Int. J. Production Economics 137 (2012) 176–189

Contents lists available at SciVerse ScienceDirect

Int. J. Production Economics

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

A framework for designing robust food supply chains ☆

Jelena V. Vlajic *, Jack G.A.J. van der Vorst, René Haijema

Operations Research and Logistics Group, Wageningen University, Hollandseweg 1, 6706 KN Wageningen, The Netherlands

ARTICLE INFO

Available online 1 December 2011

Keywords:
Disturbances
Vulnerability sources
Preventive redesign strategies
Reductive redesign strategies
Supply chain performances
Supply chain vulnerability

ABSTRACT

After years of emphasis on leanness and responsiveness businesses are now experiencing their vulnerability to supply chain disturbances. Although more literature is appearing on this subject, there is a need for an integrated framework to support the analysis and design of robust food supply chains. In this paper we present such a framework. We define the concept of robustness and classify supply chain disturbances, sources of food supply chain vulnerability, and adequate redesign principles and strategies to achieve robust supply chain performances. To test and illustrate its applicability, the research framework is applied to a meat supply chain.

1. Introduction

Today's business environment has become an international playing field in which companies have to excel in logistics performance, i.e. markets require full responsiveness, high quality products and high reliability of supply in small time windows at the lowest cost. As a consequence, supply chains have eliminated most non-value adding activities and have become leaner. However, lean supply chains without much inventory are more vulnerable to disturbances in logistic processes, which mean that they might be less consistent in their performance, i.e. are less *robust* (cf. Kleindorfer and Saad, 2005; Dong, 2006). Consequently, the competitive power of vulnerable supply chains in the market may diminish. In practice, in recent years there have been reported many events that have led to disturbances in supply chains processes (e.g. supplier failures caused by natural disasters or fires in the warehouses, delivery delays due to traffic accidents, product recalls due to lack of fulfilment of quality or safety requirements, etc.). Because of that, there is increasing interest by practitioners and academics to reduce supply chain vulnerability and design robust supply chains. This holds especially for food supply chains as these chains have specific characteristics that increase its vulnerability, such as seasonality in supply and demand and a limited shelf-life of products.

In supply chain management theory, robustness and vulnerability are perceived as opposite though not mature concepts (Asbjørnslett and Rausand, 1999; Wagner and Bode, 2006). As a term, *robustness* has a broad meaning and it is often couched in different settings (Qiang et al., 2009). However, despite its frequent use, there is no general, widely accepted definition (Vlajic et al., 2010).

In a supply chain literature robustness is mainly considered as the ability of the system to continue to function well in the event of a disruption (Dong, 2006; Tang, 2006a; Waters, 2007) i.e. an unexpected event that severely impacts performance. Here, three points get attention. First, if the system functions well depends on what is measured and how it is measured and it varies from application to application (Snyder, 2003). Second, robustness of the supply chain could be jeopardized by various kinds of unexpected events: accidental events (e.g. a fire in the facility, a machine failure, flood or a traffic accident), and events that result from or belong to the systems characteristics (e.g. poor communication or decision making processes). Third, consequences of unexpected events could be measured at process or at system's (company or supply chain) level and the severity depends on system's design. The severity of the consequences determine the level of supply chain robustness, or it is opposite—supply chain vulnerability. In this paper we focus on (process) disturbances, i.e. any consequences of unexpected events at the process level and their impact to the robustness of the supply chain performance.

A literature review on supply chain robustness (Vlajic et al., 2010) shows that there is a lack of an integral framework that guides companies in managing disturbances and designing robust supply chains. With this paper, we aim to contribute to supply chain management theory by developing such an integrated framework for the design of robust (food) supply chains. To develop this framework we have conducted an extended literature review, participated in a number of workshops and conducted several interviews with field experts to get insight into practical issues in

☆ Paper selected from presentations at the 14th International Symposium on Logistics 'Global Supply Chains and Inter-Firm Networks', Istanbul, Turkey, July 5–8, 2009. The selection process has been managed by Dr Robert J. Mason, Cardiff University Business School, Cardiff CF10 3EU, United Kingdom, masonrj@cf.ac.uk.

* Corresponding author. Tel.: +31 317 485644; fax: +31 317 485646.
E-mail addresses: jelena.vlajic@wur.nl (J.V. Vlajic),
Jack.vanderVorst@wur.nl (J.G.A.J. van der Vorst),
Rene.Haijema@wur.nl (R. Haijema).

0925-5273/$ - see front matter © 2011 Elsevier B.V. All rights reserved.
doi:10.1016/j.ijpe.2011.11.026

food industry relevant for the framework. To test it, we applied it to a case in the meat supply chain, as one of the main chains in food industry. The data collection is based on observations, historical data and semi-structured interviews.

This paper is organized as follows. Section 2 discusses what supply chain robustness is. Section 3 presents the framework for designing robust food supply chains, and here we focus on the following elements: supply chain disturbances, sources of vulnerability and redesign strategies. Section 4 presents the application of the research framework in the case study. We conclude the paper with a discussion and issues for further research.

2. What is supply chain robustness?

The term robustness can be defined in many ways, depending on the specific context and research area (see Jen, 2005; Bundschuh et al., 2006; Qiang et al., 2009). In the supply chain management literature, robustness is considered both at a qualitative conceptual level and at a quantitative modeling level (Vlajic et al., 2010).

At *qualitative conceptual level*, robustness is considered as an important property of supply chains or as a strategy that can be used to improve supply chain resilience. In both cases, robustness is related mainly to supply chain vulnerability and uncertainty in general, and vulnerability is seen as consequence of various disruptions (Tang, 2006a). One of the first papers that considered robustness, resilience and vulnerability is the paper of Asbjørnslett and Rausand (1999). They introduced robustness and resilience as concepts that are opposite of the vulnerability concept. They define different kinds of disruptions that affect the business performances of a production system. Asbjørnslett (2009) continued this work in the context of supply chains. According to him, a *robust* system (supply chain) has the ability to resist disruptions, retaining its system structure intact, whilst a *resilient* system is adaptable, i.e. it will adapt to regain a new stable position. This approach to robustness is used also by Ferdows (1997) in the context of network robustness. Considering uncertainty in the global business environment, Ferdows (1997) made a relation between robustness and security and introduced the term "robust network" (Table 1). In this definition, extreme measures imply a change in supply chain structure. Following the same line of thoughts, some authors associated supply chain robustness with its ability to keep its structure fixed (intact) in all situations including disruptions (e.g. see work of Kleijnen, 2005; Dong, 2006; Bundschuh et al., 2006; Chandra and Grabis, 2007; Dong and Chen, 2007; Viswanadham and Gaonkar, 2008). In these papers, the definitions of robustness imply that supply chains are robust if their structure is not changed and that supply chain robustness could be jeopardized only by disruptions. Moreover, dependent on the specific supply chain design various kinds of unexpected events could jeopardize the supply chain robustness, i.e. make supply chain vulnerable. Examples of various definitions on supply chain robustness are presented in Table 1.

Table 1
Some definitions of robustness in the supply chain context.

Definitions of robustness:	*Authors*
The ability of a network to cope with changes in the competitive environment without resorting to changes in the network structure.	Ferdows (1997)
The system's ability to resist an accidental event and return to do its intended mission and retain the same stable situation as it had before the accidental event.	Asbjørnslett and Rausand (1999)
The ability of a supply chain design to find a supply chain configuration that provides robust and attractive performance while considering many sources of uncertainty.	Mo and Harrison (2005)
The ability of supply chain to maintain a given level of output after a failure.	Bundschuh et al. (2006)
The supply chains ability to withstand external and internal shocks.	Chandra and Grabis (2007)
The ability of a supply chain network to carry out its functions despite some damage done to it, such as the removal of some of the nodes and/or links in a network.	Dong (2006) Dong and Chen (2007)

At *quantitative modeling level*, robustness is mainly used in a context of modeling solutions or models for various problems in supply chains – such as planning (e.g. Zapfel, 1998; Van Landeghem and Vanmaele, 2002; Goetschalckx and Fleischmann, 2005; Leung et al., 2007), scheduling (e.g. Kutanoglu and Wu, 2004; Adhitya et al., 2007), network design (e.g. Snyder, 2003; Bundschuh et al., 2006; Mo and Harrison, 2005; Meepetchdee and Shah, 2007), inventory management (e.g. Tee and Rossetti, 2002; Ouyang, 2007), etc. Today, the term robustness as a measure is used a lot in Operations Research literature – especially in stochastic programming (e.g. see work of Goetschalckx and Fleischmann, 2005; Mo and Harrison, 2005) and robust optimization (e.g. see work of Mulvey et al., 1995; Snyder, 2003; Wu, 2006; Leung et al., 2007). The precise formulation of robustness depends on the particular technique used or type of the problem that is modeled. For instance, in robust optimization the modeling solution is defined as robust if it performs well for all scenarios of input data (Snyder, 2003), and a model is defined as robust if it remains "almost feasible" for all data scenarios (Mulvey et al., 1995). The definition of "performing well" varies from application to application and choosing an appropriate measure of robustness is part of the modeling process (Snyder, 2003). Despite an abundance of literature in the context of model and solution robustness, little work has focused on measuring supply chain's robustness, i.e. the ability of a supply chain to cope with unexpected events (Dong and Chen, 2007; Qiang et al., 2009).

2.1. Definition of robustness

In our view, supply chain robustness is a *desired property of a supply chain that is reflected in supply chain performances*. That is extremely important because today's business environment is characterized by increasing requirements toward robust performances (e.g. demands for reliable supply and higher product quality levels within smaller delivery time windows). According to Waters (2007, p. 159), a traditional way in business specifies an acceptable range for specifications, and the performance is considered acceptable if it stays within this range. We define supply chain robustness as *the degree to which a supply chain shows an acceptable performance in (each of) its Key Performance Indicators (KPIs) during and after an unexpected event that caused disturbances in one or more logistics processes.* To operationalize this definition, a supply chain is robust with respect to a KPI if the value of that KPI, adequately measured over an observation period, is sustained in a predefined desired range, even in the presence of disturbances. We call this predefined desired range the *Robustness Range*, and it is characterized by a lower and/or upper level. If a KPI performs above or below the robustness range, the supply chain is considered vulnerable. The stronger and longer the negative impact to performances is, the more vulnerable supply chain is to that disturbance.

3. Research framework

Now that we have defined supply chain robustness, this section discusses our research framework for designing robust