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Optimal integration of third-parties in a coordinated supply chain management environment

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ABSTRACT

A generic tactical model is developed considering third party price policies for the optimization of coordinated and centralized multi-product Supply Chains (SCs). To allow a more realistic assessment of these policies in each marketing situation, different price approximation models to estimate these policies are proposed, which are based on the demand elasticity theory, and result in different model implementations (LP, NLP, and MINLP). The consequences of using the proposed models on the SCs coordination, regarding not only their practical impact on the tactical decisions, but also the additional mathematical difficulties to be solved, are verified through a case study in which the coordination of a production–distribution SC and its energy generation SC is analyzed. The results show how the selection of the price approximation model affects the tactical decisions. The average price approximation leads to the worst decisions with a significant difference in the real total cost in comparison with the best piecewise approximation.

1. Introduction

A Supply Chain (SC) is constituted by a set of echelons: suppliers, storage facilities, production plants, distribution centers, and markets (retailers), which are located in different geographic sites, linked together through distribution systems, and interacting with third parties. When all these echelons belong to one single organization, the SC may be managed in a "centralized" way, and some coordination is necessary to harmonize the resources flow among these echelons, and their third parties. Supply Chain Management (SCM) aims to optimize the performance of a SC (e.g., its financial revenues), establishing how and when: the resources flow between echelons, raw materials should be transformed into intermediate/final products, and finally the final products should be distributed to customers.

In recent years, the competitiveness among global SCs has grown resulting in new challenges in the area of Process System Engineering (PSE) which include an enhanced management of the chemical supply chain. In this sense, the European Petrochemical Association (EPCA) as well as the European Chemicals Industry Council (CEFIC) have suggested that improving SCM at all levels will increase business competitiveness (McKinnon, 2004). Among the SCM developments that have been proposed to reduce the SC cost and to increase profitability are: the effective distribution of resources over the SC network (Shah, 2005), collaboration and coordination between SCs considering all participants enterprises (Hjaila et al., 2015a,b), integrating marketing and financial issues (Laínez et al., 2007, 2010), Sustainability (Pérez-Fortes et al., 2012), and incorporation of demand management and corporate financial decisions (Shapiro, 2004; Grossmann, 2005; Laínez et al., 2012).

These issues can be addressed at different hierarchical decision levels, through designing the SC (Laínez et al., 2009), providing an improved master plan (Amaro and Barbosa-Póvoa, 2009; Cao et al., 2013; Zeballos et al., 2014; Zamarripa et al., 2014; Hjaila et al., 2014, 2015a), and/or controlling the involved operations (Guillén et al., 2006; Sung and Maravelias, 2007; Shah and Ierapetritou, 2012), as will be discussed later.

Abbreviations: CEFIC, European Chemicals Industry Council; CPU, Central Processing Unit; DC, Distribution Center; EPCA, European Petrochemical Association; GAMS, The General Algebraic Modeling System; GB, Gigabyte; GHz, Gigahertz; LP, Linear Programming; MIP, Mixed Integer Programming; MILP, Mixed Integer Linear Programming; MINLP, Mixed Integer Non-Linear Programming; NLP, Non-Linear Programming; PSE, Process System Engineering; RM, Raw Material; SC, Supply Chain; SCM, Supply Chain Management; SCs, Supply Chains; SCsCo, Supply Chains Coordination.

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Nomenclature

Indexes

E	echelon
R	resource (raw material, product, energy, cash, . . .)
T	time period

Sets

dc	distribution center
e	echelon
m	external markets (final consumers)
pl	production plant
r	resources (raw materials, products, steam. . .)
s	external suppliers
t	time periods

Parameters

$dist_{r,e}$	travel distance of resource r at echelon e
$dmd_{r,e,e',t}$	external demand of resource r in echelon e' (final consumer) at time t
$PE_{r,e',t,n}$	price elasticity of demand or resource r in echelon e' at time t in price zone n
$prf_{r,r',e}$	production factor: quantity of resource r required to produce resource r' in echelon e
$PRD^{min}_{e,t}$	minimum production capacity in echelon e, time t
$PRD^{max}_{e,t}$	maximum production capacity of echelon e, time t
$PL_{r,e',t,n}$	max price at piecewise price zone n, time t
$QL_{r,e',t,n}$	resource r limit in price zone n at echelon e (external supplier), time t
$rp_{r,e',t}$	unitary retail price of resource r at echelon e' (final consumer), time t
$ST^{min}_{e,t}$	minimum storage capacity at echelon e, time t
$ST^{max}_{e,t}$	maximum storage capacity at echelon e, time t
$ust_{r,e}$	unit storage cost of resource r at echelon e
$uprd_{r,e}$	unit production cost of resource r at echelon e
$utr_{r,e}$	unit transport cost of resource r at echelon e
$x_{a,r}$	factor depends on the polynomial grade a of resource r

Variables

$COST$	total cost of the centralized SC
$COST_e$	cost of echelon e
CPR_e	production cost at echelon e
CRM_e	cost of the externally supplied resources at echelon e
CST_e	storage cost at echelon e
CTR_e	transport cost at echelon e
$D_{r,e,e',t}$	amount of resource r delivered from echelon e to echelon e' (final market) at time t
$Dmi_{r',e,t}$	internal demand of resource r' at echelon e, time t
$PN_{r,e',t,n}$	elastic price of resource r at echelon e (external supplier) in price zone n, time t
$P_{r,e',t}$	price of resource r at echelon e (external supplier), time t
$prod_{r,e,t}$	production levels of resource r in echelon e, time t
$PROF$	aggregated profit of the global SC network
$QE_{r,e',e,t}$	resource r from third party echelon e' to each echelon e, time t
$Q_{r,e',t}$	total resource r from third party e', time t
$QN_{r,e',t,n}$	resource r purchased from 3rd party e' in price zone n, time t
$QR_{r,e,t}$	resource r flows between entities at echelon e, time t
$ST_{r,e,t}$	storage levels of resource r at echelon e, time t
$SALE_e$	economic sales (income) of echelon e

Binary Variables

$y_{r,e,t,n}$	binary variable of price piece n of resource r at echelon e (external supplier), *time t*

This work makes a specific emphasis on the tactical decision-making level of centralized SCs. More specifically, we focus on efficient SCs Coordination (SCsCo) that deals with all echelons (i.e., supplier's echelons, production echelons) as full SCs, taking into account the decisions of the third parties which becomes a challenging problem as enterprises seek competitive performance.

SCsCo has been studied from different perspectives; one of the more appealing approaches intends to integrate different hierarchical SCM decision-making levels within a single SC model. For instance, Laínez et al. (2009) integrate the strategic and tactical levels within a single flexible model, representing the manufacturing process recipe, and considering all possible feasible links and material flows. Several ways to address this management integration problem at the lower levels of the decision-making hierarchy have been proposed, as in the work by Guillén et al. (2006), where an enterprise budgeting approach following a cash flow formulation for a multi-product SC is proposed. Sung and Maravelias (2007) develop an integration approach for multiproduct process networks, where the operational model is solved off-line to obtain convex approximation functions of the production costs and production levels. Shah and Ierapetritou (2012) extend the single site formulation proposed by Li and Ierapetritou (2010) for multi-site multi-product multi-purpose batch plants. But neither these works, nor any other work addressing the integration between the different SC hierarchical levels, consider the coordination among different echelons (with their respective SCs) of a global SC structure at the same level (i.e., tactical level) taking into consideration the main objectives of all these participating echelons/SCs, including the decisions related to third parties.

The need of effective SCsCo also appears when several SCs with different policies/objectives work together, such as the case of closed-loop SCs, where the coordination between forward and reverse flows is required on one side, and between their respective SCs and the third parties on the other side. In closed-loop SCM, this coordination should be introduced into the model formulation by considering the recovery processes and the reuse of the final products, where the final demand is satisfied by both new and remanufactured products. In this way, Amaro and Barbosa-Póvoa (2009) develop a closed-loop tactical model considering that the retail price and demand of final products are uncertain; however, the final product price is considered as uncertain parameter independently from the quantity demanded along the planning time horizon. The closed-loop formulations are also applied to SCM integration models, such as in Zeballos et al. (2014), who propose an integrated strategic and tactical multi-period multi-product closed-loop model for a 10-layer SC network (forward and reverse flows). Notwithstanding, the aforementioned closed-loop models aim to optimize the global objective resulting from the coordination between the direct and reverse flows, disregarding the individual objectives of the participating echelons SCs and their third parties, which may lead to inadequate decision-making.

The coexistence and coordination of different individual objectives have been analyzed using approaches based on Game Theory, such as in the work of Hjaila et al. (2015a), who represent the individual objectives as non-cooperative non-zero-sum Stackelberg game considering the risk associated with the uncertain nature