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INTRODUCTION

Groups at work: lessons from research into large-scale coordination

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Abstract Study of large-scale coordination seeks us to understand work between and across groups beyond earlier conceptions of social human factors. Revealing the complexity of work domains and the subtle yet effective ways that workers negotiate its challenges opens the way to develop support tools that are grounded in a scientific understanding. This first special issue in Large-Scale Coordination shows the breadth of application research from air traffic control to the military and multi-agency emergency response. A second special issue later this year will show depth of research at large scale in healthcare.

Keywords Large scale · Coordination · Naturalistic decision making · Cognitive systems engineering

1 Introduction to the first of two special issues

This first of two special issues of *Cognition, Technology and Work* started as a symposium of five papers at the September 2005 Human Factors and Ergonomics Society annual meeting in Orlando, FL (Nemeth, 2005). Six additional authors and a guest editorial by Dr. Larry Hirschhorn expand on the theme to expand the discourse and range of applications.

Issues of *Cognition, Technology and Work* typically feature four to six papers that treat their topics in depth. This issue and a second special issue that follows later this year feature a total of 11 papers that are a more concise treatment of a wider range of topics. The first issue is organized in order to demonstrate how the large scale coordination theme plays out across a range of application areas from air traffic control to military logistics and emergency response centers. The second issue demonstrates the variety of issues and findings that can be found at large scale within a single sector: healthcare.

Both special issues on large scale coordination validate naturalistic decision-making (NDM) (Klein 2000) and cognitive systems engineering (CSE) (Hollnagel and Woods 2005) as means to engage and understand complex, high hazard work settings. CSE evolved from the efforts of cognitive psychologists to develop methods and a base of knowledge that are suited to understand human performance in complex real world settings. These papers explore the use of NDM methods including CSE to reveal how groups of operators have developed ways to perform inter-group work in real world settings. Insights from such studies inform the development of system-level products, including safety countermeasures and information and communication technology (ITC) that are intended to support this work.

The work studies tradition (De Keyser 1988; Luff et al. 2000) recognizes and reveals the sophisticated approaches to work that individuals and groups develop. The systemic aspects of work, though, are not available through the study of individuals or a single group. They can be revealed by cognitive research at large scale—*among* and *across* groups. That is the focus of this special issue of *Cognition, Technology, and Work*.

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2 Research into large scale coordination

For the human factors professional, collaboration among workers is large in scale when it takes place beyond small, stable groups that can accomplish their work within limited time spans. At large scale, complex work is typically divided into subtasks and assigned to individuals who interact with one another when their subtasks interact (Obradovich and Smith 2003). This is *joint activity*, an extended set of actions that is carried out by an ensemble of people who are coordinating with one another. Coordination of the work across time (Bardram 2000, p. 163) ensures that collaboration takes place at the right time within and among groups through resource synchronization, scheduling and allocation.

Participants in joint activity must intend to work together, be mutually predictable and directable, and maintain a common ground. (Klein et al. 2004) High-level performance of the cognitive activity that is involved in these work settings depends on the provision of support for two purposes: resilience (the ability to anticipate and adapt to potential surprise and error) and coordination (the ability to synchronize activity across agents) (Woods 2005).

Both the real world of work and the information and communications technology (ICT) that is available to support it are in constant flux. Operators adapt to changes in the environment. A variety of factors influence work relationships across groups, including individuals' ad hoc networks (Nardi et al. 2002), time, and distance. Interactions occur within groups, among groups, between operators and the ICT systems that are intended to support them, and with the environment in which they operate. Technology evolves on its own path of opportunities based on new conceptions, software, materials, and production processes. The interaction of these elements, or *agent-environment mutuality* (Woods 2000), challenges those who perform research in complex settings to look past a work domain's available (but ultimately superficial) traits in order to discover its deeper, durable aspects. The use of cognitive engineering methods (Woods and Roth 1988) enables the researcher to confront and make sense of what has been referred to as the ''messy details'' of each work domain (Nemeth et al. 2004). Cognitive research using this approach at large scale, among and *across* groups, reveals systemic aspects of work that are unavailable through the study of individuals or a single group.

3 Issues at large scale

This issue's authors have studied a diverse selection of applications and their papers explore the use of NDM methods to reveal how groups of operators have developed ways to perform inter-group work in real world settings. The first two papers examine theoretical issues in coordination at large scale. Johansson and Hollnagel's paper discusses how control at large scale emerges as a product of human interaction. Ritter et al. propose a framework to assist the development of widely distributed systems and teams to support military logistics coordination. The second two papers describe the results of efforts to simulate large scale coordination. Militello et al. account for the successes and shortcomings among ad hoc teams that sought to manage emergency response to natural disasters. Mackenzie et al. explored large scale coordination at international scale, experimenting with complex communications technologies to support expert decision making during an emergency. The final paper by Smith et al. discusses improvements to managing the complex, dynamic US national air transportation system.

Larry Hirshhorn's reflections offer insights into what such work may reveal. Each of the authors presents findings on *work as done*, which is the reality of how workers engage the constraints of their work setting. This diverges from *work as imagined*, which is the notion of what is supposed to be accomplished. The disparity between the two forms a gulf of expectations and accomplishments (Norman 1986) that creates differences in the ways that sharp end operators and blunt end managers view work. This gulf leads to critiques of workers that they are not performing to the *work as imagined* ideal, and efforts to manage them in that direction. However, *work as imagined* floats free from understanding what it takes to deal with the realities of the workplace. This is the reason why a manager needs exposure to *work as done* through activities such as riding along with drivers and spending time on the factory floor. Activities such as these are only short term, though, and are not practical in many enterprises. More thorough, insightful, and substantive research such as the studies that are included in this issue makes *work as done* evident. Making the reality of work apparent shifts the focus away from why workers are inadequate to perform *work as imagined*. It also prevents futile efforts to get workers to perform *work as imagined*. In addition, it makes it possible to devote more effort to develop a closer correlation between the two

Despite the particular details of each application, this issue's authors discovered a number of interactions among people, technology and work (Woods 2000) that were common traits among the organizational settings that they studied. In each instance, initiatives by groups of workers make it possible to perform in challenging and frequently unforgiving settings. Each

of the papers, which are referred to here by their senior author, shows how the theme plays out in the real world from small crisis management centers to national and global networks.

3.1 Short-term goals are nested with long-term goals

In this issue: Focusing on the way that work is distributed reduces the demands on any one person while also introducing longer term safety benefits that are based on built-in redundancies (Smith et al.).

In the forthcoming special issue: The goal of operating room (OR) team stability is nested within longer term goals of equity in the assignment of work and allocation of resources (Xiao et al.). Clearing space to accommodate sicker patients in a patient care unit is nested within the longer term goal of accommodating the demand for care (Wears et al. and Nemeth et al.). Making sense of diagnostic and therapeutic needs ''on the fly'' in a hospital intensive care unit (ICU) is nested within a plan for a course of treatment that serves as a defense against future days, weeks, or months to come (Albolino and Cook)

3.2 Stakeholders interests compete with each other

In this issue: Flight dispatcher focus on safe, timely, cost-effective completion of one flight and its effect on other flights in his airline can conflict with an air traffic manager concern over safely routing traffic flows at a higher level of throughput (Smith et al.). Public information officer need to inform the press conflicted with emergency response core group members focused on resource dispatching (Militello et al.)

In the forthcoming special issue: Competition for limited OR resources results in various departments such as neurosurgery and orthopedics ''bumping'' each other out of scheduled procedures as surgeons perform multiple simultaneous procedures to optimize billing. These require coping efforts such as mediation by the coordinators who are responsible for scheduling, exchange/bargaining, and ingratiation/friendliness (Xiao et al.). Intensive care units and patient wards are responsible for their own patient population, but lack the resources to negotiate patient transfers between services (Nemeth et al.).

3.3 Organizational and professional structures are intertwined

In this issue: A joint cognitive system consists of a social system, technical system, and organizational system that necessarily overlap each other (Johansson and Hollnagel).

In the forthcoming special issue: The needs of individual practitioners such as surgeons to optimize billing rates conflicts with hospital organizational needs to use resources fairly ands efficiently (Xiao et al.). Professionals such as nurses, physicians and pharmacists are also members of functional units such as shifts that minimize interaction in order to reduce complexity (Wears et al.).

3.4 Organizational boundaries impede work by being either too weak or strong

In this issue: Even when it would benefit the organization, constituent groups can fail to communicate if organizational boundaries such as a strong hierarchy impede human abilities to adapt to situations (Johansson and Hollnagel). During crisis management, the core group with the most information and tasking in a crisis can become separated into a ''stovepipe'' that exists apart from others who also have a role in the event (Militello et al.).

In the forthcoming special issue: Emergency department (ED) work teams have shifting, amorphous boundaries that can result in parochial perceptions and interpretations of the organization (Wears et al.). Healthcare workers use cross-checking outside of official roles and responsibilities as a way to build team effectiveness (Patterson et al.). ICT exerts a democratizing influence across work groups that can erode the ability of OR coordinators to structure relationships and assignments (Xiao et al.). Local action by workers outstrips the ability of centralized ICT (e.g., medical records) to share information, which resulted in a failure to integrate crucial healthcare information among medical units (Nyssen).

3.5 Initiatives at the operator level create resilience

Resilience (Hollnagel 2006) is the ability of a system to withstand challenges and return to normal operation with a minimum decrement in performance. Resilience engineering accounts for factors that build or erode the ability of a human-technical system to adapt in a changing environment (Patterson et al., in the forthcoming special issue)

In this issue: During a crisis exercise, offsite experts were able to provide a kind of ''transactive'' memory to assist problem solvers who are preoccupied with making decisions (Mackenzie et al.). Passively sharing information through methods such as voice loops makes it possible to increase the flow of information

among crisis managers without increasing efforts to share it (Militello et al.).

In the forthcoming special issue: When rules no longer suffice, healthcare workers create consensus procedures that make it possible to subtly adjust their responses to meet current and prospective needs (Nemeth et al.). Cross-checking methods such as hand-offs can make processes more evident and detect and correct erroneous assessments and actions, although poor versions can create gaps in care continuity (Patterson et al.).

3.6 Operators collectively cope with complexity

In this issue: The use of ICT enabled experts who are remote from the scene to assist on-site decision-makers (Mackenzie et al.). Operators accommodated inflexible displays by repositioning themselves in a crisis room (Militello et al.). Fragile interlaced ICT systems impeded worker ability to understand and act (Mackenzie et al.). Rather than persons working with tools, ICT systems should instead support persons working jointly, interacting with tools. (Johansson and Hollnagel). ICT systems that reflect human-centered collaboration are most likely to facilitate the kind of interaction among groups that is essential to create and operate logistical systems (Ritter et al.)

In the forthcoming special issue: Operators developed local procedures and sanctions as a defense against unilateral efforts by individuals to manipulate the allocation of resources (Xiao et al.).

4 Conclusion

In order to be a team player (Christoffersen and Woods 2002) in these work settings, ICT must reflect the sophisticated ways that workers have evolved to deal with sometimes daunting constraints. Each of the themes provides insights that can guide the development of ICT to aid groups as they confront the constraints and challenges of daily work.

Procedures, people and technology do interact. Understanding how they interact and what the implications are for future ITC systems flows from research using NDM and CSE methods. Additional inquiry into this rich and challenging field can address questions that include what it means be a team, how IT can aid cognitive work, and how IT can be used to enrich cognitive work within and among groups.

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