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A novel rolling horizon strategy for the strategic planning of supply chains. Application to the sugar cane industry of Argentina

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ABSTRACT

In this article, we propose a new method to reduce the computational burden of strategic supply chain (SC) planning models that provide decision support for public policy makers. The method is based on a rolling horizon strategy where some of the integer variables in the mixed-integer programming model are treated as continuous. By comparing with rigorous solutions, we show that the strategy works efficiently. We illustrate the capabilities of the approach presented by its application to a SC design problem related to the sugar cane industry in Argentina. The case study involves determining the number and type of production and storage facilities to be built in each region of the country so that the ethanol and sugar demand is fulfilled and the economic performance is maximized.

1. Introduction

Supply chain management (SCM) has recently gained wider interest in both, academia and industry, given its potential to increase the benefits through an efficient coordination of the operations of supply, manufacturing and distribution carried out in a network (Naraharisetti, Adhitya, Karimi, & Srinivasan, 2009; Puigjaner & Guillén-Gosálbez, 2008). In the context of process systems engineering (PSE), these activities are the focus of the emerging area known as Enterprise Wide Optimization (EWO), which as opposed to SCM, places more emphasis on the manufacturing stage (Grossmann, 2005).

The SCM problem may be considered at different levels depending on the strategic, tactical, and operational variables involved in the decision-making process (Fox, Barbuceanu, & Teigen, 2000). The strategic level is based on those decisions that have a long-lasting effect on the firm. These include, among many others, the SC design problem, which addresses the optimal configuration of an entire SC network. The tactical level encompasses long- to medium-term management decisions, which are typically updated a few times every year, and include overall purchasing and production decisions, inventory policies, and transport strategies. Finally, the operational level refers to day-to-day decisions such as scheduling, lead-time quotations, routing, and lorry loading (Guillén-Gosálbez, Espuña, & Puigjaner, 2006).

In the recent past the SCM tools developed in these hierarchical levels have primarily focused on maximizing the economic performance in the private sector. By contrast, the academic literature on SCM applications for public policy makers is still quite scarce (see Preuss, 2009). The use of SCM tools in the latter area is very promising, since they can provide valuable insight into how to satisfy the population's needs in an efficient manner, thus guiding government authorities towards the adoption of the best technological alternatives to be promoted and eventually established in a given country.

The goal of this paper is to provide a general modeling framework and a solution strategy for SC design problems, with focus on the strategic level of SCM, and with special emphasis on applications found in the public sector. Particularly, given a set of available production, storage and transportation technologies that can be adopted in different regions of a country, the goal of the analysis performed is to determine the optimal SC configuration, including the type of technologies selected, the capacity expansions over time, and their optimal location, along with the associated planning decisions that maximize a given economic criterion. In this work, such a design task is formulated in mathematical terms as a mixed-integer programming problem with a specific structure that includes integer and binary variables of different nature. To

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Nomenclature

Indices

i	materials
g	sub-region zones
l	transportation modes
p	manufacturing technologies
s	storage technologies
t	time periods

Sets

$IL(l)$	set of materials that can be transported via transportation mode l
$IM(p)$	set of main products for each technology p
$IS(s)$	set of materials that can be stored via storage technology s
$LI(i)$	set of transportation modes l that can transport material i
SEP	set of products that can be sold
$SI(i)$	set of storage technologies that can store materials i

Parameters

α^{PL}_{pgt}	fixed investment coefficient for technology p
α^{S}_{sgt}	fixed investment coefficient for storage technology s
β	storage period
β^{PL}_{pgt}	variable investment coefficient for technology p
β^{S}_{sgt}	variable investment coefficient for storage technology s
ρ_{pi}	material balance coefficient of material i in technology p
τ	minimum desired percentage of the available installed capacity
φ	tax rate
avl_l	availability of transportation mode l
$CapCrop_{gt}$	total capacity of sugar cane plantations in sub-region g in time t
DW_{lt}	driver wage
$EL_{gg'}$	distance between g and g'
$\overline{FCI}$	upper limit for capital investment
FE_l	fuel consumption of transport mode l
FP_{lt}	fuel price
GE_{lt}	general expenses of transportation mode l
LT_{ig}	landfill tax
ME_l	maintenance expenses of transportation mode l
$\overline{PCap_p}$	maximum capacity of technology p
$\underline{PCap_p}$	minimum capacity of technology p
$\overline{PR_{igt}}$	prices of final products
$\overline{Q_l}$	maximum capacity of transportation mode l
$\underline{Q_l}$	minimum capacity of transportation mode l
$\overline{SCap_s}$	maximum capacity of technology p
$\underline{SCap_s}$	minimum capacity of storage technology s
$\overline{SD_{igt}}$	actual demand of product i in sub-region g in time t
SP_l	average speed of transportation mode l
sv	salvage value
T	number of time intervals
$TCap_l$	capacity of transportation mode l
TMC_{lt}	cost of establishing transportation mode l in period t
UPC_{ipgt}	unit production cost
USC_{isgt}	unit storage cost

Variables

CF_t	cash flow in time t
DC_t	disposal cost in time t
DTS_{igt}	delivered amount of material i in sub-region g in period t
FC_t	fuel cost
FCI	fixed capital investment
FOC_t	facility operating cost in time t
$FTDC_t$	fraction of the total depreciable capital in time t
GC_t	general cost
LC_t	labor cost
MC_t	maintenance cost
NE_t	net earnings in time t
NP_{pgt}	number of installed plants with technology p in sub-region g in time t
NPV	net present value of SC
NS_{sgt}	number of installed storages with storage technology s in sub-region g in time t
NT_{lt}	number of transportation units l
$PCap_{pgt}$	existing capacity of technology p in sub-region g in time t
$PCapE_{pgt}$	expansion of the existing capacity of technology p in sub-region g in time t
$Q_{ilgg't}$	flow rate of material i transported by mode l from sub-region g' to current sub-region g in time period t
Rev_t	revenue in time t
RNP_{pgt}	“relaxed” number of installed plants with technology p in sub-region g in time interval t
RNS_{sgt}	“relaxed” number of installed storages with storage technology s in sub-region g in time interval t
RNT_{lt}	“relaxed” number of transportation units l in time interval t
$SCap_{sgt}$	capacity of storage s in sub-region g in time t
$SCapE_{sgt}$	expansion of the existing capacity of storage s in sub-region g in time t
ST_{isgt}	total inventory of material i in sub-region g stored by technology s in time t
TOC_t	transport operating cost in time t
PE_{ipgt}	production rate of material i in technology p in sub-region g in time t
PT_{igt}	total production rate of material i in sub-region g in time t
PU_{igt}	purchase of material i in sub-region g in time t
$X_{lgg't}$	binary variable, which is equal to 1 if material flow between two sub-regions g and g' is established and 0 otherwise
W_{igt}	amount of wastes i generated in sub-region g in period t

expedite the solution of such formulation, we propose a novel decomposition method based on a customized “rolling horizon” algorithm that achieves significant reductions in CPU time while still providing near optimal solutions.

The paper is organized as follows. First, a literature review on strategic SCM tools based on mathematical programming is presented, followed by a more specific review on the particular application of these techniques to the sugar cane industry. A formal definition of the problem under study is given next along with its mathematical formulation. The following section introduces a tailor-made decomposition strategy that reduces the computational burden of the model by exploiting its mathematical structure. The capabilities of the proposed modeling framework and solution