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A control model for object virtualization in supply chain management

C.N. Verdouw [a,b,*], A.J.M. Beulens [b], H.A. Reijers [c,d], J.G.A.J. van der Vorst [b]

[a] LEI Wageningen UR, P.O. Box 29703, 2502 LS The Hague, The Netherlands
[b] Logistics, Decision and Information Sciences, Wageningen University, P.O. Box 8130, 6700 EW Wageningen, The Netherlands
[c] Department of Computer Science, VU University, Amsterdam, The Netherlands
[d] Department of Mathematics and Computer Science, Eindhoven University of Technology, The Netherlands

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ABSTRACT

Due to the emergence of the Internet of Things, supply chain control can increasingly be based on virtual objects instead of on the direct observation of physical objects. Object virtualization allows the decoupling of control activities from the handling and observing of physical products and resources. Moreover, virtual objects can be enriched with information that goes beyond human observation. This will allow for more advanced control capabilities, e.g. concerning tracking and tracing, quality monitoring and supply chain (re)planning. This paper proposes a control model for object virtualization in supply chain management, which is based on a multiple case study in the Dutch floriculture. It includes a typology of distinct mechanisms for object virtualization, which discerns reference objects and future projections next to the representation of real physical objects. The control model helps to define feasible redesign options for the virtualization of supply chain control. It is also of value as a basis to define the requirements for information systems that enable these redesign options.

1. Introduction

Virtual supply chains are often advocated as an agile alternative to static pipelines that efficiently push products to the marketplace, e.g. [1–3]. A key driver of virtual supply chains is the virtualization of products and resources as enabled by new information and communication technologies. In virtual supply chains, the control and coordination of supply chain processes are based on virtual objects instead of on the direct observation of physical objects. This allows for the decoupling of physical flows and information aspects of supply chain operations [4,5].

Virtualization has been an important topic in research already for a long time. Traditional research streams particularly focus on virtual machines, e.g. [6], virtual reality, e.g. [7], virtual organizations, e.g. [8], and virtual teams, e.g. [9]. Another perspective is the virtualization of physical objects as digital representations, which is addressed especially by the literature on Product Information Management including Product Lifecycle Management and Intelligent Products, e.g. [10–14]. This perspective has recently received much interest, specifically due to the emergence of the Internet of Things (IoT) concept. In the IoT, physical entities have digital counterparts and virtual representations; things themselves become context-aware and, as a result, they can sense, communicate, interact, and exchange data, information and knowledge [15]. As such, virtualization goes beyond simulation of objects, because virtual objects are used dynamically in the operational control of a company, which assumes a tight integration with operational information systems.

The introduction of virtual objects as a central means for planning, orchestration, and coordination has the potential to revolutionize supply chain management (SCM). Virtualization removes fundamental constraints concerning place, time, and human observation. As a consequence, SCM would no longer require physical proximity, such that the actors responsible for control and coordination are not necessarily also the ones handling and observing the physical objects. This allows for them to be at totally different locations. Moreover, virtual objects do not only represent actual states, but can also reproduce historical states and simulate future states. A final interesting angle is that virtual objects can be enriched with sensor data about object properties that cannot be observed (or not accurately) by the human senses, e.g. temperature information or X-rays. The representation of these data in virtual objects enhances its fitness for use, which allows for

* Corresponding author at: LEI Wageningen UR, P.O. Box 29703, 2502 LS The Hague, The Netherlands. Tel.: +31 317 4 84752; fax: +31 70 3615624.
E-mail address: Cor.Verdouw@wur.nl (C.N. Verdouw).

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advanced control capabilities, including tracking and tracing, quality monitoring and (re)planning functionalities.

In the context of SCM, the objects are transferred between many different partners from primary production to the market. As a result, virtual objects are composed of information from different companies and need to provide multiple views for different organizations. All of these have distinct purposes for their usage, which may cover applications in the complete supply chain, including stock control and replenishment, production planning & control, product design, transport control, logistic planning & scheduling, quality inspection, asset management and commercial applications [16,17].

At this point, however, the research on how virtualization of physical objects can impact supply chain control is still in its infancy. It can be noticed that the available SCM literature on virtual supply chains takes no account of object virtualization, but it mainly considers virtualization from an organizational perspective. Cases in point form the work by Chandrashekar and Schary [1], Ho et al. [18], Gunasekaran and Ngai [19] and Manthou et al. [20]. On the other hand, there are many papers in the product information management and IoT literature that present examples or discuss opportunities for supply chain applications, e.g. [10,11,15,21–23]. However, virtualization is not the main topic in most of these papers. The underlying mechanisms of how the virtualization of physical objects impacts supply chain control remain rather implicit. Moreover, related product information management and IoT literature seem to focus on the representation of real objects. From other research fields, in particular from the Virtual Reality domain, we can infer that also *imaginary objects* and *future representations* are relevant.

This paper proposes a control model, i.e. a systematic classification of concepts for modeling the virtualization of control in a supply chain context. The model builds on the concept of virtual objects as addressed before by the Product Information Management and IoT literature. Its novelty especially lies in our explicit identification and definition of the distinct mechanisms behind object virtualization as to make an impact on supply chain control. The objectives of the control model are threefold. First, it should help to define feasible redesign options for decoupling the handling and observing of physical objects from the control activities based on virtual objects. Second, the control model will be defined as an information model, which can be used as a basis to define the requirements for information systems that enable the aforementioned redesign options. As such, it will contribute to the switch from control systems that rely on their own, often tacit, object information to control systems that rely on explicit virtual objects. The latter are automatically derived from the information of external observers. A final objective of the paper is to assess the value of the control model for SCM. For that purpose, the control model will be based on case studies of virtualization practices in horticultural supply chains. The horticulture is an instructive sector because it is characterized by a high variety and volatility of supply chain processes. These characteristics impose great demands on the diversity and dynamics of virtualizations.

In the remainder of this paper, we first give an account of the applied research method in Section 2. Subsequently, Section 3 introduces the theoretical background and presents a generic control model for supply chain virtualization. Section 4 summarizes the mapping of the studied cases. Section 5 describes the main results of this paper. It defines the distinct mechanisms for object virtualization that are applied in the mapped cases and elaborates the control model accordingly. Next, Section 6 describes how the control model is applied to the cases. The paper concludes by summarizing the main findings, discussing the specifics of our main contributions, and addressing future challenges.

2. Methodology

The research reported upon in this paper is based on a design-oriented methodology, which is increasingly applied to management sciences, inspired by Simon [24]. Design-oriented research focuses on building purposeful artifacts that address heretofore unsolved problems and which are evaluated with respect to the utility provided in solving those problems [25,26].

The design artifact developed in the present paper is a control model, i.e. a systematic classification of concepts for modeling the virtualization of control in a supply chain context. A control model represents the control functions needed to ensure that a system's objectives are achieved, even if disturbances occur (see Section 3.2). One of these control functions is a decision-making function, which decides on specific control actions based on a decision-making model. The majority of the literature on supply chain modeling focusses on the development of such, mostly quantitative, decision-making models [27]. The virtualization of control does not affect the decision-making models, but it in particular influences the interactions between the control functions of a control model. For this reason, our control model concentrates on the definition of control functions and information flows among these functions. The designed control model is defined as an information model. Information models provide systematic representations (visualizations, descriptions) of software architectures from different viewpoints and at various levels of abstraction. As such, they support different stages of software engineering: requirements definition, design specification and implementation description. The control model of the present paper can be used as a basis for the requirements definition phase.

Design-oriented research is typically involved with 'how' questions, i.e. how to solve a certain problem by the construction of a new artifact [28,29]. A case study strategy usually fits best for this type of questions, because artifacts intended for real-life problems are influenced by many factors [29]. Case studies can deal with such complex phenomena, which cannot be studied outside their rich, real-world context [30–32].

The present research has conducted an extracting multiple case-study, which is a type of best practice research that aims at uncovering technological rules as already used in practice [29]. For the purposes of this paper, the cases should reflect the diversity and dynamics of virtualizations in a supply chain context, i.e. a heterogeneous selection based on theoretical replication logic [30,32]. For that reason, we have chosen to focus on the Dutch floriculture. After all, in this sector trade relations change frequently, product quality is variable because flowers and plants are living products, product variety is high, products are distributed via diverse marketing channels, and demand is volatile. Furthermore, the availability of virtualization practices was expected to be high, because the Dutch floriculture is working actively on the virtualization of its supply chains [5].

The case study was carried out as part of the DaVinc^{3}i project in close interaction with the involved business partners, which represent the majority of the Dutch sector, including auction, traders, growers and industry associations, [33] [www.davinc3i.com]. The selection of the cases is based on an investigation of virtualization practices as reported in Verdouw et al. [5], who identified in total 34 of these. For the present paper this list was updated with eight additional practices by consulting the industry partners of the Da Vinc3i project. The identified practices include technologies that are preconditions for virtualization of supply chains, such as identification codes, object sensing technologies, and standards for data exchange. The paper at hand has focused on practices that are directly related to virtualization applications. Specifically, we have chosen to focus on Business-to-Business applications. The practices in this domain can be classified into