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Representing energy efficiency diagnosis strategies in cognitive work analysis

Antony Hilliard*, Greg A. Jamieson

Cognitive Engineering Laboratory, Department of Mechanical & Industrial Engineering, University of Toronto, 5 King's College Rd., Toronto, Ontario, M5S 3G8, Canada

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A B S T R A C T

This article describes challenges encountered in applying Jens Rasmussen's Cognitive Work Analysis (CWA) framework to the practice of energy efficiency Monitoring & Targeting (M&T). Eight theoretic issues encountered in the analysis are described with respect to Rasmussen's work and the modeling solutions we adopted. We grappled with how to usefully apply Work Domain Analysis (WDA) to analyze categories of domains with secondary purposes and no ideal grain of decomposition. This difficulty encouraged us to pursue Control Task (ConTA) and Strategies (StrA) analysis, which are under-explored as bases for interface design. In ConTA we found M&T was best represented by two interlinked work functions; one controlling energy, the other maintaining knowledge representations. From StrA, we identified a popular representation-dependent strategy and inferred information required to diagnose faults in system performance and knowledge representation. This article presents and discusses excerpts from our analysis, and outlines their application to diagnosis support tools.

1. Introduction

Diagnosis tasks are a theme in Rasmussen's research. He first studied diagnosis in electrical equipment (Rasmussen and Jensen, 1973), and subsequently in power plants (Rasmussen, 1983), healthcare (Pedersen and Rasmussen, 1991), and library information retrieval (Rasmussen et al., 1994). Rasmussen's early work at Risø was concerned with safety in the nuclear power industry, and energy remains at the heart of the greatest systemic safety risk of the 21st century: climate change (Stern, 2007).

Systems engineering can contribute to climate change solutions by helping businesses improve energy efficiency, identified by the International Energy Agency (2014) as preferable to increasing energy supply. Monitoring & Targeting energy (M&T) is a well-established efficiency support activity (ASHRAE Guideline Project Committee 14P, 2002; Harris, 1989). However M&T has been difficult for businesses to sustain, for reasons including skill requirements, IT project risk, and credibility demands (Hilliard et al., 2009). Diagnosing energy waste is difficult since it is intangible, uncertain, and only indirectly measurable. Quicker, easier, or more accurate energy efficiency diagnosis would preserve the financial benefits of M&T and encourage more widespread (and reliable) practice.

In this paper, we reflect on eight theoretic and methods issues we encountered applying three phases of Cognitive Work Analysis (CWA) (Rasmussen et al., 1994) to energy M&T with the goal of developing diagnosis support tools. These issues, paraphrased, are how to describe categories of work domains, with secondary purposes, at appropriate decomposition levels; how to describe time-dependent tasks in a goal, situation, and representation-independent way; and how to specify strategies in terms of stable knowledge products at a useful level of detail. We discuss how we

* Corresponding author.
E-mail address: anthill@mie.utoronto.ca (A. Hilliard).

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addressed these issues, and present excerpts from the analysis. Finally, we briefly outline how the CWA effort supported formative design (Vicente, 1999) of a novel statistical strategy for diagnostic search.

2. Principles for applying CWA to design

The most well-developed method to apply CWA, and one of Rasmussen's influential legacies, is Ecological Interface Design (EID) (Vicente and Rasmussen, 1992). Its theoretic principles are to:

- Seek psychologically relevant regularities in the work environment (e.g. functional structure).
- Design unambiguous representations of these useful regularities (e.g. analogies or metaphors).
- Implement interfaces to support thought experiments and active information searches.
- Format interfaces to be easily perceived and manipulated by workers using any cognitive mode of control.

We intended to apply EID principles to the energy M&T domain, but as we investigated we found standard methods (Burns and Hajdukiewicz, 2004) were not well suited to design general-purpose M&T work support tools (Hilliard and Jamieson, 2014a).

3. Domain: energy monitoring & targeting

Energy M&T is a technical and managerial task with the goal of reducing business energy costs (Carbon Trust, 2008; CIPEC, 2010; Harris, 1989). M&T includes detecting, locating, diagnosing, and correcting energy waste, subject to limited time and resources (Hooke et al., 2004). As a simple example, to perform M&T on a car, you would measure energy input (gasoline), then monitor how efficiently the car achieves the owner's transportation goals (distance, perhaps). With this information mechanics might find maintenance problems, operators learn eco-driving skills, or managers decide to replace their car fleet. Few drivers make this effort; M&T is generally-applicable but only practical where energy bills are large enough for efficiency savings to support labor and tool costs.

We studied M&T through participant observation, literature review, and field studies at a chemical manufacturer and a large institution (Hilliard and Jamieson, 2014b). We observed field study participants of different backgrounds (an operations engineer, facilities manager, electrical supervisor, and two consulting analysts) as they used a commercial M&T software package to interpret business gas and electric consumption over eight weeks.

Domains where M&T is practiced (Fig. 1) are usually mixed causal–intentional (Rasmussen et al., 1994, p. 50), making consumption difficult to interpret. While utility supply networks obey conservation laws, businesses consume energy to satisfy intentions, reject disturbances, and economically substitute for labor, time, or control. While sophisticated analyses of energy consumption can be developed, M&T must be social to be effective. Machine-readable data are rarely sufficient to diagnose energy waste, and consumption is affected by every worker's operational and supervisory control decisions. M&T is practiced in diverse, loosely structured systems whose intentional structures change over time. Furthermore, an explicit goal of M&T is to change work domain structure through informing renovations and retrofits. Rapidly-changing domains challenge WDA-based EID methods (Flach et al., 2011, p. 515).

EID was first and most frequently applied to highly-structured domains with strong causal constraints like nuclear power (Vicente, 2002). For semi-intentional systems, Rasmussen suggested that ecological information systems could be based on cognitive strategies (Rasmussen et al., 1994, p. 187). However, this EID alternative was not explored by foundational authors; Vicente (2002) focused on causal systems, and Rasmussen discussed only Pejtersen's "BookHouse" library information retrieval case study (Rasmussen et al., 1994).

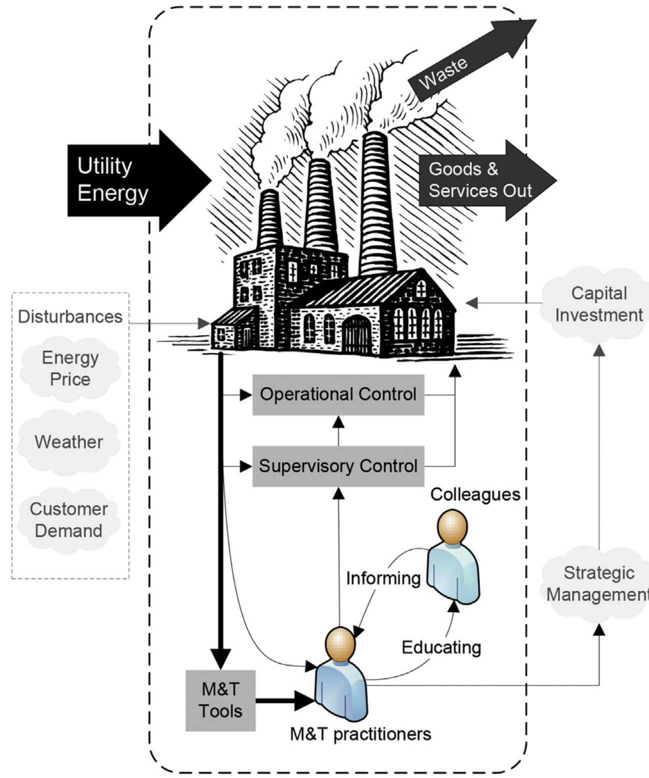

Fig. 1. Conceptual diagram of M&T work system including the work domain (e.g. factory), related control tasks (automated or manual), and workers (e.g. operators, engineers, maintenance staff). M&T work considers outside disturbances and informs operational changes, colleagues' behaviors, and longer-term management decisions.

We pursued this under-developed EID approach. Rather than pre-analyzing specific domain structures and mapping them to human perception (thereby presumably inducing effective strategies) we drew directly from the task and strategy analysis phases of CWA. We will next discuss the three CWA phases we performed a) in terms of Rasmussen's theory and methods legacy, b) as issues we encountered in analyzing the M&T domain, and finally c) as we addressed them in our analysis of M&T work. We conclude with a summary of our design intervention and discussion.

4. Rasmussen's legacy in work domain analysis

Work Domain Analysis (WDA) was originally developed to describe aspects of mental models "of importance for technicians in diagnostic tasks in the control rooms and the workshops of industrial plants" (Rasmussen, 1979, p. 3). Rasmussen derived categories of mental models from terms vocalized in field work (Rasmussen and Jensen, 1973) and scientific models used in engineering. Conducting a WDA involves developing a set of purpose-driven physical and functional system representations. The representations are ordered from the tangible and physical to the abstract and purpose-driven, and linked by structural means-ends and part-whole relationships (Naikar et al., 2005).

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