Using Cognitive Artifacts to Understand Distributed Cognition

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***Abstract*—Studies of patient safety have identified gaps in current work including the need for research about communication and information sharing among healthcare providers. They have also encouraged the use of decision support tools to improve human performance. Distributed cognition is the shared awareness of goals, plans, and details that no single individual grasps. Cognitive artifacts are objects such as: schedules, display boards, lists, and worksheets that form part of a distributed cognition. Cognitive artifacts that are related to operating room (OR) scheduling include: the availabilities sheet, master schedule, OR graph, and OR board. All provide a "way in" to understand how teams in the acute care setting dynamically plan and manage the balance between demand for care and the resources available to provide it. This work has import for the way that information technology supports the organization, management, and use of healthcare resources. Better computer-supported cognitive artifacts will benefit patient safety by making teamwork processes, planning, communications, and resource management more resilient.**

***Index Terms*—Cognitive science, healthcare, human factors, information technology, research and development, safety.**

I. Introduction

STUDIES of patient safety [4] have identified gaps in current patient safety research, including the need for "research about communication and information sharing among healthcare providers…" Recent research into patient safety issues [5] strongly encourages the use of decision support tools to improve human performance. Research into cognitive activity in the acute care (hospital) environment is challenging for a number of reasons. Care settings, patient populations, and system constraints vary widely. Practitioners often suffer from poor insight into how their work is organized [7]. Information and interaction at the sharp (operator) end is dense and complex.

The researcher in this setting needs to employ methods from outside of the field of healthcare in order to effectively expose practitioner cognition. Methods including ethnomethodology and conversational analysis have been used for two reasons. The first is that the traditional model of individual goals-oriented human conduct does not reflect the complex nature of situated decision making that occurs among groups of individuals. The second is the notion that successful design depends on understanding the ordinary work practices, tasks, and situational requirements of users [8].

Manuscript received April 21, 2004; revised May 2, 2004 June 15, 2004. This work was supported by the National Library of Medicine, National Institute of Health under Grant RO3LM07947. This paper was recommended by Guest Editor D. D. Woods.

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Digital Object Identifier 10.1109/TSMCA.2004.836798

This research seeks to develop and use descriptive models of actual behavior in acute healthcare. Simulations attempt to create an environment that can be more easily studied. However, this produces a subset of the real work setting. Decisions and their results are laid bare in the actual work environment as no laboratory could simulate. Actual work settings synthesize related fields, creating issues that do not appear in a laboratory setting. For example, the anesthesia coordinator has the responsibility to make allocation decisions "on the spot" and the consequences for those time-pressured decisions quickly become evident. This research relies on naturalistic decision making (NDM) [11], [13], [18] to study these behaviors.

The operating room (OR) suite of a hospital is a naturalistic decision setting [17]. This collection of similar but distinct activities occurs in a set of operating rooms, each with its own team of staff members. Synchronizing the interactions among many elements within short periods makes it *time pressured*. In critical care, it is routine that *stakes are high*, as outcomes affect morbidity and mortality. The seniority that is required to perform and manage daily activities means that *practitioners are experienced*. No one person has all of the knowledge that is needed, and as a result *information is inadequate* for individuals. The multiple agendas that different staff members pursue means that team goals are *ill-defined* and sometimes conflict. The activity of providing care occurs in a *rich context*. Emergencies, cancellations, and unprepared or absent patients interrupt plans. Staff members arrive and leave. The number, type, and duration of procedures change throughout the day. Emergent needs can upset plans at any moment. As a result, the environment is *dynamic*, with frequent changes in the demand for and supply of resources.

The smooth operation of the OR suite requires a particular kind of expertise, which makes *coordination among all team members essential*. Multiple professional skills are brought together in order to perform services, from physicians to nurses, technicians, and clerical staff. Intricately related elements including staff, facilities, equipment, procedures, patients, and their families must come together at specific times in a certain state of readiness. Accomplishing this task requires the coordination of many individuals and departments across various times and locations.

The capture, use, and sharing of information is crucial to team coordination. This paper asks how practitioner cognition in this setting can be understood, and describes the analysis of cognitive artifacts as a way to understand it. The findings can be used to guide the development of computer-based cognitive artifacts to support healthcare planning and management tasks such as anesthesia resource scheduling.

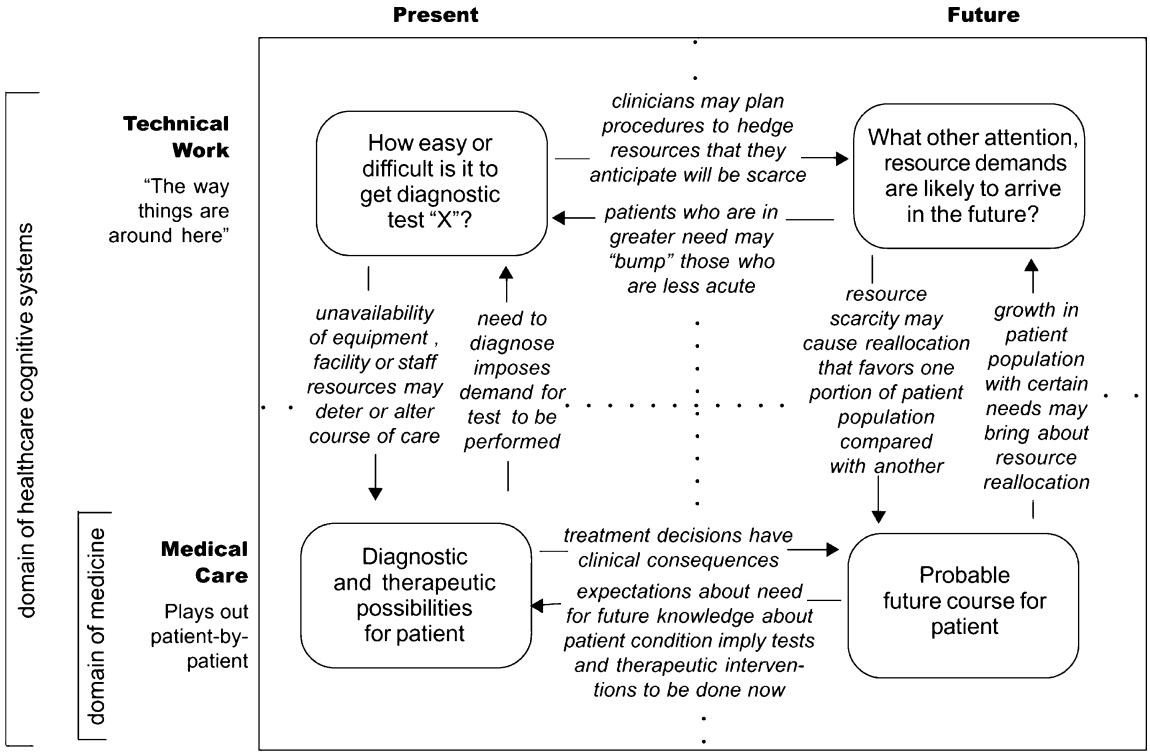

Fig. 1. Medical care and technical work domains are contingent on each other.

A. Technical Work and Domain Knowledge

The work of healthcare practitioners includes diagnostic and therapeutic interventions that enable a practitioner to influence the patient's future course. This work is supported by a large body of knowledge, a tradition of training, and many artifacts. Practitioner work is not simply about clinical details. It also includes what has been termed technical work [5]. Each individual procedure depends on the timely synchronization of people, equipment, tools and facilities. The collective management of that process throughout an entire day for the entire suite of operating rooms also requires coordination. Technical work coordination involves a myriad of practical but essential activities that are needed to carry out clinical care: resource availability assessment, resource allocation, anticipation, prediction, tradeoff decisions, speculation, and negotiation, among others. Many practitioners consider this type of activity to be the "background noise" of the workplace. When asked about such issues, clinicians identify technical work issues as merely "the way we do things around here." Yet the details of technical work are not trivial. Technical work is intimately related to clinical care and it exerts real influences on decisions that are made. Fig. 1 illustrates the interaction between the domain of medical care and the domain of technical work, using the example of whether a patient will receive a simple diagnostic test. Whether a patient undergoes a particular test depends on a number of considerations beyond its clinical features. Those considerations include whether staff, equipment and facility resources are available, how long the queue is, and whether other suitable tests may be available. Each of the interactions matters because each has clinical consequences. The needs of clinical care shape technical work, just as technical work shapes clinical care. The regular use of clinical resources influences the expectations for resource use and allocation. Practitioners and those who coordinate their work tend to act in anticipation of future possibilities. How they view the prospects for available resources tends to influence how they act in the present.

The distinction between clinical and technical work is not readily apparent and practitioners typically do not consider the two separately. However, technical work is a crucial component of practitioner activity and is essential to understanding how practitioners handle conflicts and tradeoffs between and among cases. Practitioner cognitive work engages both narrow clinical issues and the details of technical work. Insight into the operation of healthcare as a system flows from making the interactions between the two levels explicit and from understanding their implications.

B. Distributed Cognition

Distributed cognition [11] is the shared awareness of goals, plans, and details that no single individual grasps. Through it, individuals cultivate a mutual awareness and an understanding of their situation. To be effective, this awareness and understanding needs to be timely, thorough, and accurate enough to collectively accomplish shared goals. Hutchins and his colleagues contend that internal and external cognitive processes involve complex coordination at many different time scales between internal resources (memory, attention, and executive function) and external resources (the objects, artifacts, and materials). A cognitive process is bounded by the relationships among the elements that are part of it, instead of how close the elements are

in physical space. For example, the examination of memory processes in an airline cockpit showed that memory "involves a rich interaction between internal processes, the manipulation of objects, and the traffic in representations among the pilots." Studies of group cognition in natural settings have discovered that cognitive processes may be distributed among the members of a social group. They may involve coordination between internal and external (material or environmental) structures. They may also be distributed through time so that the products of earlier events can transform later events [9].

Work and cognition are distributed throughout the OR suite. Successful acute care requires the orchestration of multiple kinds of knowledge and expertise: anesthesia, surgery, nuclear medicine, obstetrics and gynecology, gastrointestinal endoscopy, diagnostic and interventional radiology, psychiatry, and nursing. Bringing this expertise to bear requires coordinated collective activity across practitioners that is ongoing, adaptive, and flexible.

C. Cognitive Artifacts

Cognitive artifacts [12] are objects such as schedules, display boards, lists, and worksheets that are part of a distributed cognition. The artifacts that are used to mediate collective work need to be shared as a way to maintain an overview of the total activity [1]. Cognitive artifacts that are used in the hospital organization are products of various work activities that are distributed in time and location. Coordination of the work relies on artifact development and use to collect and represent information, assessments, plans, possibilities, and uncertainties. Many artifacts evolve as they pass through many different hands, reflecting organizational needs, as well as practitioner expertise and roles. The effort that is expended to develop and maintain cognitive artifacts and the reliance that practitioners place on them demonstrates their value. Badram [1] outlines five strategies that teams in acute care employ in order to coordinate collective activities across department, time and space: minimize articulation among collaborators, prioritizing and scheduling work and ensuring commitment to the schedule, sharing information and maintaining an overview, ensuring fair and optimal workloads and anticipating, planning, and prehandling work.

D. Coordinator Activities

Attending and resident anesthesiologists along with certified registered nurse anesthetists (CRNAs) care for patients during critical healthcare procedures, particularly surgery. A select group of more senior anesthesiologists take on additional work as anesthesia coordinators (AC). Coordinators plan and manage anesthesia staff assignments because virtually all procedures in the OR involve anesthesia. This coordination is intimately involved with the day's work on the unit. The conduct of a single procedure requires synchronized and coordinated effort from the various departments that are involved. The process of planning and managing the day's work is far more complex than most outsiders appreciate. Those who provide care and support staff have to appraise the published schedule, distribute resources, synchronize their efforts with those of other personnel, and reassess the situation and their plans through the day. Cognitive artifacts are an integral part of this process.

The twenty-four ORs where this research was conducted handle roughly 50 to 80 procedures every day. Some of these are brief and take thirty minutes. Others last most of the day. Some are routine and their duration can be predicted reliably. Others are complex and less predictable. Some procedures will go on as scheduled. Others will be delayed and cancelled. There is always the possibility of an emergent need for an OR and staff to perform a procedure. The coordinator's responsibility is to manage the activities of the staff in order to accommodate these demands efficiently.

E. Planning Process

Plans for each day of anesthesia procedures start twelve months beforehand and seek to reduce uncertainty to the smallest possible amount before it begins. Fig. 2 shows the time line that starts with the anesthesia department's annual plan. The annual plan reflects long-term staff issues such as leaves of absence, retirements, schooling, hiring intentions, expected numbers of residents, and vacation plans. The master schedule for anesthesia assignments evolves from annual to monthly to daily schedules. The sequence to develop, execute, and complete the master schedule for each day actually spans three days, as the diagram shows. The anesthesia coordinator prepares the final master schedule at around 11:00 each day, starting the cycle for the next 24 h. Production of the OR graph on the next day completes the cycle. The path that the AC takes in making assignments strives to reduce the degree of uncertainty to a manageable set. Care demand, economics, efficiency, and teaching suffuse the process with conflicts.

Demand—The type and number of demands varies. A patient may experience a heart attack. An organ may become available for transplant. Each occurs in its own time.

Economics—The larger the number of procedures that are performed tends generates more revenue for the surgeon and the hospital. Each surgeon schedules cases according to specialty and patient population.

Efficiency—The anesthesia department is responsible for managing the use of resources and the cost of providing services in the OR suite. Resource management keeps staff and equipment from being under- or overemployed. There are only sixteen rooms in the OR suite. Some are dedicated for specific uses and cannot be given over to general assignment.

Teaching—As this is a teaching institution, the anesthesia department trains residents to perform as physicians in a variety of medical fields.

What makes writing a schedule easy or difficult? Both ease and difficulty flow from the nature of demand for care (volume, acuity, composition) and of the resources to meet it (availability, flexibility, resilience).

Demand Volume—A larger number of patients requires more unit members to staff the ORs on "heavy" days. On "light" days, the coordinator can allow more senior staff to work off the unit on research ("lab days") or take personal time.

Demand Acuity—Urgent and emergent cases must be treated. The greater number of acute cases, the greater the pressure to treat them. Emergency cases interrupt the schedule. More emergencies results in more schedule instability.

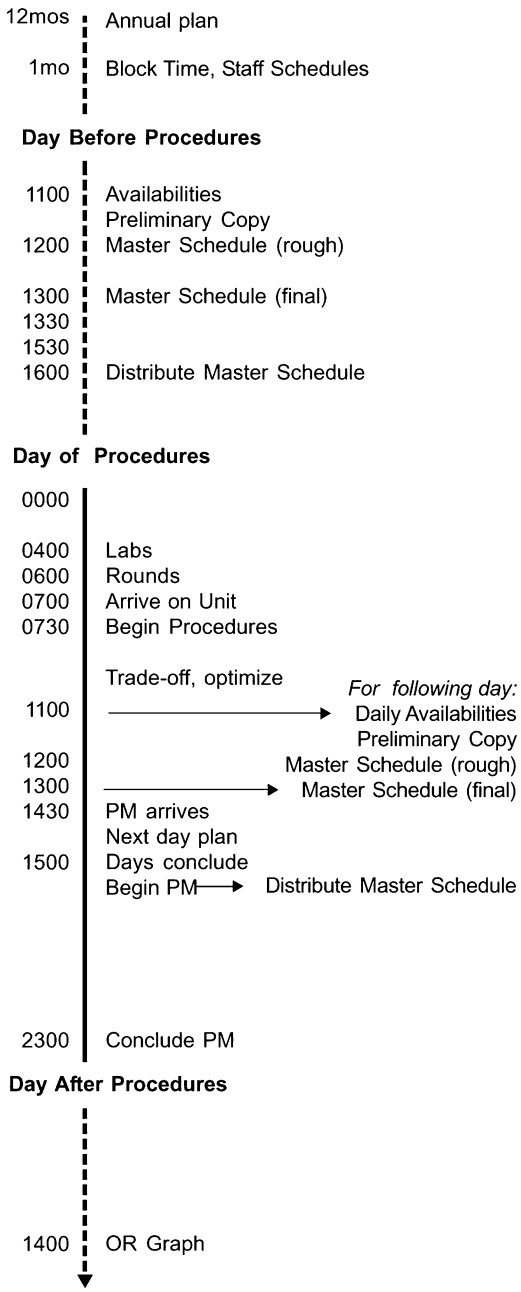

Fig. 2. Schedule time line.

Demand Composition—Specific demands may have a local effect on certain qualifications. For example, transplant procedures are typically complex and occur when an organ is available. That can require members of the transplant on-call team to put in long hours, making them unavailable for assignment postcall.

Resource Availability—Only a portion of the anesthesia staff are available for assignment on any given day. Demand can be accommodated is there are enough staff members on hand who are qualified to perform required procedures.

Resource Flexibility—Having enough staff members who are qualified in skills such as cardiac or pediatric anesthesia means that all demands can be met despite particular requirements. Staff members who are willing to accept assignments without regard for personal preference afford the coordinator greater flexibility.

The easiest days to schedule and manage have low volume, few acute patients, and no emergencies, as well as enough staff to allow personal and lab days, enough qualified staff to handle special demand requirements, and no staff personal issues. The hardest days are those in which staff resources are tight, such as the end of the academic year in June, when residents are departing and demand remains constant.

II. Cognitive Artifacts as a Research Tool

Information technology is rapidly entering the healthcare setting in the interest of improving work process accuracy, reliability, and efficiency. The creation of such systems relies on understanding work activities and the problems that practitioners encounter and manage. In order to study this, the systems researcher needs a tool to use in understanding the coordination activity that makes the place go every day. One logical starting place to look is the tasks that are involved in the coordinator role. The master schedule, which is the cognitive artifact that the anesthesia coordinators create and use, provides the researcher with such a tool.

Blumer's [3] symbolic interactionism explains social behavior as each individual's response to the meaning that the person attaches to others' actions. In order to understand the actions of people, it is necessary to identify their world of objects, whether physical, social, or abstract. Objects reflect the nature and changes that occur in the life of the group because human group life is a process in which objects are being created, affirmed, transformed, and cast aside. People actively manage the dynamic characteristics of their workplace by drawing on a deep knowledge of their work domain to create and use artifacts. Studying the cognitive artifacts that team members create and use in order to manage their work environment reveals the well-founded understanding that team members have used to create them.

This research was conducted over nine months at a major urban teaching hospital. It included informal interviews with roughly 25 nurses and coordinators and 40 anesthesiologists/CRNAs and anesthesia coordinators at the coordinator station in the OR suite. It involved the review of the structure and variations of roughly 15 daily availabilities, master schedules, and OR graphs over three months. It also involved making individual video recordings of three anesthesia coordinators while each developed a schedule of outpatient clinic anesthesia assignments. Two themes guided this research into practitioner cognition. The first is the effort to understand the work domain as a complex, high hazard, time-pressured, interrupt-driven environment. The second is the effort to understand how practitioners manage their work domain using strategies such as: anticipation, hedging and husbanding resources, and making tradeoffs. Cognitive artifacts reveal information about both themes. Artifacts are highly encoded representations of what matters in this domain. Artifact encoding conveys the information in a compact, efficient manner and their content is inherently connected to what is meaningful in the domain.

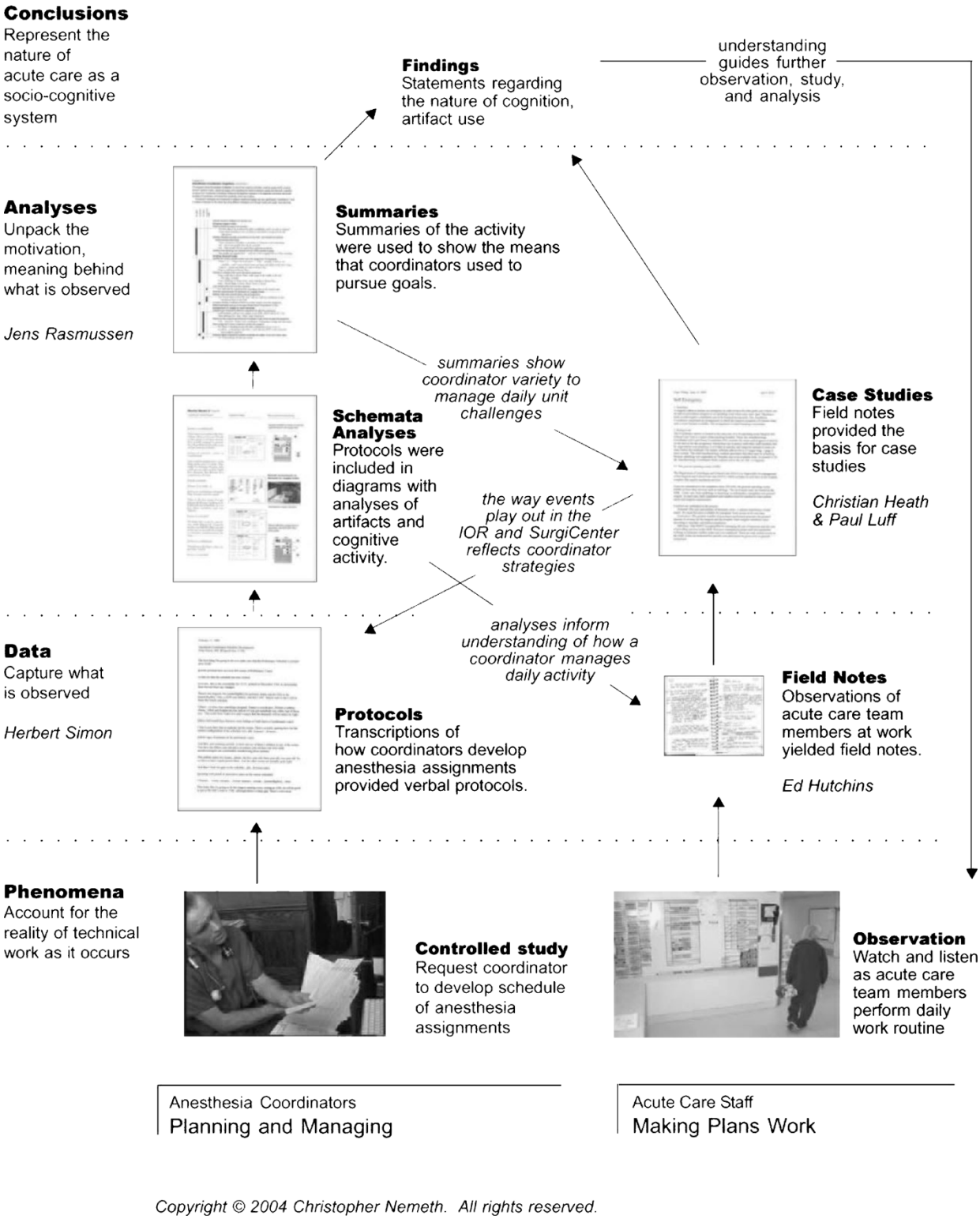

Fig. 3. Methods used to research practitioner cognition.

Nemeth [15] demonstrates how the study of cognitive artifacts including the availabilities sheet, master schedule, OR graph and OR board provides a "way in" to understand how teams plan and manage the balance between care demands and staff resources.

Fig. 3 shows how this research used artifacts to study cognition at the unit level in two paths. One path, on the left side of the figure, observed how a coordinator creates a cognitive artifact (the master schedule) while using two others (the daily availability sheet and the master schedule preliminary copy). Video recording captured how the coordinator used artifacts. Verbal protocol transcriptions documented coordinator comments about schedule decisions. Review of the video, audio transcripts and artifacts made it possible to create analyses with comments on coordinator cognitive work. Summaries of the analyses also provided the opportunity to describe how each coordinator scoped resources and demand, assigned resources,

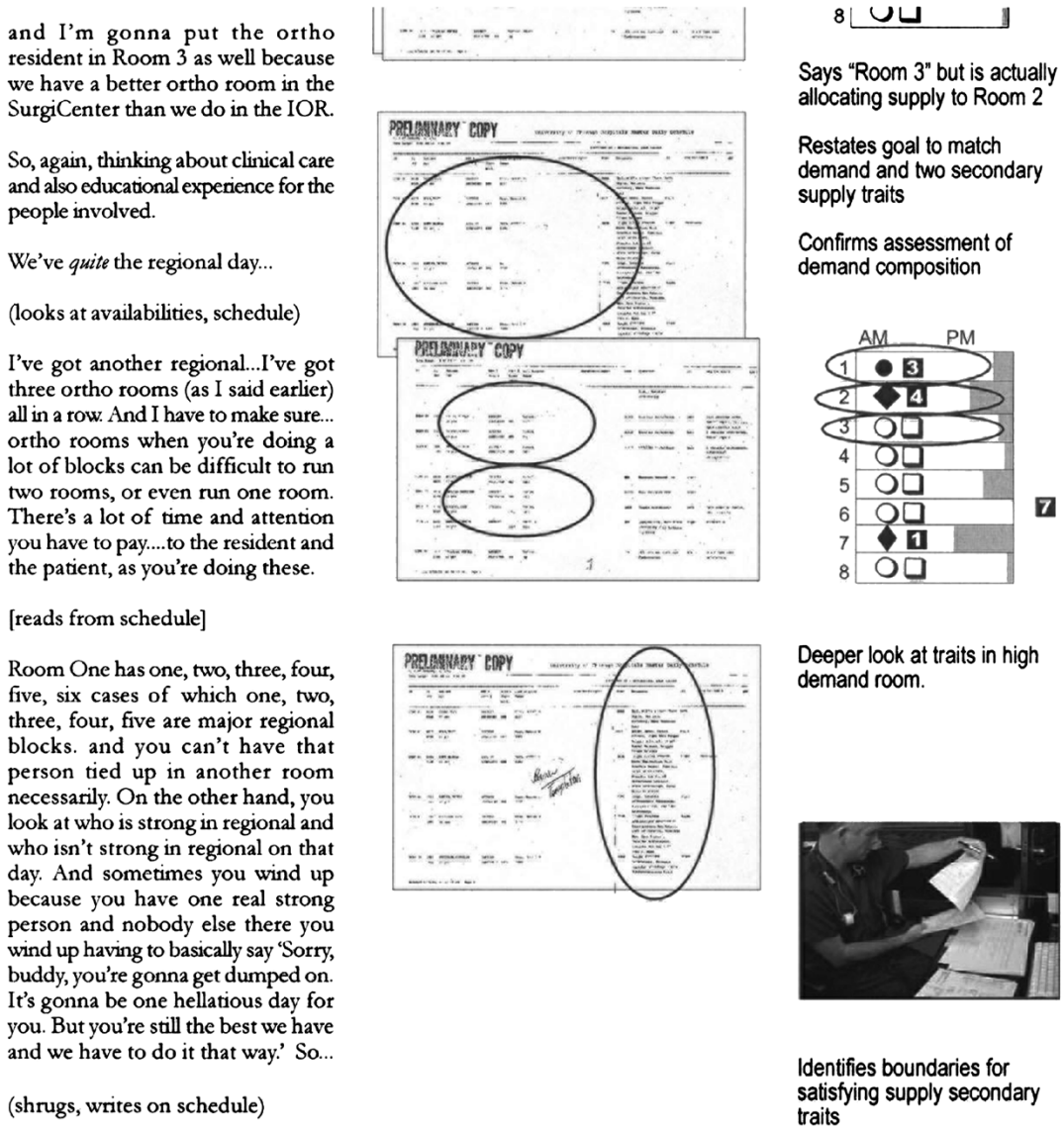

Fig. 4. Sample schemata analysis of coordinator schedule writing.

and evaluated the balance between resource and demand. The second path, which is shown on the right side of the figure, observed how practitioners in the OR suite use the master schedule to manage their daily work. Field notes documented that activity. Case studies summarized the notes and added analytic comments. While the first path shows how the artifact is created, the second uses the artifact to reveal the basis for its creation.

A. Laboratory Study

The first approach studied how anesthesia coordinators plan for the daily schedule in the OR unit and outpatient clinic by inviting individuals to each write a schedule while being recorded on videotape. Four coordinators out of eight were available and three agreed to participate. Summaries of the sessions removed all identifying information and included three elements: verbal transcript, annotated artifacts, and comments on coordinator cognitive work. Categorization, classification, and analysis were used to produce a formalized performance description [10] for a number of anesthesia coordinators who wrote daily schedules. As Fig. 4 shows, the analysis of each session was formatted in three columns in order to show the simultaneous interaction between cognition and artifact. The left and center columns depict the phenomena that were observed during the session, while the right column contains an analysis of what was observed. The left column contains verbatim transcripts of the coordinator's verbal protocol while writing the schedule. The center column contains images of the cognitive artifacts that the coordinator used during the session. Circles on the artifact images identify where the coordinator was paying attention, based on video analysis. The right column contains diagrams that represent how resources are being allocated through the session, along with comments on the major phases and incremental steps of cognitive work.

The analyses reveal the cognitive work that is behind coordinator scheduling. Transcripts of their description while writing the schedule indicated the processes that coordinators employ. Analyses of the sessions show how the coordinators allocate resources to meet demand in the interest of staging how activity should occur the following day.

While each coordinator creates a schedule, the way that each develops a schedule varies. The first coordinator reviewed demand, assigned all attending anesthesiologists, then assigned residents and CRNAs. The second coordinator took a far longer look at demand, spent time reconfiguring demand, assigned all residents and CRNAs, then assigned attending anesthesiologists. The third coordinator uses a different approach altogether. While the first two coordinators assigned attending anesthesiologists in a group and resdients/CRNAs in a group, the third assigned each attending and resident or CRNA as a pair. Rather than treating demand and supply as a block, he considered each room, the attending best suited for it and the resident or CRNA that is best suited for the work in the room and the attending who will supervise it. This variety among coordinators is evidence of resilience in the face of constraints. Multiple approaches such as these are useful in the face of highly varying demand.

B. Observational Study

The second approach employed observation and interview methods in order to understand how the staff members in the OR suite use cognitive artifacts to manage their daily activity. One of the authors captured practitioner comments and events as they occurred by writing field notes of daily activity into two pocket-sized booklets. He conducted informal interviews with roughly 25 nurses and coordinators and 40 anesthesiologists/CRNAs and anesthesia coordinators during observations. He reviewed the structure and variations of roughly 15 daily availabilities, master schedules and OR Graphs over three months. During this time the author wrote twelve case studies to synthesize the observations, comments from informal interviews, and analysis. Each case study followed a similar structure: title, brief summary, background, sequence, and comment. The "sequence" section of the case study included actual behavior and quotations that occurred during observations. These data form the foundation on which conclusions about practitioner cognition are based. He "unpacked" the meaning that was embedded in observed behavior in the case study comment section. Comments showed how schedule development played out in the OR and SurgiCenter, reflecting coordinator strategies.

The case-study approach is a good method to describe the many complex, variable activities that occur in a technical work setting. The method meets many of the criteria for qualitative research [16], incorporating observation, informal interview, and artifact analysis to depict the actual nature of human behavior with cognitive artifacts. Direct quotations and literal descriptions of artifacts and their use demonstrate study rigor and provide evidence that supports study comments. Informal review by a few senior anesthesiologists confirmed that the studies were well-calibrated to what actually occurred in the IOR. Case study details are available in Nemeth [15].

C. Artifact Analyses

Cognitive artifacts can be used to learn about the work that they have been designed to support. For Hutchins [12], "cognitive artifacts are involved in a process of organizing functional skills into functional systems." This amounts to "a category of processes that produce cognitive effects by bringing functional skills into coordination with various kinds of structure."

The study of a cognitive artifact yields insight into the nature of the artifact itself as well as insight into the technical work situation and intentions that the artifact represents. Our observations showed that cognitive artifacts are an essential part of schedule development and use. For example, each coordinator who developed a schedule read and wrote on the daily availabilities and the preliminary copy while drafting the master schedule for the following day. Each day, acute care team members arriving on the unit first stopped at the master schedule and the OR board to determine the day's work and their role in it. Throughout the day, team members and the coordinator referred to and wrote notes on the OR board. What they wrote and when they wrote it enabled the team to keep a current, accurate idea of how the day's events would, and might, play out.

Focusing on artifacts provides an opportunity for the researcher to identify critical features of the work domain. Physical artifacts and the notes that practitioners make on them can also reveal gaps in computer support for cognitive work. This is because cognitive artifacts typically are used to support important, difficult activities. The work that the artifact is designed to support can also be improved by making a better artifact. Better information design or improved use of information technology (software) can make technical work more enjoyable, more efficient, and more reliable.

III. Discussion

The study of cognitive artifacts is an effective means to understand high-hazard complex work domains. It is also an efficient approach because it gets directly to what matters. Even though it takes significant effort, the effort that is invested is productive. Nemeth [15] used the methods that are described in this paper to observe practitioner use of both paper and computer-supported versions of the master schedule. At a minimum, any cognitive artifact in this environment, whether paper or computer-supported, must be accurate, efficient, reliable, informative, clear, and malleable. Each has implications for the development of digital cognitive artifacts.

Accurate—Current and valid in its representation of the system state.

Each coordinator updated the paper artifact with simple pen notations upon learning new information. Under the computer-based system, case status information posting is frequently late by a half hour or more. This forces team members to do extra cognitive work as they make in-person trips and phone calls to verify case status.

Efficient—Impose the least burden on users to create and obtain information.

Practitioners could scan and find cases on the paper master schedule throughout the day. The roster on the electronic display shifts each time a case is deleted, causing the reader to search for

cases. In addition, the computer interface requires practitioners to drill down as a far as four menu levels to find information that was previously available in one glance using the paper version of the master schedule.

Reliable—Available for use when needed.

The paper artifact was posted daily at the coordinator station. Computer-supported displays that go "down" prevent team members from seeing or entering information. This causes great difficulty in making the kind of moment-by-moment decisions that are necessary for resource allocation.

Informative—Contain information that pertains to circumstances of interest to the team.

Coordinators evaluate the day of procedures according to what has already happened and how the remainder of the day can be planned. The paper master schedule allowed for the collection of information related to cases through the day. The computer-based version removes a case from the display after the patient has been sent to postanesthesia recovery. Displays that offer only a static or a "keyhole" view of the day prevent practitioners from making connections that are a necessary part of their cognitive work.

Clear—Unambiguous and free from confusion.

Procedures must be completely and precisely described in order to specify what is to be done. Minor differences in wording result in major differences in the kind of supplies and equipment that will be required for a procedure. The paper artifact contained complete descriptions of each procedure to be performed. The computer-based display only allows truncated descriptions, which create misleading procedure descriptions that have caused departments to plan for the wrong procedure.

Malleable—Able to be manipulated by those who use them.

Practitioners interact with many artifacts frequently as they obtain and provide information among the team. They also use artifacts in a variety of subtle ways, depending on their confidence in the information they have. Nursing and anesthesia coordinators were able to write notes on the paper artifact to track pertinent information. The structure of artifacts can also be changed. For example, the team can modify the OR board layout to better support cognitive work as it evolves. The computer-based display does not allow for this kind of interaction.

With success in these criteria, cognitive artifacts that are computer-supported can move forward to add value to resource planning through prompting, and support for speculation, consequence assessment, and value-based decisions.

Prompting—Coordinator interviews indicated that schedule development expertise rests on deep domain knowledge that can only be cultivated through time.

Computer-supported artifacts might survey information in the distributed cognition for gaps and inconsistencies that go unnoticed. Nominating such item(s) for the schedule writer to consider would enrich and improve the cognition.

Speculation—Coordinators and team members were routinely observed to speculate about different courses of action in anticipation of known and possible demands for care.

Computer-supported artifacts can make it possible for coordinators to speculate about possible courses of action and then choose among them. Providing multiple options for evaluation would make their consideration more thorough.

Consequences—During schedule-writing sessions, coordinators routinely mentioned the implications of the decisions they made while assigning resources. However, coordinators varied in their attention to implications. In one instance, a coordinator writing the same sample schedule as a previous coordinator noticed an opportunity for Medicare reimbursement that the other coordinator had not mentioned.

Applying evaluation criteria to potential courses of action could make it possible to display the consequences of choices. For example, a system might show how billing could be increased or how costs could be minimized by opening one room or closing another.

Value-based decisions—Schedule-writing sessions showed how coordinators vary in their approach to scheduling decisions, based on different preferences that include making the day easy for the coordinator to manage, giving residents the optimal learning opportunity, and making the best match among attendings, residents/CRNAs, and procedures.

Computer-supported artifacts can be used to develop templates of schedule-planning strategies. Coordinators can review and employ a template that best matches their values and preferences. Such templates can capture scheduling expertise and make it available for use by others, expanding best schedule writing practices beyond a single individual. Study of template use through time might open the way to insights about coordinator training and the development of schedule models to ease coordinator work loads.

This research has provided a number of insights into methods as well as cognitive artifacts and practitioner individual and group behavior in the healthcare setting. Practitioner cognition is distributed in order to strike and manage the balance of constrained resources with the continually changing demand for services. Their cognition is also temporal, as team members view past, present and expected events as the day progresses. All participants rely on other departments through a daily set of expectations and anticipated action in order to execute the procedures.

The study of physical cognitive artifacts showed how members of the organization seek to reduce uncertainty to the smallest possible amount to make it manageable on the day of procedures. Artifacts show how practitioners apply their expertise to the creation and management of a plan to perform a complex set of procedures. Artifacts also reveal organizational change by evolving from a plan of procedures that may be performed at day's start into a log of procedures that have been performed by day's end. Artifacts can make research efficient by enabling the researcher to get in at the right level (where help is useful), and to deal with the most meaningful aspects of a complex technical work setting.

Future artifacts will need to succeed on two levels. They will first need to incorporate the kind of research approach that is described here in order to overcome the shortcomings of computer-supported systems that simply mimic physical artifacts. Second, they can add value beyond the limitations of physical

artifacts to better support practitioner needs to improve patient care and resource use.

The research methods that have been described here get at the nature of practitioner behavior including goals and strategies practitioners employ to achieve them. Methods make it possible to evaluate new cognitive artifacts by determining the fit between an artifact and the work domain for which it is intended. Those who seek a way to understand the cognitive work in a domain will need to use such an approach in order to develop information technology that is authentically suited to practitioner needs.

IV. Conclusion

Computer-supported cognitive artifacts have much in common with physical cognitive artifacts. Computer-supported artifacts are often modeled as iconic representations of paper artifacts. Yet, without research, these systems are necessarily blind to the sophisticated and refined interactions that practitioners have developed in order to perform complex work. Understanding the origin and nature of the physical artifacts relies on deep and sustained observation of the groups and activities they support in order to derive their meaning. The method described in this paper provides a constructive direction to lay the foundation for future information technology systems in healthcare.

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