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Integrated decision making for the optimal bioethanol supply chain

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ABSTRACT

Bioethanol production poses different challenges that require an integrated approach. Usually previous works have focused on specific perspectives of the global problem. On the contrary, bioethanol, in particular, and biofuels, in general, requires an integrated decision making framework that takes into account the needs and concerns of the different members involved in its supply chain.

In this work, a Mixed Integer Linear Programming (MILP) model for the optimal allocation, design and production planning of integrated ethanol/yeast plants is considered. The proposed formulation addresses the relations between different aspects of the bioethanol supply chain and provides an efficient tool to assess the global operation of the supply chain taking into account different points of view. The model proposed in this work simultaneously determines the structure of a three-echelon supply chain (raw material sites, production facilities and customer zones), the design of each installed plant and operational considerations through production campaigns. Yeast production is considered in order to reduce the negative environmental impact caused by bioethanol residues. Several cases are presented in order to assess the approach capabilities and to evaluate the tradeoffs among all the decisions.

1. Introduction

Nowadays, new perspectives have arisen around the firms integration resulting in new strategic challenges. Different entities or enterprises (suppliers, industrial facilities, warehouses, clients, etc.) integrate their activities in order to achieve global objectives. Generally, they do not belong to the same company, work in different trades and common actions affect their operations and performances. Previous approaches have pursued individual objectives, neglecting the combination of the units in the network. In this context, a supply chain (SC) is a common option where a set of units (e.g. suppliers, plants, warehouses, customers) makes a set of activities ranging from the purchase of raw materials to the transportation of finished products to clients. Thus, a first integration requirement can be posed respect to the links among the SC members.

In order to achieve an appropriate coordination, many decisions have to be taken into account. They can be classified into three levels regarding to their significance and the time period required in the planning horizon. Firstly, decisions about location, sizing and technology of plants and distribution centers are generally classified as strategic and they correspond to a planning horizon of several years. In a second level, procurement, product assignment as well as distribution channel and transportation policy are considered as tactical decisions and they can be reviewed every few months. Finally, production planning, and the distribution of raw material, semi-finished and finished products in the supply chain are considered as operational decisions that are easily changed in the short term [1].

In general, previous works have addressed decision levels in hierarchical approaches in which SC design is first determined. SC design has been traditionally defined by determining the number and location of production plants, the sizing for each facility, and the flows among the different nodes of the network, pursuing economic objectives. Then, for each plant involved in the network, plant design decisions are made. Finally, planning decisions are determined using demand targets previously defined. On the other hand, there are few works dealing with SC design where first the plants are designed and then the surrounding SC. For example, in Baliban et al. [2] the synthesis and design of a thermochemical refinery is first solved and, then, in Elia et al. [3] the SC network of this kind of plants is designed. However, these hierarchical approaches do not consider any interactions between decision making levels and thus the SC design and planning decisions may result in suboptimal or even infeasible plant planning problems. Due to significant relations between decisions levels, it is necessary to consider the simultaneous optimization in order to determine the global optimal solution and to assess the tradeoffs among the different elements involved. Thus, a second integration

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Nomenclature

Indices

afer	alcohol fermentor
b	batch
bak	baker's yeast
bfer	biomass fermentor
c	customers zone
cen	centrifuge
cream	centrifuged cream
d	points for discretizing the number of campaign repetitions
dis	distillation
et	ethanol
f	production plant
i	product
j	stage
k	unit
l	slot
m	discrete size for semicontinuous unit
M_{jf}	number of available discrete sizes for a unit of semicontinuous stage *j* of plant *f*
mol	molasses
n	number of batches of a product
p	discrete size for batch unit
P_{jf}	number of available discrete sizes for a unit of batch stage *j* of plant *f*
r	raw material
s	raw materials site
tor	torula
vin	vinasses

Sets

BI_i	batches of product *i* proposed for the production campaign
EB_i	batch processing stages used for producing *i*
ES_i	semicontinuous processing stages used for producing *i*
SR_{jf}	available discrete sizes for units of semicontinuous stage *j* in plant *f*
SV_{jf}	available discrete sizes for units of batch stage *j* in plant *f*

Parameters

Cap_1	Capacity of molasses truck
Cap_i	truck capacity for transporting product *i*
CCF	capital charge factor
inc_f	fixed cost for plant *f* installation
Cfuel	fuel cost
$CSCane_s$	sugar cane procurement cost, per mass unit, in site *s*
CTC_f^{UP}	upper bound for variableCTC_f
$CTIFC_{ifc}$	transportation cost, per mass unit, of final product *i* from plant *f* to customer *c*
$CTRAW_{srf}$	transportation cost, per mass unit, of raw material *r* from site *s* to plant *f*
D_{ij}	duty factor of product *i* in semicontinuous stage *j*
$dist1_{sf}$	distance between raw material site *s* and plant *f*
$dist2_{fc}$	distance between plant *f* and customer zone *c*
DM_{ic}^{LO}	minimun demand of product *i* from customer zone *c*
DM_{ic}^{UP}	maximun demand of product *i* from customer zone *c*
fc_f	conversion factor that indicates the kg of molasses required to produce one L of ethanol at plant *f*
H_f	time horizon for plant *f*
K_{jf}	maximum number of identical parallel units that can be allowed at batch stage *j* of plant *f*
L_{kjf}	number of slots postulated for unit *k* of stage *j* in plant *f*
NBC_{if}^{UP}	maximum number of batches of product *i* in the campaign of plant *f*
NN_f^{LOW}	left end of discretization interval of variable NN_f
NN_f^{UP}	rigth end of discretization interval of variable NN_f
$Oper_{if}$	operation cost coefficient for product *i* in plant *f*
Q_{if}^{UP}	upper bound for the production of product *i* in plant *f*
QSC_s^{UP}	maximum amount of sugar cane
RF_{jmf}	discrete size *m* for semicontinuous units in stage *j* at plant *f*
SF_{ij}	size factor of product *i* in batch stage *j*
T_{ij}	processing time for product *i* in stage *j*
tt_{df}	*d*-th point obtained from the discretization of variable NN_f
VF_{jpf}	discrete size *p* for batch units in stage *j* at plant *f*
α_{jf}	cost coefficient for batch units of stage *j* at plant *f*
β_{jf}	cost exponent for batch units of stage *j* at plant *f*
ρ_i	conversion factor, *i* = tor, bak

Binary Variables

ex_f	indicates if plant *f* is installed
NNC_{df}	specifies if the campaign of plant *f* is repeated tt_{df} times over the time horizon H_f
r_{jmf}	denotes if the units of semicontinuous stage *j* at plant *f* have size *m*
v_{jpf}	denotes if the units of batch stage *j* at plant *f* have size *p*
x_{inf}	denotes if *n* batches of product *i* are processed in the campaign of plant *f*
Y_{bjklf}	denotes if *b* is assigned to slot *l* and processed in unit *k* of stage *j* in plant *f*
z_{jkf}	specifies if unit *k* of stage *j* at plant *f* is employed

Continuous variables

ANB	annual net benefit
B_{if}	batch size of product *i* at plant *f*
CTC_f	cycle time of the campaign of plant *f*
e_{jkpf}	represents the bilinear term $z_{jkf}\ v_{jpf}$
ee_{jkmf}	represents the bilinear term $z_{jkf}\ r_{jmf}$
INSC	installation cost
INVC	investment cost
IS	income for sales
NB_{if}	total number of batches of product *i* processed at plant *f* in the time horizon H_f
NBC_{if}	number of batches of product *i* included in the campaign of plant *f*
NC_f	number of times that the campaign of plant *f* is cyclically repeated over the time horizon H_f
OC	operating cost
Q_{if}	amount of product *i* produced in plant *f*
QC_{ifc}	amount of product *i* sent from plant *f* to customer zone *c*
QM_s	amount of molasses produced at site *s*
QR_{sf}	amount of molasses sent from site *s* to plant *f*
R_{jf}	size of a semicontinuous unit in stage *j* of plant *f*
ResC	disposal cost
SCC	sugar cane cost
TF_{jklf}	final processing time of slot *l* in unit *k* of stage *j* at plant *f*
TI_{jklf}	initial processing time of slot *l* in unit *k* of stage *j* at plant *f*
TRANC	transportation cost of raw materials from sites to plants and of final products from production plants to customer zones
u_{ijmnf}	variable that denotes to Q_{if} if the binary variables r_{jmf} and x_{inf} simultaneously take the value 1