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Supply chain planning and scheduling integration using Lagrangian decomposition in a knowledge management environment

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ABSTRACT

The integration of planning and scheduling decisions in rigorous mathematical models usually results in large scale problems. In order to tackle the problem complexity, decomposition techniques based on duality and information flows between a master and a set of subproblems are widely applied. In this sense, ontologies improve information sharing and communication in enterprises and can even represent holistic mathematical models facilitating the use of analytic tools and providing higher flexibility for model building. In this work, we exploit this ontologies' capability to address the optimal integration of planning and scheduling using a Lagrangian decomposition approach. Scheduling/planning sub-problems are created for each facility/supply chain entity and their dual solution information is shared by means of the ontological framework. Two case studies based on a STN representation of supply chain planning and scheduling models are presented to emphasize the advantages and limitations of the proposed approach.

1. Introduction

Enterprise supply chain (SC) management encompasses the whole set of activities which aim at the control of material, financial and information flows among raw material suppliers, production sites, distribution centers, retailers, and final customers. The performance of SCs results from the synchronization of the previous flows which is based on mass balances, SC capacity and technological constraints, budget limitations, suppliers' capacity, market demand and competition, and customer satisfaction requirements among others, so as to achieve corporate goals efficiently.

In order to deal with this problem complexity, it is necessary to decouple the system across a hierarchy of appropriately chosen levels without disregarding the interrelationships that exist among them. Indeed, in the integrated SC planning problem, several dimensions may be identified, namely geographical distribution, hierarchical levels, and business functionalities (Stephanopoulos and Reklaitis, 2011). From a functional perspective, the enterprise has been traditionally divided in three basic decision levels: strategic, tactical and operational. Long-term strategic level defines the business scope by determining the structure of the SC in a planning horizon of years. Medium-term tactical planning is concerned with decisions such as the assignment of production targets to facilities and the distribution from facilities to market places. The operational level is related to short-term planning or scheduling which determines on a daily or weekly basis the assignment of tasks to equipment units and the sequencing of tasks in each of them. The aforementioned functional decision levels have different space and time scales, but they are intrinsically related to each other since the decisions made at one level directly affect others. According to Shobrys and White (2002), companies pursuing integration among the different decision levels in production management environments report substantial economic benefits.

In the chemical process industry, two key methodological components of SC management are scheduling and planning technologies. The latter function focuses on the creation of the production, distribution, sales and inventory plans based on customer and market information while observing all relevant process constraints. In particular, operational plans are aimed to structure future production, distribution and other related activities to reach the business objectives (Kallrath, 2005; Shah, 2005). According to Kallrath (2002), most of planning problems in the process

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Notation

Indices

e	suppliers
f, f'	facility locations
i	tasks
j	technologies
k	iterations of the Lagrangian decomposition
s	materials (states)
t, t'	planning periods

Sets

E_{rm}	set of suppliers e that provide raw materials
$\tilde{E}_{prod}$	set of suppliers e that provide production services
$\bar{E}_{tr}$	set of suppliers e that provide transportation services
FP_s	set of materials s that are final products
$\bar{I}$	set of tasks i with variable input
I_j	set of tasks i that can be performed in technology j
IS_s	set of states s that are intermediate states
$\tilde{J}_f$	technology j that is installed at location f
J_i	technologies that can perform task i
K_{is}	set of tasks i producing material s
$\bar{K}_{is}$	set of tasks i consuming material s
Mk_f	set of market locations f
NTr_i	set of production, or non-transport, tasks
Pr_f	set of production facilities f
RM_s	set of materials s that are raw materials
Sup_f	set of supplier locations f
Tr_i	set of distribution tasks i

Parameters

B_i^{MIN}, B_i^{MAX}	lower/upper bounds on the batch size of task i
CP_{sn}	storage capacity for state s at time event n
Dem_{sft}	demand of product s at market f in period t
$FCFJ_{jft}$	fixed cost per unit of technology j capacity at location f in period t
$fixt_i$	fixed processing time of process stage i
h_t^{period}	hours in period t
H	big number
NMk	total number of markets
$Price_{sft}$	price of product s at market f in period t
SF_{ij}	size factor of task i performed in equipment j
$vart_i$	batch size-variable processing time of process stage i

Greek symbols

$\hat{\alpha}_{sij}$	mass fraction of material s produced in task i in equipment j
$\bar{\alpha}_{sij}$	mass fraction of material s for consumption in task i in equipment j
$\hat{\beta}_{jf}$	minimum utilization rate of technology j capacity that is allowed at location f
$\theta_{ijff'}^{f}$	fixed capacity utilization rate of technology j by task i whose origin is location f and destination location f'
$\theta_{ijff'}^{v}$	variable capacity utilization rate of technology j by task i whose origin is location f and destination location f'
$\hat{\rho}_{eff't}^{tr}$	unitary transportation costs from location f to location f' during period t
λ_{sft}^{k}	Lagrangian multipliers for state s in facility f at time t in iteration k
κ	scalar for calculating the step in the Lagrangian decomposition
τ_{ijfet}^{ut1}	unitary cost associated with task i performed in equipment j from location f and payable to external supplier e during period t
τ_{sfet}^{ut2}	unitary cost associated with handling the inventory of material s in location f and payable to external supplier e during period t
χ_{est}	unitary cost of raw material s offered by external supplier e in period t

Continuous variables

Bf_{fin}	batch size of task i finishing at or before time point n
Bp_{fin}	batch size of task i being processed at time point n
Bs_{fin}	batch size of task i starting at time point n
CT_f	cycle time
D_{fin}	processing time of task starting at time point n corresponding to stage i
$EPurch_{et}$	economic value of purchases executed in period t to supplier e
$ESales_t$	economic value of sales executed in period t
$FCost_t$	fixed cost in period t
F_{jft} [h]	total capacity of technology j during period t at location f
M_{sft}	amount of stock of material s at location f in period t
MS_{sn}	amount of state s available at time point n
$P_{ijff't}$	rate of activity i carried out in equipment j which is originated from location f and delivered to location f' in period t
PD_{fs}	demand of state s at the end of the time horizon of the scheduling for facility f
$Profit$	total profit
$Purch_{et}^{prod}$	amount of money payable to supplier e in period t associated with production activities
$Purch_{et}^{rm}$	amount of money payable to supplier e in period t associated with consumption of raw materials
$Purch_{et}^{tr}$	amount of money payable to supplier e in period t associated with consumption of transport services
$Revenue_f^{SCH}$	revenue of production facility f
$Sales_{sff't}$	amount of product s sold from location f to location f' in period t
ST_{fin}	starting time of activities i (starting of time point n and ending of $n-1$) in facility f
T_{fn}	absolute time of time point n (starting of time point n and ending of $n-1$) in facility f
TE_{fj}	end time of the tasks at unit j in facility f
Tf_{fin}	finishing time of task i that starts at time point n in facility f
Ts_{fin}	starting time of task i that starts at time point n in facility f
WT_{fin}	waiting time of task i at time point n in facility f
Y_f	frequency of the schedule (inverse of the number of cycles in a year) in facility f
Z^{SC}	objective function of the supply chain planning problem
Z_f^{SCH}	objective function of the scheduling problem of facility f
$Z^{overall}$	objective function considering the whole supply chain planning and scheduling

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