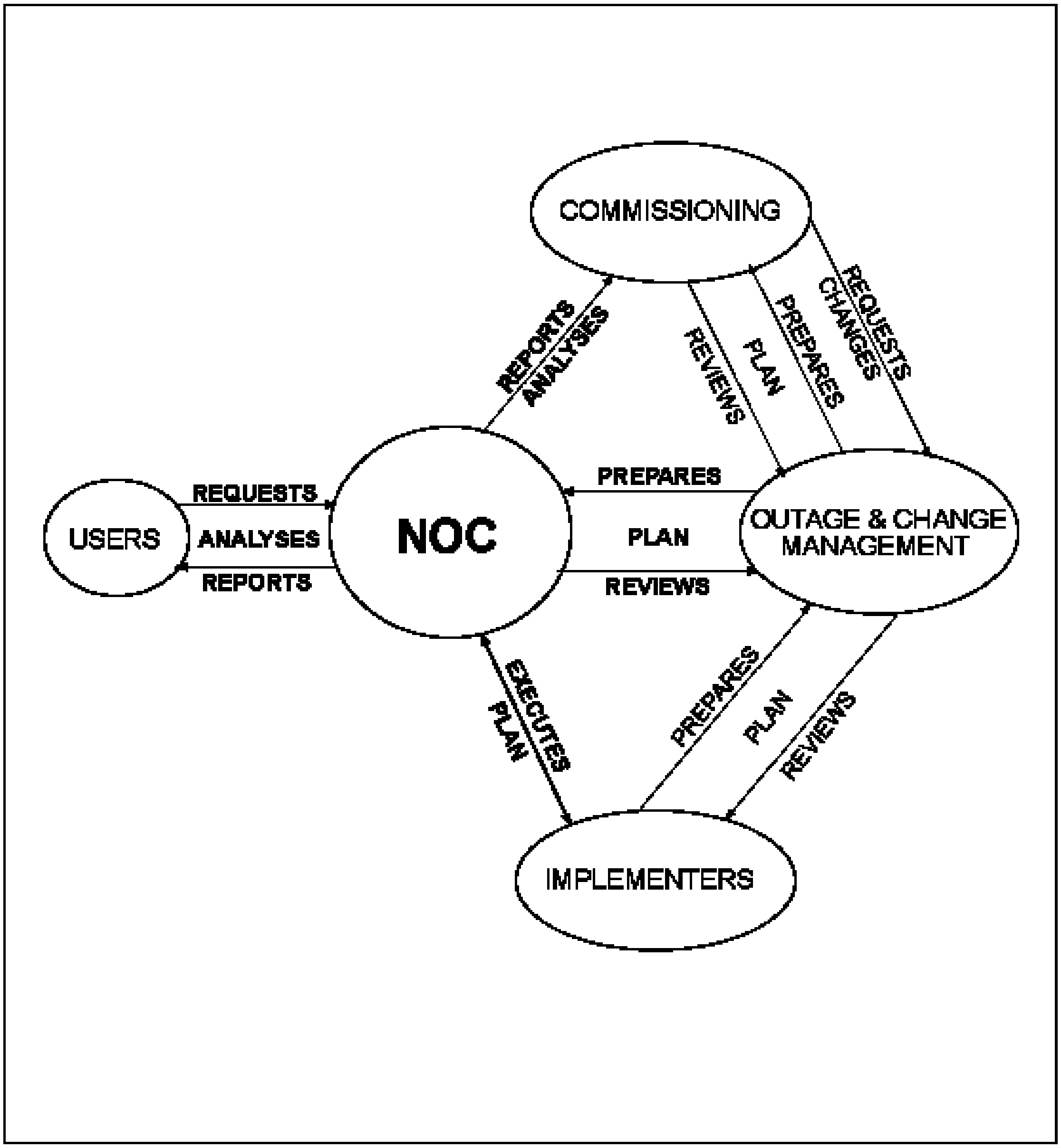

Figure 5: Collaboration in Change Management

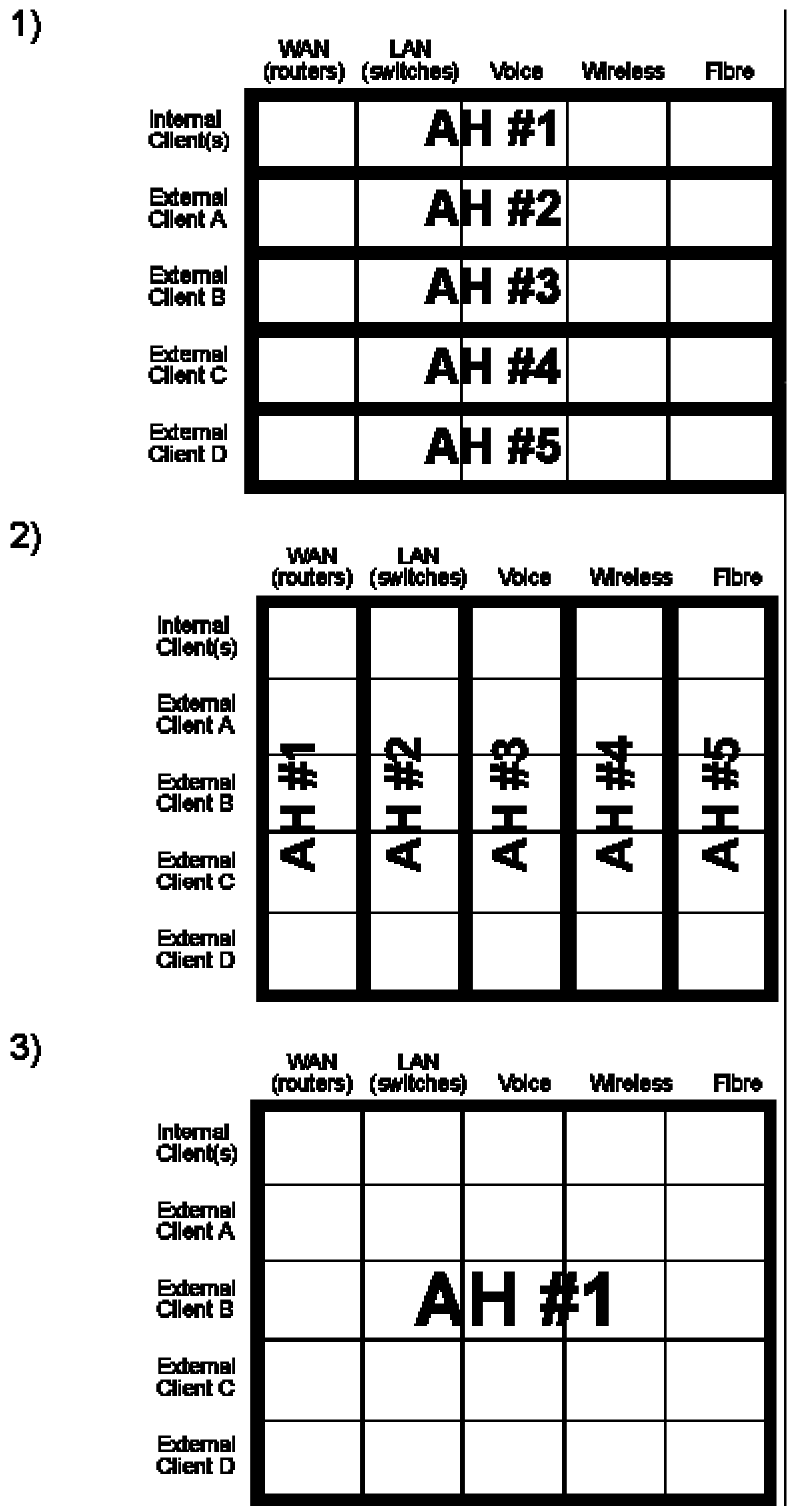

Figure 6: Three Possible Approaches to Conducting a WDA for a NOC

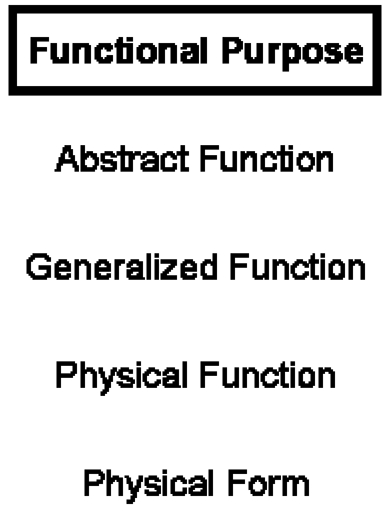

Figure 7: The Severity Status Monitor – Information Content

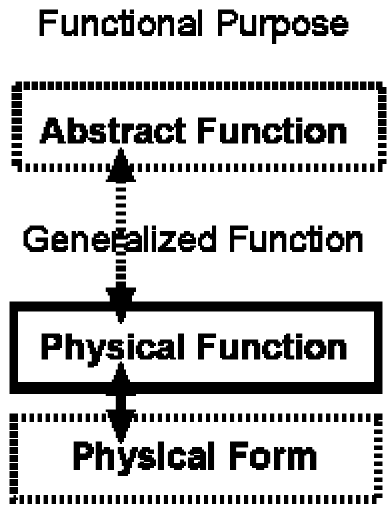

Figure 8: Functional Map Display for Business Services – Information Content

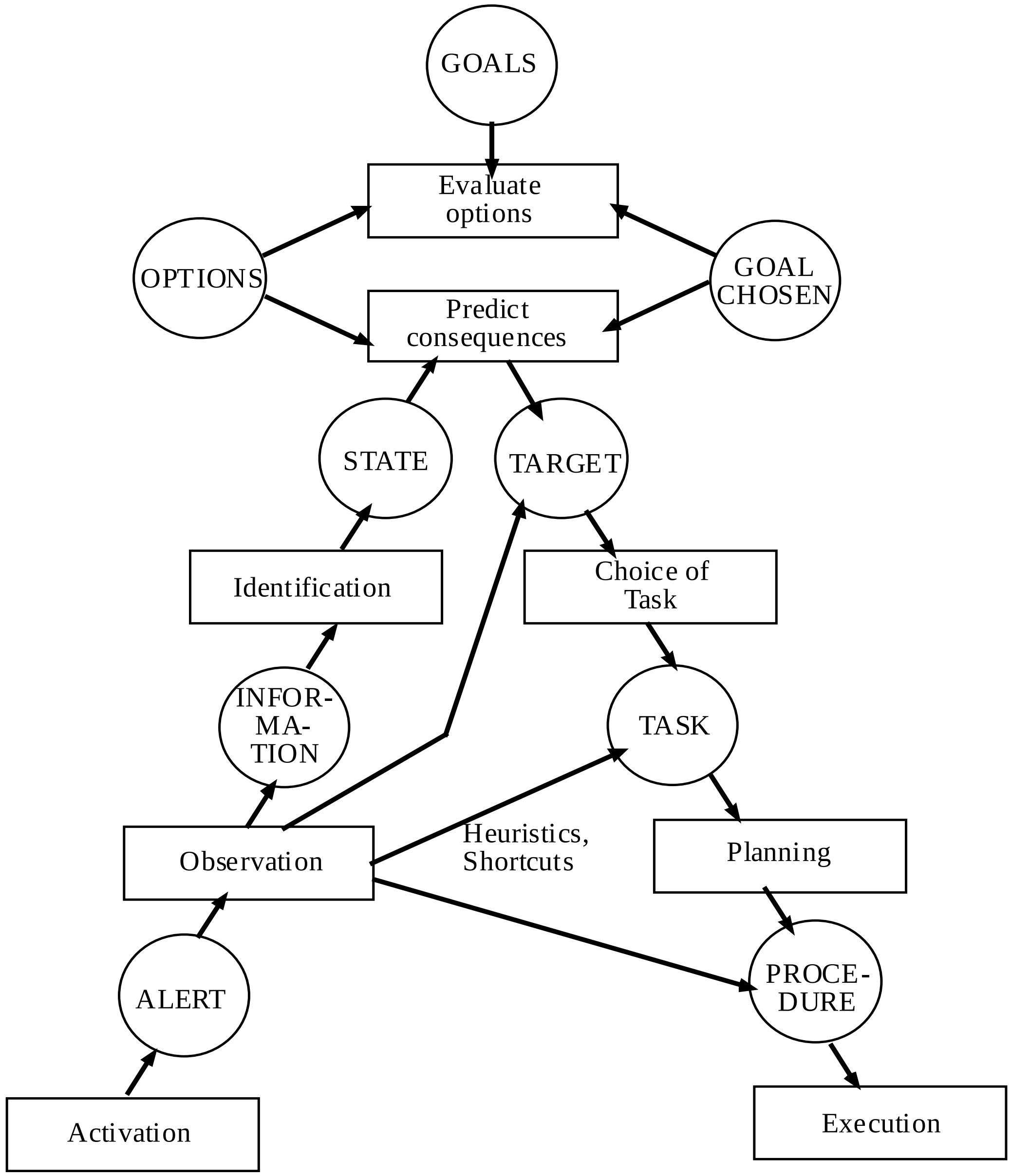

Figure 9: The Decision Ladder (reproduced from Vicente, 1999)

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