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The uses of tracking in operations management: Synthesis of a research program

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ABSTRACT

The significance of tracking in operations management has been overshadowed, theoretically by the concept of supply chain visibility, and practically by the attention grabbing radio frequency identification (RFID) technology. This paper describes how uses of tracking for operations management, specifically, to improve the management of project and service supply chains, were explored and developed in a ten-year research program. Key results of the program are synthesized and linked to the relevant academic discourse in operations management using design science methodology.

1. Introduction

The tracking of shipments, materials, and products has been recognized in the operations management literature both as a problem in practice and as a potentially important tool for improving inventory management and operations performance. Davenport and Short (1990) were the first to recognize critical importance of tracking to operations management. Among technological enablers of business process re-engineering, tracking was identified as one of the key tools for linking tasks across functions and organizations. Later studies of ways to improve various aspects of operations management have identified tracking as a practical challenge (Rho and Yu, 1998; Hyer and Brown, 1999; Dennis and Meredith, 2000; Guide, 2000; Guide et al., 2003; Yao and Carlson, 2003; Fleisch and Tellkamp, 2005), and leading industrial companies such as Volkswagen and Boeing have recently begun in earnest to introduce individual product tracking in an effort to improve the performance of their product and service supply chains (Computerweekly, 2009; RFID Journal, 2009).

Despite recognition that tracking is important, it is a topic that only recently has become the explicit focus of operations management research (Kärkkäinen, 2003; Kovács and Paganelli, 2003; Li and Shue, 2003; McFarlane et al., 2003; Otto, 2003; Främling et al., 2007a; Ngai et al., 2007). In the domain of information management, papers dedicated to tracking and its implications date back further. Realistic proposals for applying technological solutions and designs to the tracking of products and deliveries across organizational boundaries first appeared in the 1990s (Bingham and Pezzini, 1990; Janah and Wilder, 1997). More empirically based proposals date from the 2000s (van Dorp, 2002; Ngai and Riggins, 2008; Alfaro and Rábade, 2009).

The most recently proposed designs for tracking solutions have been presented as intelligent products and Internet of things (Meyer et al., 2009). In the context of these recent design proposals, tracking can be defined as the process of naming in a unique way, and linking to, a physical entity relevant information attributes such as handling history and instructions (Rönkkö et al., 2007; Meyer et al., 2009). According to this definition, control and planning tasks associated with such physical entities are not part of tracking, but potential uses of tracking to improve operations management. The function of an Internet of things is to track the individual entities and provide the foundation for more advanced tracking-based services, such as tracing and condition monitoring.

This paper describes how uses of tracking to improve operations management practice were explored and developed over the course of a ten-year research project. Today, with leading software providers and manufacturers developing tracking solutions, tracking is on its way to becoming established among the cadre of technological innovations (PROMISE, 2008).

But despite these developments, no serious attempts have yet been made to understand theoretically the potential implications of tracking for operations management. The significance of using tracking to improve operations management is obscured both by the theoretical concepts of information sharing and visibility (Lee et al., 2000; Gunasekaran and Ngai, 2004; Kulp et al., 2004) and by product identification and data capture technologies (Lindau, 1997; Lindau and Lumsden, 1999; McFarlane and Sheffi, 2003). To such an extent has recent interest in radio frequency

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identification (RFID) overshadowed tracking that the latter is viewed in the operations management literature primarily as a particular application of RFID (for recent overviews of RFID focused research in operations management, Dutta et al., 2007; Ngai et al., 2008). But the implications of tracking for operations management have been shown to be much broader than RFID (Kärkkäinen et al., 2003a; Meyer et al., 2009). Moreover, RFID is only rarely a requirement for tracking (Kärkkäinen, 2005).

This paper finds tracking to be useful in operations management particularly in the areas of project delivery, industrial asset management, and after-sales service delivery. This is because in managerial decision-making involving highly variable customer processes and requirements, information loss can be reduced to a greater extent by making use of tracking information than by relying on standard classifications of products, customers, and events. The findings presented here are a synthesis of the constituent elements of a ten-year research program that progressed from exploratory case studies, through experimentation in real-life settings, to contributions to research and development in large scale integrated projects within the European framework programs.

In the next section, we develop a methodology based on design logic and explore its suitability for studying the uses of tracking in operations management. We elaborate the results of the research program regarding uses of tracking in operations management, and explain, again using design logic, why tracking is useful in the operations management contexts we analyze.

2. Design science methodology

With research into new types of solutions, it takes time for key theoretical concepts to become well defined and problem contexts, solution proposals, and descriptions well structured. As such research is extremely challenging from a methodological point of view, Handfield and Melnyk (1998) recommend using exploratory and descriptive approaches for research topics in the early theory building stage.

One methodological approach that can be used to explore and explain emerging operations management practice is design science (Holmström et al., 2009). The direction of the exploratory research effort that seeks to discover opportunities to make new inventions and innovations is forward looking, that of the explanatory effort to synthesize and elucidate the results of exploratory work backward looking. Denyer et al. (2008) formulated and tested fact-based management theory by systematically combining independently conducted research from different sources. In this paper, we exploit the design science methodology's synthesis of forward- and backward-looking explanatory researches.

In the field of management, design science methodology relies on design propositions. The design propositions used for exploration in Holmström et al. (2009) are termed "means–ends propositions." Means–ends propositions specify the means to reach desired ends in particular situations. In Denyer et al. (2008), the design propositions used to synthesize previous research are termed "CIMO-logic". CIMO-logic specifies the *context (C)* in which certain *interventions (I)* produce, through generative *mechanisms (M)*, intended *outcomes (O)*. Means–ends propositions follow the same structure, save that the generative mechanism is not specified.

Structuring new and interesting means–ends propositions and identifying tentative mechanisms by which they might be made to work in different settings, described by Holmström et al. (2009) as bridging practice and theory, would constitute substantive academic contributions. More specifically, the academic contribution lies in describing how practically relevant means–ends propositions might be expanded into theoretically interesting, and as soon as possible tested, CIMO propositions (van Aken, 2004).

A three-part approach to synthesizing an exploratory research program based on design propositions (Denyer et al., 2008; Holmström et al., 2009) can be summarized as follows.

- *Explore*: Search for promising interventions. Take as the starting point a new technology or type of management intervention. Use a solution-spotting procedure that locks "I" and varies "C" and "O". Consider alternative objectives and shift contexts. Goldenberg et al. (2001) distinguish between two systematic approaches to posing questions that shift interventions, contexts, and outcomes. The first, solution spotting, fixes the intervention and varies contexts and objectives. The second, problem solving, fixes context and objective while searching for interventions. The aim is to find a context in which to pilot, do a practical implementation, conduct small-scale trials, or construct use cases involving potential users.
- *Abduct*: Develop specific means–ends propositions in greater depth and detail by introducing ideas and results from other areas of research as well as from practical trials. Design propositions make it easier to introduce, or abduct, elements from different areas (Klahr and Simon, 1999). Try a problem-solving procedure that locks "C" and "O" and varies "I". Innovation may result from abducting from another domain an "I" that is similar or complementary to the original "I". If an interesting modification can be made to the "I", switch back to exploring. Solution spotting with the new "I" can potentially lead to more interesting and promising "C" and "O" than the ones defined previously.
- *Explain*: Explanation expands the initial proposition into a CIMO proposition. The focus is on identifying mechanisms that might explain how interventions lead to outcomes (Arthur, 2007). In the field of operations management, explanations are mid-range theory, *mid-range* referring to a limited, but defined, domain of applicability (Merton, 1957). Empirical research, analytical models, and simulations are alternative ways of studying mechanisms that explain how interventions (I) lead to outcomes (O). Emphasis of research in operations management is conventionally on explanation, and methodological literature offers much useful advice (Eisenhardt, 1989; Meredith, 1998; Stuart et al., 2002).

This approach does not differ from other design oriented research approaches—action science, action research, action innovation research, participatory action research, participatory case study, academe–industry partnerships, and the like—in its focus on developing a means to an end, or creating an artifact to solve a problem. It does differ, however, in terms of how different components of the CIMO proposition are emphasized and evaluated. Action research often emphasizes the process of finding the right intervention in a context (Argyris et al., 1985). Design science in information systems research emphasizes the intervention and its evaluation (Hevner et al., 2004). The design science approach in operations management is more interested in novel combinations of context, intervention, and outcome than in the novelty and evaluation of interventions (Holmström et al., 2009).

Developing design propositions helps to override the internal logic of different knowledge domains. Design propositions make the use of problem solving, solution spotting, and other search and weak reasoning methods visible (Klahr and Simon,