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In-transit services and hybrid shipment control: The use of smart goods in transportation networks

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ABSTRACT

This paper describes how the incremental introduction of smart goods and tracking-based information management practices enables hybrid shipment control of less-than-truckload (LTL) transport networks and the provision of in-transit services to transport-buying customers. A design theory is developed using interface modeling and discrete event simulation methodology. Interface modeling shows the types of in-transit services that are possible to introduce using smart goods. An empirically grounded simulation demonstrates how transporters can achieve incremental efficiency improvements through hybrid shipment control as customers adopt in-transit services. The results show how in-transit services offered to customers constitutes a platform on which transporters can implement hybrid shipment control, which can substantially reduce resource requirements and the carbon footprint of LTL transportation networks. The design theory articulates a strategy for simultaneously improving customer service and operating efficiency through the introduction of smart goods. The originality and value of the paper is the demonstration of how smart goods can simultaneously benefit transport-buying customers and transporters, thus showing how to overcome the bootstrapping problem of digital infrastructure creation and enabling the vision of a Physical Internet in transportation.

1. Introduction

In a less-than-truckload (LTL) road freight system for general cargo, in which either direct or hub and spoke shipment control is employed, every regional terminal transports goods to and from every other terminal in the system. There is rarely day-to-day operational optimization using capacity planning for, and execution of, long haul transportation between terminals. This is due to time constraints regarding terminal operations and service characteristics such as late deadlines for accepting new orders. To increase efficiency without relaxing the time constraints of transport, operators would need a method that helps them dynamically control shipments in the transportation network. In this paper, we show how the concept of hybrid shipment control (Kalantari, 2012), which dynamically combines direct shipment and hub and spoke, provides a simple smart goods-based (Meyer et al., 2009) approach to increasing transport efficiency and improving customer service without violating tight operational time constraints. The paper addresses the challenge of developing models and algorithms utilizing smart goods for planning and control of operations in transportation networks (Crainic et al., 2009).

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Introducing intelligent transport systems potentially transform the architecture of transportation networks, (Hall, 1995). However, intelligent transport systems have not yet been deployed by transporters to the degree one might expect based on their potential benefits (Baumgartner et al., 2008; Sternberg, 2011). Currently, transporters waste capacity with LTL network-wide efficiencies significantly lower than what would be possible using potential optimization approaches (McKinnon, 2007; Montreuil, 2011). The challenge is a bootstrap problem (Hanseth and Lyytinen, 2010): to become widely deployed, intelligent transport systems must directly meet early users' needs to set the foundation for the expansion required to yield efficiency improvements on the network level. How to improve control over goods flows directly in response to customer requirements while building a foundation for improved transport network utilization is addressed by the in-transit interface and hybrid shipment control proposed in this paper.

We show by means of a discrete event simulation of goods flows based on data from a national LTL transportation network how customers' incremental adoption of in-transit services, such as redirecting and merge-in-transit, yields immediate and significant benefits to transporters. Customer adoption of in-transit services is shown by our analysis to enable transporters to introduce a hybrid control solution that increases fill rate and reduces the size of the truck fleet needed to operate a direct shipment LTL transport network. At the same time, introducing hybrid shipment control that entails combining a direct shipment network and a hub and spoke network increases efficiency without creating congestion at the hub because only marginal flows would have to be routed via the hub. Our simulation of hybrid shipment control of an LTL transportation network shows how network level benefits accrue to transporters as the number of customers adopting different in-transit services of goods delivery increases incrementally, before leveling off at an adoption rate of 50%.

The research contribution of the paper is a design theory (Gregor and Jones, 2007) of how the introduction of smart goods can be used to simultaneously benefit customers and transporters.[3] The practical implication of the research is to provide a foundation for developing strategies for introducing intelligent transport systems that improve customer service and operating efficiency.

The paper first introduces design science methodology before reviewing the literature to establish the context of the problem and the key constructs. A design theory is then developed step by step for the use of smart goods in an LTL transport network based on simulation of outcomes and examination of mechanisms producing observed outcomes.

2. Design science methodology

In the methodology section, we explain how the present study was conducted and briefly describe the design science approach employed.

2.1. Design science

Design science is a methodological approach to exploring and explaining emerging practices in operations management. It is particularly suited to research that develops a theory of design and action (Gregor and Jones, 2007) for employing novel technological means in the management of operations (Holmström et al., 2009).

Two major strands of design science can be found in the literature: an information systems research stream originating with Walls et al. (1992) that is focused on the process of design and evaluation of IS artifacts (Hevner et al., 2004; Gregor and Jones, 2007; Peffers et al., 2007; Sein et al., 2011) and a management stream instituted by Simon (1996) that is focused on the effective use of available means to obtain managerial ends (van Aken, 2004; Romme and Endenburg, 2006; Denyer et al., 2008). The research approach of this paper combines elements from both major strands of design science. From the management side of design science, we deploy design logic (Denyer et al., 2008) to specify the context in which certain interventions produce, through generative mechanisms, intended outcomes. Design logic is used to formulate means-ends propositions for using smart goods as in-transit interfaces between customers and transporters in a transportation network. From the IS side of design science, we adopt the recommended structure for design theory, specifying purpose and scope, key constructs, form and function, outcome examples (i.e., expository instantiations), mutability, principles of implementation, justificatory knowledge, and testable propositions. The design theory structure is used in the paper to report the results of design logic development, interface modeling (Odell et al., 2001), and discrete event simulation (Banks, 1998) of less-than-truckload operations in a real-world transportation network.

The design science approach is adopted for studying the use of intelligent transportation systems to provide in-transit services to customers and hybrid shipment control to transporters. We develop design propositions from the distinct perspectives of customer and transporter, specifying both intervention and desired outcome for each actor, and thereby increasing the likelihood of congruent technological frames (Orlikowski and Gash, 1994) for these key actors.

We develop interface models using UML (Odell et al., 2001) to conceptually describe how, as an in-transit interface between customer and transporter, the shipment supports its own differentiated handling (Wegner, 1997). The interface model describes how different uses can be implemented with the same object-oriented control approaches based on the infrastructure for interacting with and handling smart goods. The analytical evaluation using discrete event simulation illustrates how transporters can improve efficiency through hybrid shipment control as customers adopt in-transit services. Simulation

[3] See end of each section for the design theory elements introduced. Table 7 in the concluding chapter summarizes the design theory.