Coordinative and Collaborative Behavior for Anomaly Response Teams Supporting Critical Digital Infrastructure: A Summary of Relevant Literature

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INTRODUCTION

Today, software systems support a vast array of tasks across virtually every domain. A large segment of the global economy is dependent on the functionality of these critical digital infrastructure systems, which include online services such as banking, retail, and content streaming. almost all of these digital systems undergo a continuous rollout of software updates, typically overseen by DevOps software (SW) engineers. The continuous nature of patch rollouts introduces a new level of complexity to existing SW packages, and occasionally software failures will occur, causing outages. When these service outages occur, there can be major economic repercussions to the entities involved, as major retailers, international banks, and other corporations depend on this software for the functionality of their service. Organizations can lose significant capital for every minute of downtime. Naturally, this has been documented, and organizations are adapting to promote more resilient software anomaly response teams.

To minimize downtime durations for web-facing servers, SW engineers within DevOps teams are tasked with anomaly response to resolve the failure in the system which caused the circumstance. Anomaly response teams are typically comprised of information technology professionals and software engineers who collaborate to solve service outages under immense time pressure. These SW engineers are acting in a fundamentally different problem space than previously studied areas of complex decision making, and are faced with a time-critical, complex, and uncertain task. The Cognitive Systems Engineering Laboratory at Ohio State University is researching this work domain of Software Resilience Engineering through SNAFUcatchers consortium, a partnership of industry tech leaders and engineers developing the emerging field's toolkits and intellectual backbone. The consortium supports inquiry into how software anomaly response teams cope with the complexity of their tasks and how we can support them better, a mission approached through reviewing postmortems of past incidents.

Within DevOps anomaly response teams, a novel circumstance is their remotely distributed nature. Often, team members will be thousands of miles apart, requiring the introduction of group software tools to coordinate and collaborate in real time.

Although the findings of previous literature concerning group collaboration have some relevance and can be applied to bring to light further questions surrounding team behavior in the face of complex tasks. This literature search and review allows for an examination of previous literature in psychology and organizational science to understand past works regarding team behavior. Significant contributions are found and outlined, concerning topics such as computer-supported collaborative work, team cognition, collective cognition, and distributed mental models. These works provide a basis for further development of cognitive systems engineering ideas as they relate to geographically distributed work teams.

LITERATURE REVIEW

The review largely aimed to provide background information relevant to remotely distributed anomaly response teams performing complex tasks and prompt a discussion in which new connections can be made and applied. The review had multiple goals. The first goal was to determine if the coordinative and collaborative efforts of remote problem-solving teams to solve problems had been documented before, and to what degree. The second goal was to see how previous literature collected information on this phenomena, and which fields the articles were commonly found in. The last goal was to gain a base of knowledge regarding cognition and team-based anomaly response: how remote computer-based communication affected problem solving, cooperative behavior, and how these factors translated into effectiveness or ineffectiveness of respective groups. We also sampled research interested in cognitive and organizational psychology, information technology/systems, and logistics, to help gain a more broad perspective into both the perceived merits of each categorical mode of communication used, as well as the effectiveness of these systems when cognitive assets were distributed in a remote, decentralized fashion.

One key finding was a chapter from the 2004 book, Challenges in Virtual Collaboration: Videoconferencing, Audioconferencing, and Computer-Mediated Communications (Davis and Walnfan, 2004). This work performed a survey of the literature focusing on the effectiveness and individual drawbacks of different modes of computer-based communication, specifically focusing on Face to Face, Videoconferencing, Audioconferencing, and text chat (together called computer-mediated communications). They outlined an effective and predominant group-decision making processes, and noted trends found in other meta-analyses and studies. It was observed that all types of mediated communication limit non-verbal, paraverbal, and status cues, as well as the richness of the information communicated as well. Another finding from this work was that small delays in mediated communication, particularly in videoconferencing, can frustrate participants and seriously disrupt their ability to reach mutual understanding. This review helped us gain very useful and specific knowledge regarding various modes of communication but lacked insight into the cognitive processes driving remote-computerized coordination and problem solving.

To incorporate relevant cognitive and organizational psychology research, we drew from multiple papers focusing on distributed and collective cognition. Distributed cognition was a term found in cognitive psychology research, defined as “an approach which applies classical cognitive science principles, namely that cognition is information processing, to a unit of analysis other than the individual” (Banks and Millward, 2009). Banks and Millward (2009) emphasize the distribution of cognition and group cognitive processes by reviewing previously unconnected literature on mental models and distributed cognition. They then extend the theory to include broader cognitive systems, such as groups collaborating to solve a problem.

Collective cognition, as mentioned previously, was also a focal point of this review. Organizational psychology research denotes collective cognition as the emergent group cognitive processing that exists only when team members work together towards a goal or purpose. A review of 50 years of psychological research on small group and team performance (Kozlowski & Ilgen, 2006) found that a higher level of cognitive processing emerges through dynamic actions among the distributed cognitive processing of multiple individuals. When operating well, this sum of cognitive power of team-based problem solving is greater than the sum of cognitive power of its individual parts (Hung, 2013). Other work considers collective cognition as a cyclical knowledge accumulation and accommodation system and examines methods through which the emergence of this higher-level group

cognition can be optimized. It was noted that in order for teams to effectively solve complex and ill-structured problems, team members must be able to "collectively and systemically reason together as a cognitive system" to solve the problem (Hung, 2013). Notably, it was found that when groups knew what was required to perform a task, worked independently, and valued collectivism, the relationship between group-efficacy and group effectiveness was positive (Gibson, 2001). Further research may be necessary to specifically examine group/collective cognition as a property of remote IT groups and professionals, but for the purpose of this review we wanted to connect the lines between various fields and ideas.

Other relevant psychology work included Team Cognition (Cooke, 2007). This book chapter reviews knowledge elicitation techniques and reviews the inception of modern group cognition research, highlighting the Chernobyl and Three Mile Island accidents and the push for knowledge that resulted from them. The aspects of group cognition from these incidents highlight safety critical, time sensitive decision making, and spawned a wave of research by Klein and others, in the form of "Naturalistic Decision-Making", or NDM (Zsambok, C. E., & Klein, 2014). NDM highlights a more systems level approach to observing and understanding role responsibilities in the face of real-world complexity, rather than a manufactured lab environment.

On a broad scale, we also focused on group planning and task effectiveness with an eye towards how teams used the technology to make decisions. DeSanctis and Jackson (1994) was an important piece of literature surveyed, consisting of a case study of team-based structures and computer-based communications systems. It carefully broke down the Information Technology (IT) systems in place at a company called Texaco. This work also provided insights as to the degree of rigidity of the IT structure itself. "Hybrid forms of management", it claims, are favorable, as they aim for horizontal coordination and direct contact and reporting activities while problem solving. The paper also examines other coordination mechanisms in detail, outlining two distinct ways to enable horizontal coordination (structural designs and process modes).

Research in an educational context was also surveyed: Hewitt and Scardamalia (1998) describe a "Computer Supported Intentional Learning Environment" in which students could communicate, establish, and build using real time software. This was included in the search because of the potential usefulness of a similar software in a task-oriented environment, especially since other literature classifies and elaborates upon the advantages and disadvantages of multiple computer-based communication systems.

CONCLUSION

Although little research exists on the coordinative and collaborative behavior of remotely distributed anomaly response teams, the background outlined in this summary serves to stimulate discussion and facilitate further synthesis of these ideas. Ideally, future research will be performed surrounding the effects of remote team distribution and group software communication on complex anomaly response tasks. From those efforts, we could begin to further understand the implications of remotely distributed versus geographic consolidation in terms of team performance and resilience. Acquiring a deeper understanding of the work performed in this problem space will be fundamental to the conceptualization of an adequate systems-level approach. With that understanding, there is significant potential for the development of integrative software tools to allow Software Resilience Engineers to collaborate in real time and minimize service outage duration through superior anomaly response methodologies in software.

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