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Tactical management for coordinated supply chains

Miguel Zamarripa, Kefah Hjaila, Javier Silvente, Antonio Espuña*

Chemical Engineering Department, Universitat Politècnica de Catalunya, ETSEIB, Diagonal Avenue 647, 08028 Barcelona, Spain

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This work is dedicated to the memory of Mrs. Ektimal Qadom (Hjaila).

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ABSTRACT

Current supply chain (SC) optimization models deal with material and information flows along few echelons of the SC ("own SC"), minimizing the role of the complex behavior of third parties (raw materials and utilities suppliers, clients, waste and recovery systems, etc.) in the decision-making process of this SC of interest. Third parties are just represented by simplified parameters (capacity, cost, etc.) usually considered constant, but the decisions based on this picture are not adequate when the third parties' behavior is significantly affected by these decisions or other circumstances, especially when global coordination is attained. In this work, the role of these third parties, which might face different objectives, has been integrated and a solution based on the full SC management problem is proposed. This results on a generic model which may be used to optimize the planning decisions of the multi-product multi-site SC of interest (production/distribution echelons), taking into account the production vs. demand coherence among this SC and the third parties. The features of the proposed model are illustrated using a case study which considers the coordination of a series of resource (energy) generation SCs linked to a production/distribution SC ("SC of interest"). The results show how the behavior of the considered SCs determines the best planning decisions of each organization, which will depend on the way used to coordinated them (e.g. toward less total or individual costs), adding to the PSE science a new point of view which allows all involved organizations to share responsibilities in the system.

1. Introduction

Current changes in the way to run business around the world open the door for new issues to be considered in the Supply Chain Management (SCM) models and procedures, including environmental considerations, new market trends, decision making under uncertainty, and market globalization. Typical SCM approaches consider single SC material flow information to improve the decision making (DM) process at the strategic, tactical, and/or operational DM levels, and their capacity to deal with these new issues depends not only on the possibility to incorporate new information and models associated to the internal organization (i.e. environmental assessment information, financial models, etc.), but also on the ability to correlate current and new working information with the behavior of the SC working scenario (i.e. price negotiation, demand elasticity, etc.).

Regarding strategic decision making, multiple approaches have been published considering several potential suppliers, production plants, and distribution centers to serve some fixed markets. Higher complexity scenarios, like the resulting from the consideration of flexible operation among the SC network, with multiple retailers and distribution centers serving others under uncertain market demands, have been also successfully addressed (Shu, Teo, & Shen, 2005).

On the tactical DM level, Tsiakis and Papageorgiou (2008) provided optimal product site allocation among sites with outsourcing availability for multi-product multi-site networks. Furthermore, Susarla and Karimi (2012) presented a mixed integer linear programming (MILP) model to find the optimal procurement, production, and distribution levels for a large scale multi-site multi-product network (multinational pharmaceutical SC with 34 entities producing 9 different products).

Operational applications, including single stage facilities for multiproduct, multi-task and batch processes, have been also covered (Castro & Grossmann, 2012; Castro, Erdirik-Dogan, & Grossmann, 2008). In addition, multi stage facilities have been considered by Prasad and Maravelias (2008).

Nevertheless, in order to deal with the problem of managing a competitive SC facing a global market, the coordination of its echelons (acquisition of raw material, production sites, warehouses, and markets) with their supporting external SCs is needed at the planning level, and formulations including multiple SCs coordination are weakly dealt up today, especially if a detailed production–storage–distribution plan is to be established.

* Corresponding author. Tel.: +34 93401 1732.
E-mail address: antonio.espuna@upc.edu (A. Espuña).

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Nomenclature

Indexes

e	echelon (distribution center, market, production plant, . . .)
r	consumable resource (raw material, product, energy, steam, cash, . . .)
s	supply chain
t	time period

Sets

E	echelons (distribution centers, markets, production plants, . . .)
M	external markets (final consumers)
M_s	external markets for SC s
N	raw material suppliers
N_s	raw material suppliers for SC s
R	consumable resources (raw materials, products, steam, . . .)
S	supply chains
T	time periods

Parameters

$\mathrm{dis}_{e,e'}$	distance between echelon e and echelon e'
$\mathrm{dmd}_{r,e,t}$	external demand of resource r in echelon e (final consumer) at time t
$\mathrm{prd}^{\max}_{r,e,t}$	maximum delivering capacity of resource r at echelon e (plant/supplier) at time t
$\mathrm{prd}^{\min}_{r,e,t}$	minimum delivering capacity for resource r at echelon e (plant/supplier) at time t
$\mathrm{prf}_{r,r',e}$	production factor: quantity of resource r required to produce resource r' in echelon e
$\mathrm{st0}_{r,e}$	initial storage level of resource r in echelon e
$\mathrm{sto}^{\max}_{r,e,t}$	maximum storage capacity in echelon e for resource r at time t
$\mathrm{sto}^{\min}_{r,e,t}$	maximum storage capacity (safety stock) in echelon e for resource r at time t
$\mathrm{val}_{r,e,t}$	unitary cost value of resource r at echelon e, time t
$\mathrm{vpr}_{r,e,t}$	unitary production cost value to produce resource r from its raw materials at echelon e, time t
$\mathrm{vpy}_{r,e,t}$	unitary penalty cost for extra-delivery of resource r at echelon e (market) at time t
$\mathrm{vst}_{r,e,t}$	unitary storage cost of resource r at echelon e at time t
$\mathrm{vtr}_{r,e,e'}$	unitary transport cost for resource r from echelon e to echelon e'

Variables

COS	total cost
CPR_t	production cost
CRM_t	cost of the externally supplied resources
CST_t	storage cost
CTR_t	transport cost
$\mathrm{DLV}_{r,e,e',t}$	amount of resource r delivered from echelon e to echelon e' at time t
PFT	aggregated profit of the entire system
$\mathrm{PRD}_{r,e,t}$	production levels of resource r in echelon (plant) e at time t
SAL	economic incomes (sales value)
$\mathrm{STO}_{r,e,t}$	storage level of resource r in echelon e (or its associated warehouse) at time t

In this sense, after an extensive Process Systems Engineering (PSE) literature review, three main issues have been identified which, even they have been object of interest of the scientific community in the last years, still require specific attention:

(i) *Multiple Objective Optimization*: the consideration of multiple objectives regarding market, social, and other external or internal issues currently justify introducing new elements related to environmental and risk regimes as part of the SCM objectives together with the economic performance. The need to consider the resulting trade-offs among those different objectives changes the way to deal with the decision making problem (Bojarski, Laínez, Espuña, & Puigjaner, 2009; Dugardin, Yalaoui, & Amodeo, 2010; Guillén-Gosálbez & Grossmann, 2010; Guillén-Gosálbez, Mele, Bagajewicz, Espuna, & Puigjaner, 2005; Lin, Fowler, & Pfund, 2013; Nagurney, Cruz, Dong, & Zhang, 2005; Park & Shin, 2012), but the specific incorporation of third parties' objectives in the DM procedure should be analyzed in depth.

(ii) *Uncertainty Management*: one basic characteristic of the SC planning problem is the presence of uncertainty coercing the "here and now" decision making. This uncertainty may affect the expectations about the raw materials supply and/or the market behavior (demand, prices, delivery requirements, etc.), as well as other internal elements (i.e. operating parameters like lead times, transport times, etc., or the availability of production resources). A literature review on this topic reveals that most of the systematic tools currently available to manage decision making under uncertainty have been proposed to address the SC planning problem. In this line, it is worth to mention the use of Model Predictive Control (Bose & Penky, 2000), Multi-Parametric Programming (Dua, Dua, & Pistikopoulos, 2009; Wellons & Reklaitis, 1989), Fuzzy Linear Programming (Peidro, Mula, Jiménez, & Botella, 2010) and specially Stochastic Programming (Amaro & Barbosa-Póvoa, 2009; Baghalian, Rezapour, & Farahani, 2013; Gupta & Maranas, 2003; Haitham, Mohamed, Imad, & Adel, 2004; Klibi & Martel, 2012; You & Grossmann, 2010). If the effects of the uncertainty can be minimized through the management of a reduced number of variables, the use of simulation-optimization based approaches may constitute a practical way to circumvent the complexity of the above mentioned mathematical formulations of the problem, as proposed by Jung, Blau, Pekny, Reklaitis, and Eversdyk (2004) to determine the required safety stock levels to maintain client satisfaction when facing some expected uncertain demand behavior. Nevertheless, uncertainty is not always associated to the effect of random events (white noise), since it might also reflect the difficulties to incorporate already existing information and models in the problem formulation (e.g. information related to consumers/suppliers behavior), so in these cases the costs, effort and potential benefits of integrating this information in the decision making model should be analyzed.

(iii) *Coordinated Management*: this term has been widely used in the literature as related to different management problems, since its scope has not been clearly limited. For example, in the marketing literature, some interesting applications show coordination schemes related to pricing decisions taking into consideration deterministic and uncertain demands. This is the case of the work of Xiangtong, Bard, and Yu (2004), who solved the tactical management of one-supplier one retailer SC with uncertain demands in the model formulation. Two specific SC coordination management problems are worth to be mentioned at this point:

(a) The most widely studied topic in the area of coordinated management is focused to vertical integration. The