Mapping Complexity Sources in Nuclear Power Plant Domains

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ABSTRACT

In modern NPP control rooms personnel will deal with increasing amounts of information and complexity brought about by advanced technologies, such as large digital screens and multiple displays, which can lead to increasing amount of information for operators to deal with. The complexity of advanced technologies may adversely impact operators' task performance and ultimately plant safety. Human performance errors are costly and not acceptable in such safety-critical work environments. Therefore, it is important to understand the sources of complexity, the factors that mitigate complexity, and the effect of complexity on human performance. Armed with this information, guidelines and assessment metrics of complexity can be developed for regulators to assess the safety impact of complexity in new control room design.

This research introduces initial steps in a systematic investigation of sources of complexity in NPP control rooms. First, a general definition of complexity is presented and several perspectives on the concept of complexity are introduced. Next, a systematic approach taken to gather NPP domain information is discussed, and a list of sources of complexity in NPP control room is presented. Lastly the interaction between these sources is discussed. The results will provide a general understanding of complexity in NPP control rooms.

Background: NPP control rooms have many elements in common with other human supervisory control systems, thus it is conceivable that complexities in NPP control rooms may share commonalities with sources in other supervisory control systems. Cummings and Tsonis (2006) proposed a Human Supervisory Control (HSC) complexity chain in an effort to isolate specific categories of complexity sources within HSC socio-technical systems, in particular the air traffic control domain (Figure 1). The HSC complexity chain identifies environmental complexity as the objective state of complexity that exists in the world and cognitive complexity as the complexity perceived by a human operator. To mitigate complexity, organizational policies and procedures along with information representations in the form of interfaces and displays can be introduced into the system. However, the introduction of these mitigations and devices also can add to the overall perceived complexity of the operator.

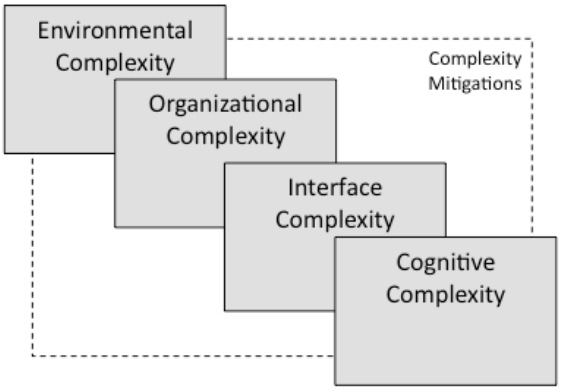

Figure 1. Modified Human Supervisory Control complexity chain, adapted from Cummings and Tsonis, 2006.

Though this complexity model identifies general categories of complexity within HSC systems, it does not specify the sources of complexity within these systems. The following section identifies and discusses sources of complexity, relating each to the context of nuclear power plant control.

Methodology: Identifying sources of complexity in NPP control rooms is an important first step in understanding the effect (both positive and negative) that particular complexity sources have on control room operation and safety. These sources of complexity can be identified through a series of qualitative methods, including interviews with control room operators, control room observations, field studies, ethnographies and cognitive task and work analyses. Our approach focuses on identifying particular sources of complexity within each of the complexity categories described in the HSC complexity chain.

Reviews of previous research in the aviation and process control environments (e.g., Cummings and Tsonis, 2006; Papin, 2002; 2004), as well as initial NPP field observations and operator interviews, led to the initial identification of important sources of complexity in NPP control rooms. Extensive interviews were conducted with personnel in the Massachusetts Institute of Technology (MIT) research reactor in order to gather domain information. Plant operations at several different facilities were observed, including the U.S. Nuclear Regulatory Commission (NRC) Technical Training Center simulator and the New York Independent Systems Operator (NYISO) electricity distribution control room. Additionally, the NRC-maintained Human Event Repository and Analysis (HERA) database and Event Notification

Reports from 1999 to 2010 (NRC, 2010) were parsed for complexity-related operator mistakes and errors. The review of these databases revealed several additional important sources of complexity.

The qualitative analysis of gathered data led to the generation of an initial list of complexity sources in NPP control rooms. Sixty-four sources of complexity within different complexity chain categories were identified. Eight sources within the environmental (e.g. control room size), fifteen organizational (e.g. number of procedures), thirty sources within the interface level (Table 1), and four sources in the cognitive level (e.g. number of years of experience in other control rooms) were identified. It is notable that the majority of sources can be categorized under *quantity* and *variety*, which represent two dimensions of complexity (Xing and Manning, 2005). The third dimension of complexity, interrelationships, is addressed in the next.

Table 1. Sources of interface complexity in NPP control rooms.

Interface Complexity	
• Number of displays • Display size • Information amount • Variety of fonts • Font size • Number of icons • Variety of icons • Variety of colors • Number of alarms • Variety of alarms • Alarm duration • Display resolution • Number of shared control devices • Number of shared displays • Display luminance • Clutter • Text to graphic ratio • Refresh rates	• Real-time update rate • Number of animated display features • Number of required unit conversions • Variety of displays • Number of redundant displays • Number of control devices • Variety of control devices • Number of redundant control devices • Distance between control devices • Distance between displays • Distance between control devices and displays • Distance between controls and their associated displays

We propose that the interconnections between NPP sources of complexity, which are in and of themselves sources of complexity, can be represented and explored via a network representation. The Complexity Source Network (CSN) represents the basic sources of complexity (nodes) within the NPP control room and the interactions that the sources share with one another (connections). These interactions may represent cause and effect or coupling information between the two sources of complexity. Figure 2 shows this network embedded in the categories of the HSC complexity chain. The identification of interactions between the sources is important in order to investigate the overall complexity of the NPP control room environment in a systematic and holistic way, and sheds some light on the nature of coupling between individual sources. Visualizing the sources within the HSC complexity chain helps identify the connections between the complexity categories as well as isolating the sources in different complexity levels. The HERA database analysis, domain expert knowledge and operator interviews were used to identify the possible interconnections. This initial resultant list of interconnections is a large set of pairwise connections, each of which is represented by a connection within the CSN.

Network Analysis: The number of edges a particular node has is related to the relative importance of the complexity source in the control room. Thus, the more edges a node has, the higher chance the source has to impact safe plant operation. For example, in this particular CSN, the node with the greatest number of connections is *Number of Information Sources per Procedure*, with 21 connections to other nodes. Number of information sources during procedural steps may have the highest number of connections because attending to different information sources requires an extensive use of cognitive resources, including searching for the correct checklist, and confirming that each step is correctly executed. By developing strategies to reduce the number of information sources per procedure, we may be able to remove a significant amount of complexity from the NPP control room.

While previous complexity research has focused on identifying sources of complexity, we seek to frame NPP complexity in network systems-theoretic terms. By systematically identifying sources of complexity that have high impact potential, specific tools and mitigation strategies can be developed to ensure safe human performance in both control rooms and other complex supervisory control systems.

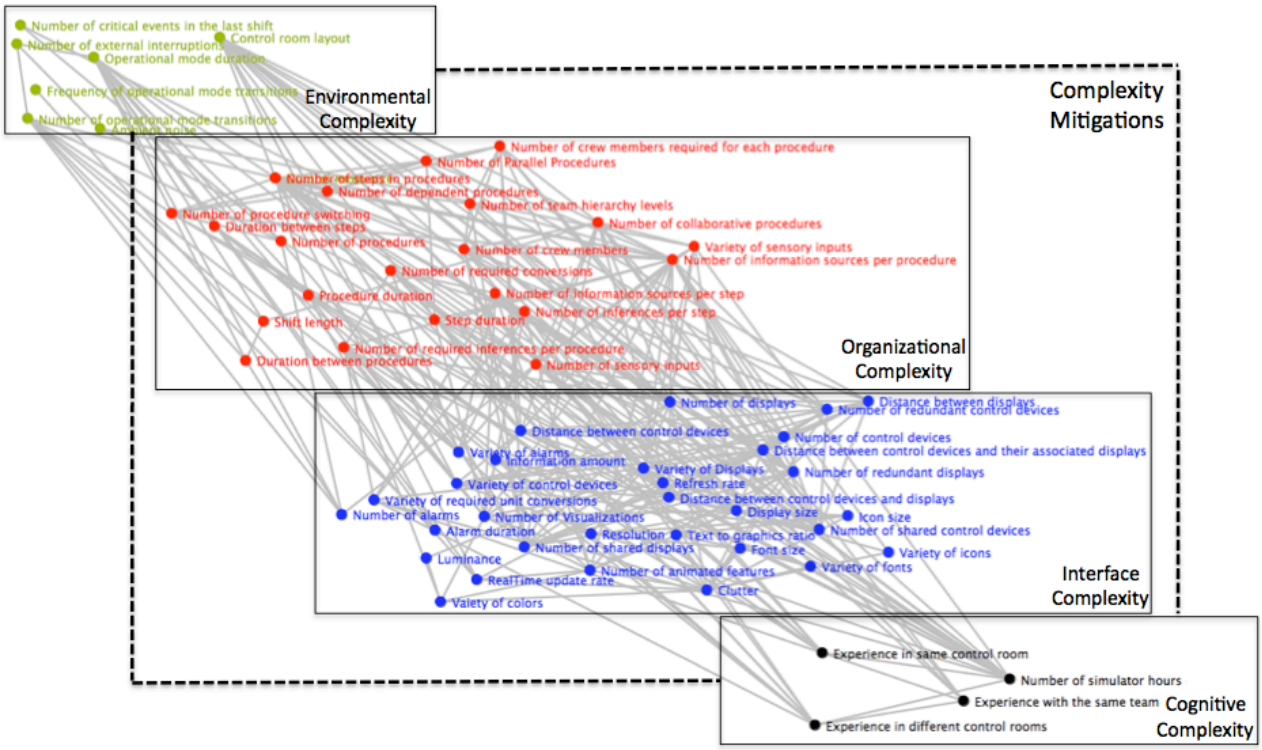

Figure 1. Complexity Source Network grouped by HSC complexity chain categories.

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