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Simultaneous production and logistics operations planning in semicontinuous food industries

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ABSTRACT

The production and logistics operations planning in real-life single- or multi-site semicontinuous food industries is addressed in this work. A discrete/continuous-time mixed integer programming model, based on the definition of families of products, is developed for the problem in question. A remarkable feature of the proposed approach is that in the production planning problem timing and sequencing decisions are taken for product families rather than for products. However, material balances are realized for every specific product, thus permitting the detailed optimization of production, inventory, and transportation costs. Changeovers are also explicitly taken into account and optimized. Moreover, alternative transportation modes are considered for the delivery of final products from production sites to distribution centers. The efficiency and the applicability of the proposed approach is demonstrated by solving to optimality two industrial-size case studies, for an emerging real-life Greek dairy industry.

1. Introduction

The operation of flexible plants involves the satisfaction of a number of production requirements placing competing demands on a set of limited resources, such as processing equipment, storage capacity, utilities, and manpower. The problem of efficient resource utilization leads to a class of scheduling problems which have received considerable attention over the past couple of decades. Much of the research effort to date has focussed on the planning and scheduling of production for individual plants situated at a single geographical site and involving a set of batch, semicontinuous or even continuous unit operations. As is well known, this is in itself a complex problem, optimal or even feasible solutions to which are often notoriously difficult to obtain. However, it must also be recognized that production scheduling is only one aspect of the wider problem of supply chain scheduling. For instance, the scheduling of plant maintenance operations, the coordinated planning of the production at a number of distinct geographical locations, and the management of distribution and Supply Chains (SCs), all lead to important scheduling problems that interact strongly with supply chain scheduling at individual plants. It might be expected that large benefits would ensue from coordinated planning across sites, in terms of costs and market effectiveness. Most business processes dictate that a degree of autonomy is required at each manufacturing and distribution site, but pressures to coordinate responses to global demand while minimizing cost imply that simultaneous planning of production and distribution across plants and warehouses should be undertaken. This would result in the most efficient utilization of all resources. A target-setting approach, where central plans set achievable production targets without imposing operational details is compatible with operational details being determined at each site.

In general, in most production facilities, the production department is responsible for scheduling the production operations so as to satisfy the production targets provided by the logistics department, which is mainly responsible for the management of inventory levels and the distribution of final products. It is evident that a strong interaction between those departments exists, and therefore their appropriate coordination is vital for the overall SC performance. This coordination is not a simple task since production and logistics departments often strive to satisfy different objectives, a fact that may result in organizational and operational problems. Hence, apparently this coordination becomes extremely complicated when several production facilities (multi-site production case) are involved. In this case, it is essential to implement an efficient communication and the coordination of the production and logistics departments of all production plants (i.e., simultaneous production and logistics planning) in order to ensure the viability of the overall SC and increase the overall competitive advantage of the firm by reducing operating, inventory, and transportation costs and increasing customer service levels.

In this work, we are focused on the Food Processing Industry (FPI) sector, one of the most important process industries, that has received little attention in the open literature so far. FPIs

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Nomenclature

Indices/sets

$d \in D$ distribution centers (DCs)
$f, f' \in F$ product families (families)
$j, j' \in J$ processing unit types (units)
$l \in L$ transportation trucks
$n, n' \in N$ planning time periods (periods)
$p \in P$ products
$r \in R$ batch recipe types (recipes)
$s \in S$ production sites

Subsets

D_l DCs d that can be supplied by truck l
D_s DCs d that can be supplied by production site s
F_j families f that can be processed on unit j
F_r families f that have the same batch recipe origin r
J_f available units j to process family f
J_p units j that can process product p
J_s units j that are installed on production site s
L_{sd} transportation trucks l that can transfer products from production site s to DC d
P^a products p that are destined for international customers or big national supermarket clients, which have their own trucks
P_f products p that belong to the same family f
P_r products p that have the same batch recipe r origin
R_f batch recipe origin r for family f
R_j batch recipes r that can be processed on unit j
R_p products p that come from batch recipe r
S_d production sites s that can supply DC d
S_l production sites s that can use transportation truck l

Parameters

α_{sjn} daily opening setup time for every unit j of production site s in period n (h); accounts for the pasteurization and homogenization stages
β_{jn} daily shutdown time for every unit j of production site s in period n (h); cleaning of production line for hygienic and quality reasons
$\gamma_{ff'sj}$ changeover time between family f and family f' on unit j of production site s (h); accounts for cleaning and sterilizing operations
δ_{spj} setup time for product p in unit j of production site s (h)
ε_l^{max} maximum capacity of transportation truck l (kg)
ε_l^{min} minimum capacity of transportation truck l (kg)
ζ_{dpn} demand for product $p \notin P^a$ of customers supplied by DC d at time n (kg)
ζ_{pn}^a demand for product $p \in P^a$ at time n (kg)
θ_{psjn} variable operating cost for product p on processing unit j of production site s in period n (€/h); includes labor and utilities costs
λ_p minimum cooling storage time for processed products (in periods n)
M_{sjn} a big number
μ_{srn}^{max} maximum production capacity of batch recipe r in production site s in period n (kg)
μ_{srn} minimum produced quantity of batch recipe r in production site s in period n (kg); accounts for pasteurization and fermentation tanks capacity restrictions
v_{sjn} fixed cost for utilizing unit j of production site s in period n (€)
ξ_{spn} inventory cost for product p in production site s in period n (€/kg)
o_{sjn} additional unit preparation time for processing unit j of production site s in periods n (h)
π_{psjn}^{max} maximum production run for product p on unit j of production site s in period n (kg)
π_{psjn}^{min} minimum production run for product p on unit j of production site s in period n (kg)
ρ_{psj} processing rate for product p on unit $j \in J_p$ of production site s (kg/h)
σ_{srn} release time for batch recipe r in production site s in period n (h)
τ_r minimum time for preparing batch recipe r (h); for producing stirred yogurt stands for the minimum fermentation time, yogurt reflects the minimum cooling time before the packing stage
υ_{sdl} variable cost for transferring products from production site s to DC d by truck l (€)
$\phi_{ff'sjn}$ changeover cost between family f and family f' in unit j of production site s in period n (€); accounts for cleaning and sterilizing operations
χ_{srn} cost for producing batch recipe r in production site s in period n (€)
ψ_{sl} fix cost for contracting transportation truck l to carry products from production site s (€)
ω_{sjn} physical available processing time in period n (h)

Continuous variables

C_{fsjn} completion time for family f in unit j of production site s in period n (h)
I_{spn} inventory of product p in production site s at time n (kg)
Q_{psjn} produced amount of product p in unit j of production site s in period n (kg)
$\overline{Q}_{psn}$ total produced amount of product p in production site s in period n (kg)
T_{fsjn} processing time for family f in unit j of production site s in period n (h)
U_{sdlpn} quantity of product $p \notin P^a$ transported from production site s to DC d by truck l in period n (kg)
$\overline{U}_{sdln}$ total transported quantity from production site s to DC d by truck l in period n (kg)
U_{spn}^a quantity of product $p \in P^a$ transported from production site s to international market or big national clients by customer trucks in period n (kg)

Binary variables

V_{sjn} $=1$, if unit j of production site s is used in period n
W_{srn} $=1$, if batch recipe r is produced in production site s in period n
$X_{ff'sjn}$ $=1$, if family f' is processed exactly after family f, when both are assigned to the same unit j of production site s in period n
Y_{fsjn} $=1$, if family f is assigned to unit j of production site s in period n
$\overline{Y}_{psjn}$ $=1$, if product p is assigned to unit j of production site s in period n
Z_{sdln} $=1$, if transportation truck l transfers material from production facility s to DC d in period n