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Quantitative models for sustainable supply chain management: Developments and directions

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ABSTRACT

Sustainability, the consideration of environmental factors and social aspects, in supply chain management (SCM) has become a highly relevant topic for researchers and practitioners. The application of operations research methods and related models, i.e. formal modeling, for closed-loop SCM and reverse logistics has been effectively reviewed in previously published research. This situation is in contrast to the understanding and review of mathematical models that focus on environmental or social factors in forward supply chains (SC), which has seen less investigation. To evaluate developments and directions of this research area, this paper provides a content analysis of 134 carefully identified papers on quantitative, formal models that address sustainability aspects in the forward SC. It was found that a preponderance of the publications and models appeared in a limited set of six journals, and most were analytically based with a focus on multiple criteria decision making. The tools most often used comprise the analytical hierarchy process or its close relative, the analytical network process, as well as life cycle analysis. Conclusions are drawn showing that numerous possibilities and insights can be gained from expanding the types of tools and factors considered in formal modeling efforts.

1. Introduction

The integration of environmental and social aspects with economic considerations, known as the triple-bottom-line (TBL) dimensions of organizational sustainability (Elkington, 1998, 2004), has continuously gained relevance for managerial decision making in general and for supply chain management (SCM) (Carter & Rogers, 2008) and operations management (Drake & Spinler, 2013; Kleindorfer, Singhal, & van Wassenhove, 2005) in particular.

Organizations have rethought and redefined the concept of operations management using the supply chain (SC) perspective through the incorporation of upstream (input) and downstream partners (output) into the boundary of investigation and management (Bettley & Burnley, 2008). Traditionally, SCM has been defined as the management of physical, logical, and financial flows in networks of intra- and inter-organizational relationships jointly adding value and achieving customer satisfaction (Mentzer et al., 2001; Stock & Boyer, 2009). From a process-oriented or cross-functional perspective, SCM comprises planning, sourcing, production, and distribution logistics (Supply-Chain Council, 2008) but is not exclusively focused on one of these areas (Cooper, Lambert, & Pagh, 1997).

In contrast to traditional SCM, which typically focuses on economic and financial business performance, sustainable SCM (SSCM) is characterized by explicit integration of environmental or social objectives which extend the economic dimension to the TBL (Seuring & Müller, 2008a). In this context, SSCM focuses on the forward SC only (Seuring & Müller, 2008a) and is complemented by closed-loop SCM (CLSCM) (Guide & van Wassenhove, 2009; Lebreton, 2007) including reverse logistics, remanufacturing, and product recovery.

The increasing importance of this field, academically, socially, and economically, is reflected by the geometric growth of related scientific publications during the past two decades and especially so in the past decade (Min & Kim, 2012; Seuring & Müller, 2008a). In addition to a large variety of empirical research papers that utilize field research, case study, and broad-based empirical surveys, numerous publications employ formal, mathematical models for practice and theory-driven research. Models are a simplified representation or abstraction of reality, and related research differentiates between conceptual models defined as a set of concepts suitable to represent but not explain real-life objects or processes and quantitative models that are based on a set of variables and their causal relationship (Bertrand & Fransoo, 2002; Meredith, 1993).

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For CLSCM, quantitative models are often applied and practical (Fleischmann et al., 1997; Srivastava, 2007; Sasikumar & Kannan, 2008a, 2008b, 2009). In contrast to this circumstance, the majority of models employed for SSCM are more conceptual. Only about one out of nine papers on SSCM utilizes formal models (Seuring & Müller, 2008a). In recent years, the quantity of formal modeling efforts has started to increase.

It is evident from literature that (reverse-oriented) CLSCM models are more popular (Ilgin & Gupta, 2010; Min & Kim, 2012), but a significant number of (forward) SSCM models do exist (Hassini, Surti, & Searcy, 2012; Min & Kim, 2012; Seuring & Müller, 2008a; and Seuring, 2012), many of which are quite recent in development. A comprehensive review of these models is not currently available and thus it is timely to take an 'inventory' of the research. The lack of a comprehensive understanding of modeling-based SSCM research is surprising since the non-sustainability modeling field has a well-developed traditional research focus on forward SCM. It may be that research focusing on CLSCM has caused many modeling researchers to overlook this forward SCM field in context to sustainability.

To help further catalyze research in this area, which has numerous opportunities to improve organizational, industrial, and commercial sustainability, further understanding of the common and unique modeling characteristics is needed. Some SSCM reviews currently exist, but most of these reviews are descriptive (e.g. Carter & Rogers, 2008; Fleischmann et al., 1997; Seuring & Müller, 2008a). Although somewhat descriptive, this paper provides additional insightful discussion, analyzing a number of important field advancing questions as discussed below.

Which aspects and factors are considered in existing quantitative SSCM models? What are the limits of these models and what issues remain? What feasible and fruitful opportunities for further research exist? To help understand the history and direction of SSCM modeling efforts and to answer these questions, this paper presents a content analysis (Krippendorff, 1980; Mayring, 2002, 2008) of related literature to assess recent developments and future directions of quantitative, formal modeling in the SSCM context. The rich descriptions offered and the overall lines of research identified this way, often have tremendous impact on future research. Therefore, we also discuss overarching lines of research as well as gaps and future research directions.

The remainder of this paper is structured as follows. In the next section, a brief overview of related literature reviews on SSCM is given. The subsequent section describes the methodology applied in this paper and is followed by a representation of the results obtained by the content analysis. Remarks comprising the summarized findings and a related discussion, limitations, and future research perspectives conclude this paper.

2. Insights from previous literature reviews

To justify the need for the content analysis presented in this paper and to position its results to extant scientific research, former reviews of scientific literature on SSCM are summarized. Existing literature reviews on SSCM can be categorized into reviews published prior to 2008 and recent reviews published within the last five years. The purpose of this background on previous literature reviews is to help derive relevant information and structures for this study. The background literature also helps to identify open issues in model-based SSCM research. These recent reviews are assessed with regards to **SCM perspectives**, e.g. level and actor of analysis, **sustainability**, i.e. the dimensions of the TBL, and **research designs**.

2.1. Literature reviews prior to 2008

The earliest related literature reviews (Gungor & Gupta, 1999; Kleindorfer et al., 2005) identify green product and process development, green operations management, remanufacturing, and CLSCM as areas to integrate planet- and people-related issues into SCM, but the reviews do not include social aspects of SSCM. Bloemhof-Ruwaard, van Beek, Hordijk, and van Wassenhove (1995) focused on operations research (OR) applications in the context of environmental management (EM) and suggest a conceptual SC-EM-framework. Daniel, Diakoulaki, and Pappis (1997) apply this framework in their survey of OR-related environmental planning and categorize related OR methods into descriptive approaches for observation and analysis and normative methods for solution identification. ReVelle (2000) provides an overview on the application of OR methods for the management of water resources, solid waste, and air quality and outlines different normative models for these areas. Sbihi and Eglese (2007) focused specifically on combinatorial optimization problems in green logistics, which comprises reverse logistics, waste management, and vehicle routing and scheduling. While these early published reviews paved the way for SSCM research, they are not able to inform on current developments and future trends of related model-based research.

2.2. Literature reviews after 2008

Recent reviews of SSCM literature can be categorized as either general or focused on empirical research or quantitative models and metrics. Table 1 overviews 14 recent reviews regarding their research focus and characteristics, such as time horizon, number of reviewed papers, main journals, employment of keyword search and content analysis as well as taken perspectives on SCM and sustainability.

In contrast to reverse logistics or remanufacturing, OR methodologies and analytic approaches for forward SSCM play a subordinate role in the published research (Ilgin & Gupta, 2010; Min & Kim, 2012). As shown in Table 2, approximately only one out of ten SSCM papers employs a research method which is based on quantitative models using formal OR modeling techniques.

With regards to the **SCM perspective**, extant research shows that sustainability is often externally motivated by government, customers, or stakeholders (Gold, Seuring, & Beske, 2010a, 2010b; Seuring & Müller, 2008a). The literature also shows that a vertical coordination and a SC-wide implementation are required (Carter & Rogers, 2008). In contrast to this focus, empirical research on SSCM mainly focuses on single firms and neglects inter-organizational aspects (Carter & Easton, 2011). This conflict leads to the question of whether model-based research takes into account the intercompany perspective and if the role and influence of legal authorities or other stakeholders is adequately reflected in quantitative SSCM models. Furthermore, Hassini et al. (2012) show that sustainability metrics are most often designed for manufacturing firms. Hence it should be assessed which SC sectors are in the focus of model-based SSCM research.

Holistic approaches of SSCM that reflect all three **sustainability dimensions** are relatively rare in the academic literature (Seuring & Müller, 2008a). However, empirical research shows the growing relevance of multiple sustainability dimensions (Carter & Easton, 2011). Given that SSCM can positively influence a firm's profitability, performance, and competitive advantage (Carter & Rogers, 2008; Gold et al., 2010b; Golicic & Smith, 2013), SSCM research tends to focus primarily on environmental issues (Seuring & Müller, 2008a), while social facets are widely neglected in empirical (Gold et al., 2010a) and in analytical SSCM modeling research