Decision Support Systems 56 (2013) 288–299

Contents lists available at ScienceDirect

Decision Support Systems

journal homepage: www.elsevier.com/locate/dss

Formal correctness of supply chain design

Joerg Leukel [a], Vijayan Sugumaran [b,c,*]

[a] Department of Information Systems 2, University of Hohenheim, Schwerzstr. 35, 70599 Stuttgart, Germany
[b] School of Business Administration, Oakland University, 306 Elliott Hall, Rochester, MI 48309, USA
[c] Department of Global Service Management, Sogang Business School, Sogang University, Seoul 121-742, Republic of Korea

ARTICLE INFO

Article history:
Received 1 May 2012
Received in revised form 25 October 2012
Accepted 13 June 2013
Available online 20 June 2013

Keywords:
Supply chain management
Supply chain design
Model verification
SCOR

ABSTRACT

Many companies use supply chain models for designing the flow of goods and services from their suppliers all the way up to the final customers. Over the past 15 years, the Supply Chain Operations Reference Model (SCOR) has become a widespread modeling technique for designing such supply chains and sharing design information with supply chain stakeholders. However, neither the syntax nor the semantics of SCOR are well defined. This limitation has important consequences for its usage: Supply chain models may be ambiguous and their correctness cannot be verified. We address this problem by mapping SCOR supply chains onto graphs and formalize the semantics of SCOR. The mapping is driven by constructs from the supply chain management literature. The proposed artifact is a supply chain grammar, which we apply to a set of SCOR models taken from industry sources. We show the grammar's usefulness by verifying the correctness of these models using analytical techniques.

1. Introduction

Supply chain design is a critical business problem. For many industries, supply chains have become an important focus for competitive advantage. With the increasing global division of labor, the performance of a single company depends more and more on its ability to maintain effective and efficient relationships with its suppliers and customers. Thus, managerial decisions are moving from an organizational scale to a supply chain scale [20]. Supply chain design is the task of determining the basic, long-term structure of the supply chain by defining its elements, objectives, locations, and key organizations [37]. The role of Information Systems (IS) to support this task has recently been the subject of inquiry.

In general, supply chain design faces two difficulties. First, the design space contains a vast number of alternatives, which makes it hard for designers to evaluate and select the best alternative. Second, designing a supply chain incorporates stakeholders from the supply and demand side, which requires sharing and understanding design information by various parties. These two difficulties can be mitigated through reference models that: (1) restrict the design space by providing core constructs that can be configured under certain design constraints, and (2) define a common terminology for sharing designs across organizations. Supply chain management (SCM) has adopted this idea in the form of the *Supply Chain Operations Reference Model* (SCOR) [34,35]. Over the past 15 years, SCOR has become a widespread modeling technique for supply chain design. It is promoted by a stellar group of firms from various industries and can be regarded as a best practice. Research has made use of SCOR for designing both descriptive and analytical methods for various supply chain problems, in particular, performance management [23,41], configuration [32], and market-based balancing of demand and supply [27].

The main disadvantage of SCOR is that neither its syntax nor its semantics is well defined. A formal specification of SCOR in the form of a grammar does not exist. The modeling technique is only described in a handbook [36], which provides a reference to model elements with simple example models that don't provide much explanation. The lack of well-defined syntax and semantics has severe consequences. If SCOR users interpret the informal description of the technique in different ways, the supply chain models built using SCOR will become ambiguous and potentially error-prone. This practice may result in syntactically incorrect models that cannot be used by any third party. Software vendors who provide SCOR modeling tools are in danger of implementing the technique incorrectly. Ultimately, the two objectives of reducing the design space and enabling cross-organizational information sharing cannot be met.

Incorrect supply chain models affect the managerial use of these models. We briefly discuss the problems resulting from incorrect models by referring to the three use case of the SCOR technique [36]:

— *Supply chain description* aims at providing an unambiguous description of an actual or planned supply chain for parties that are interested or involved in this supply chain. Incorrect design manifests in configuring the constructs of the SCOR technique falsely,

* Corresponding author at: School of Business Administration, Oakland University, 306 Elliott Hall, Rochester, MI 48309, USA. Tel.: +1 248 370 2831; fax: +1 248 370 4275.
E-mail addresses: joerg.leukel@uni-hohenheim.de (J. Leukel), sugumara@oakland.edu (V. Sugumaran).

0167-9236/$ – see front matter
http://dx.doi.org/10.1016/j.dss.2013.06.008

for example, invalid linkage of constructs or missing constructs. If these deficits cannot be detected and repaired, the description is only understandable by the designer and the individuals that share the designer's interpretation. Hence, the model is limited to a small group and does not extend to all the supply chain stakeholders.

— *Supply chain measurement* is concerned with measuring the performance of connected activities and the entire supply chain. For this purpose, the technique provides a standard set of metrics (e.g. cycle time, cost, flexibility) and standard formulae for analyses, which rely on correct models as outlined in the supply chain description. For incorrect models, the aggregation process would yield either incorrect or no results. Hence, the supply chain performance cannot be correctly measured.
— *Supply chain evaluation* is the task of assessing different designs and selecting the best configuration with regard to certain criteria. These criteria include metrics as defined by the SCOR technique. Evaluation is an iterative process of design (i.e., creating alternative models) and metrics-based measurement. If the measurement yields incorrect or no result for at least one model, then the evaluation will also become incorrect (by comparing configurations that differ due to the interpretation of the technique) or incomplete and not feasible (due to missing data).

Adding a formal specification to SCOR is non-trivial, unless we are able to get this information from SCOR's inventors or at least articulate their interpretation explicitly. However, SCOR was invented by a dynamic group of individuals who worked over a long period in a more or less informal organization. Hence, it is difficult to elicit this information from this group. What we need is a grammar that consists of a lexicon for supply chain design and a finite set of rules that specify allowable combinations of lexicon elements. There are two basic approaches for defining this grammar: deduction and induction. Grammar deduction defines lexicon and rules by analyzing relevant theories and axioms. Grammar induction learns lexicon and rules from a set of observations — here, the SCOR supply chain models. The latter's precision, however, is negatively affected by the share of incorrect models in the set of observations.

Current solutions fall into the category of grammar deduction. However, no research endeavor has yet used the existing body of knowledge from SCM research for deduction. Instead, the main source of deduction is the informal description of SCOR, which is then interpreted by the respective researcher. The disadvantage of these approaches is that the deduction is not made explicit to allow for reproducibility.

We address the problem of the lack of explicit definition of SCOR by mapping SCOR supply chains onto directed graphs and formalizing the syntax and semantics. The mapping is a deduction process supported by the constructs from the SCM literature. These constructs enable us to enrich SCOR with additional constraints that have a strong theoretical underpinning. Thus, the objectives of this research are to: (1) develop the syntax and semantics of SCOR in the form of a supply chain grammar that allows for assessing the correctness of supply chain design, and (2) apply this artifact to a set of SCOR models to demonstrate its usefulness for model verification. The contributions of this research are the formal specification (grammar) of SCOR and analysis techniques for SCOR-based supply chain design.

The remainder of this paper is organized as follows. In Section 2, we briefly introduce the SCOR technique and provide preliminary notions that will be used for enrichment by grammar deduction. In Section 3, we discuss the approaches to the correctness of supply chain design and compare our work with the relevant literature. In Section 4, we derive specific constraints on supply chain design from the SCM literature and provide the grammar. In Section 5, we demonstrate the usefulness of our proposed grammar in verifying the correctness of SCOR models taken from industry sources. Section 6 concludes the paper and outlines some of our future work.

2. Preliminaries

2.1. SCOR technique

SCOR consists of an intuitive graphical supply chain description language and a set of supply chain metrics that can be associated with supply chain activities. The graphical language is targeted for the business audience, who uses this language for effective communication of supply chain structures at different levels of abstraction. At the strategic level, SCOR provides a modeling technique for primary product flows; the resulting model is called a *SCOR thread diagram*. The designer can then add details to these diagrams by incorporating plan processes (information flow), secondary product flows (return of products to the supplier), and describing more fine-grained activities associated with the primary product flow, e.g., receiving orders, packaging, and routing shipments. These activities can be configured from a reference set of several hundred so called process elements. In the following, we consider only primary product flows, since this level represents the strategic configuration of supply chains.

A thread diagram shows the flow of products (including tangible goods and services) as a chain of linked activities. An example diagram is shown in Fig. 1. The technique provides the following elements:

— *Process* is an activity of either sourcing, manufacturing, or delivering a product (symbol: arrow-shaped rectangle). The symbols can have different colors to signify the type of activity; however, the color scheme is not precisely defined in the SCOR technique.
— *Product flow* represents the transfer of a product from one process to another (symbol: arrow).

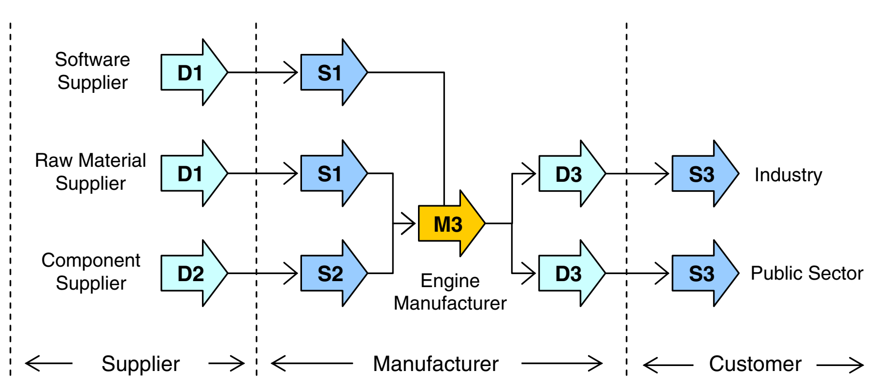

Fig. 1. Example SCOR thread diagram.