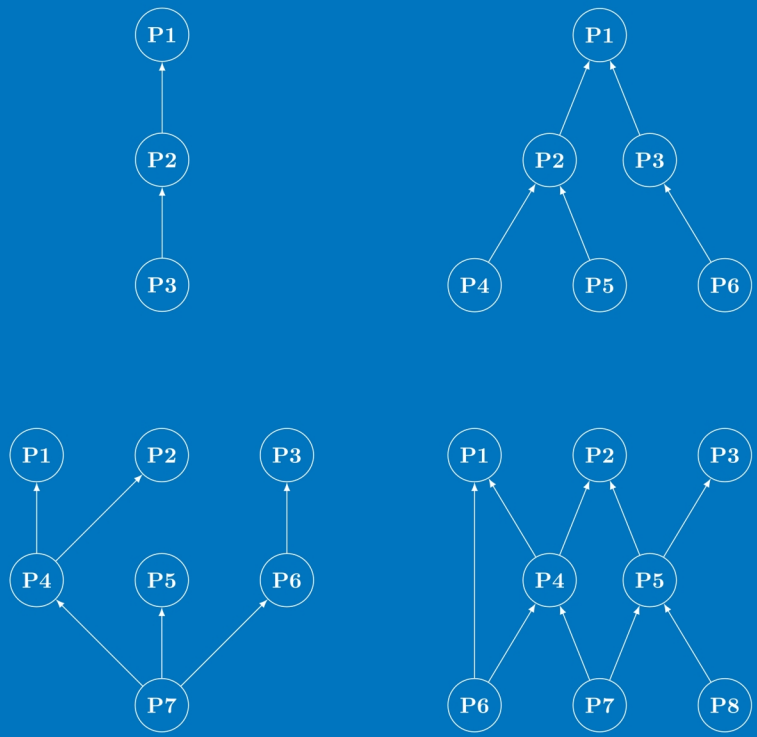
Dynamic lot sizing problems with stochastic production output



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Preface

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Michael Kirste *Cologne, June 2017*

Contents

List of Abbreviations

AN	All-or-Nothing yield
ABC	ABC heuristic
APS	Advanced Planning Systems
BI	binomial yield
BOM	bill of materials
CG	Column Generation
CLSP	Capacitated Lot Sizing Problem
CPPS	Capacitated Production Planning System
DU	discrete uniform yield
ELSP	Economic Lot Scheduling Problem
EOQ	Economic Order Quantity
FO	Fix-and-Optimize
GH	Groff heuristic
HC	Hill Climbing
IG	interruptive geometric yield
LS	Local Search
MIP	mixed integer programming
MLCLSP	Multi-Level Capacitated Lot Sizing Problem
MLPO	Multiple Lot Sizing Production to Order
MRP	Material Requirements Planning
MRP II	Manufacturing Resource Planning
p.d.f	probability density function
SIULSP	Single-Item Uncapacitated Lot Sizing Problem
SMH	Silver-Meal heuristic

SA	Simulated Annealing
SP	stochastical proportional yield
SPA	Shortest Path algorithm
SPP	Set Partitioning problem
TBO	time between orders
TS	Tabu Search

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List of Symbols

Indices

i, k	product index
j	resource index
l	piecewise linear segment index
p	plan index
s	scenario index
t, τ	period index

Parameters

a_{ki}	number of units of product k required to produce one unit of product i (production coefficient)
$\hat{b}$	observed production capacity
b_t	production capacity in period t
b_{jt}	production capacity in period t for resource j
$BigM$	large number
c_{pk}	costs of plan p for product k
ci	inventory holding costs for one unit
ci_k	inventory holding costs for one unit of product k
co	overcapacity costs
cs	setup costs
cs_k	setup costs for product k
D_{kt}	deterministic demand in period t for product k
D_{skt}	demand in period t for product k in scenario s
J	number of resources

K	number of products
K_j	set of products requiring resource j
L	number of piecewise linear segments
LC_k	low level code of product k
LS	number of levels in a multi-level product structure
P_k	number of plans for product k
PP_k	set of immediate predecessors of product k
r_{skt}	yield rate in period t for product k in scenario s
S	number of scenarios
SP_k	set of immediate successors of product k
T	length of the planning horizon
tp_k	processing time of product k
ts_k	setup time for product k
TBO_k	average time between orders for product k
TS^{CV}	threshold value indicating the maximum coefficient of variation of a p.d.f.
u	expected capacity utilization
z_k	lead time for product k
α	α-service level
β	β-service level
β^c	cycle β-service level
β^t	periodic β-service level
β^T	β-service level over the whole planning horizon
β_k^c	cycle β-service level for product k
γ	γ-service level
δ	δ-service level
Δ_0^X	y-intercept of function X
Δ_l^X	slope of function X in segment l

κ_{pkt}	capacity utilization of plan p for product k in period t
ρ	success probability of a usable unit (binomial yield)
ρ_k	success probability of a usable unit for product k (binomial yield)
Π_l	upper bound of line segment l on x-axis

Stochastic variables

$\tilde{b}_t$	random production capacity in period t
B_t	backorder in period t
B_{kt}	backorder in period t for product k
$\tilde{D}_t$	stochastic demand in period t
$\tilde{D}_{kt}$	stochastic demand in period t for product k
$\tilde{D}_{kt}^{cum}$	cumulated stochastic demand up to period t for product k
$\tilde{D}_{kt}^{total}$	total stochastic demand in period t for product k
$I_t^{b,end}$	backlog at the end of period t
$I_t^{b,prod}$	backlog immediately after production in period t
$I_t^{n,end}$	net inventory at the end of period t
$I_t^{p,end}$	inventory on hand at the end of period t
$I_{kt}^{b,end}$	backlog at the end of period t for product k
$I_{kt}^{b,prod}$	backlog immediately after production in period t for product k
$I_{kt}^{n,end}$	net inventory at the end of period t for product k
$I_{kt}^{p,end}$	inventory on hand at the end of period t for product k
q_{kt}^{real}	realized lot size in period t for product k
$Q(.,.)$	production output
$Q_t(.,.)$	production output in period t
$Q_{kt}(.,.)$	production output in period t for product k
$\tilde{r}$	yield rate (stochastically proportional yield)
$\tilde{r}_k$	yield rate for product k (stochastically proportional yield)

$\tilde{tp}$	stochastic processing time
$\tilde{tp}_k$	stochastic processing time of product k
$\tilde{Y}$	random yield
$\tilde{Y}_k$	random yield for product k

Deterministic variables

B_{skt}	backorder in period t for product k in scenario s
$I_{skt}^{b,comp}$	backlog immediately after completion of lots in period t for product k in scenario s
$I_{skt}^{b,end}$	backlog at the end of period t for product k in scenario s
$I_{skt}^{b,prod}$	backlog immediately after production in period t for product k in scenario s
$I_{skt}^{n,end}$	net inventory at the end of period t for product k in scenario s
$I_{skt}^{p,comp}$	inventory on hand immediately after completion of lots in period t for product k in scenario s
$I_{skt}^{p,end}$	inventory on hand at the end of period t for product k in scenario s
$I_{skt}^{p,prod}$	inventory on hand immediately after production in period t for product k in scenario s
o_t	overcapacity in period t
q	lot size
q^S	production share
q^{TS}	production time slot
q_t	lot size in period t
q_{kt}	lot size in period t for product k
q_{kt}^{cum}	cumulated lot size up to period t for product k
q_{kt}^{S}	production share in period t for product k
q_{kt}^{TS}	production time slot in period t for product k
q_{ktl}^{cum}	cumulated production quantity in period t for product k assigned to segment l

q_{skt}^{real}	realized lot size in period t for product k in scenario s
SS	safety stock
$v_t^{n,end}$	standardized value of the p.d.f. of the net inventory at the end of period t
$v_t^{n,prod}$	standardized value of the p.d.f. of the net inventory after production in period t
WT	total expected workload in the planning horizon
WT_j	total expected workload in the planning horizon for resource j
δ_{pk}	binary plan selection indicator (1, if plan p is selected for product k; 0, otherwise)
γ_t	binary setup indicator in period t (1, if production takes place in period t; 0, otherwise)
γ_{kt}	binary setup indicator in period t for product k (1, if production for product k takes place in period t for product k; 0, otherwise)
$\Gamma_{ktl}^{q^{cum}}$	binary production indicator (1, if $q_{ktl}^{cum} > 0$; 0, otherwise)
$\Gamma_{skt}^{I^{comp}}$	inventory status after completion of lots (1, if inventory on hand after completion of lots; 0, if backlog after completion of lots)
$\Gamma_{skt}^{I^{end}}$	inventory status at the end of period t (1, if inventory on hand at the end of period t; 0, if backlog at the end of period t)
$\Gamma_{skt}^{I^{prod}}$	inventory status after production (1, if inventory on hand after production; 0, if backlog after production)
$\Gamma_{skt}^{q^{real}\rightarrow q}$	realized lot size limitation indicator (1, if q_{skt}^{real} equals q_{kt}; 0, otherwise)
$\Gamma_{skit}^{q^{real}\rightarrow I}$	realized lot size limitation indicator (1, if q_{skt}^{real} equals $I_{sit}^{p,comp}/a_{ik}$; 0, otherwise)
ℓ_t	number of periods since the last setup in period t
ℓ_{kt}	number of periods since the last setup in period t for product k
π_t	dual variable of the capacity restriction in the SPP model
σ_k	dual variable of the plan selection restriction in the SPP model

Solution methods and algorithms

b_t^{fixed}	fixed capacity in period t
b_t^{open}	open capacity in period t
$b_t^{reserved}$	reserved capacity in period t
$C(E)$	costs for edge E
$C(P)$	costs for path P
$C_{\tau\to t}^{avg.}$	average costs per period for a lot size from period τ to period t
E	edge in the network problem
$E_{\tau\to t}$	edge from period τ to period t
$NH(s)$	neighborhood of solution s
I^{max}	maximal number of iterations
m	move
$MQ_k(i)$	move quantity in iteration i for product k
P	path in the network
P_t	path in the network up to period t
P_t^*	optimal path in the network up to period t
$P_t^{(i)}$	path in the network up to period t created in iteration i
$q_{\tau\to t}$	lot size from period τ to period t
$q_{\tau\to t}^*$	optimal lot size from period τ to period t
s	solution
s^*	best solution
s', s''	current solution
s_0	initial solution
SV	array of sample values of a scenario set
T_i	temperature in iteration i
TL	tabu list
X^{max}	maximal number of open binary setup variables for indice x

γ_{kt}^{s}	value of the binary setup indicator variable in subproblem s
$\overline{\gamma}_{kt}^{fix}$	value of the fixed binary setup indicator variable
$\mathcal{KT}$	set of all binary setup variables
$\mathcal{KT}^{fix}$	set of all fixed binary setup variables in subproblem s
$\mathcal{KT}^{opt}$	set of all open binary setup variables in subproblem s
$\mathcal{Z}_s$	objective value of subproblem s

Functions

$BIN(n, \rho)$	binomial distribution with n experiments and success probability ρ
DU	discrete uniform distribution
f^O	objective function
f_x	probability density function of x
F_x^{-1}	inverse cumulated distribution function of x
$U(a, b)$	uniform distribution with parameters a and b
$\mathcal{N}(\mu, \sigma^2)$	normal distribution with parameters μ and σ^2
$\Gamma_{k;a}$	gamma distribution with parameters k and a
$\phi(x)$	standard normal probability density function of x
$\Phi(x)$	standard normal cumulated distribution function of x
$[x]^+$	$\max(x, 0)$
$[x]^-$	$\min(x, 0)$
$\exp(x)$	exponential function of x
$rndint(lb, ub)$	random integer number in the interval $[lb, ub]$
$rnddbl(lb, ub)$	random double number in the interval $[lb, ub]$

Definitions

CV_x	coefficient of variation of x
$E\{x\}$	expected value of x

$P(X \geq c)$	probability X greater c
μ_x	expected value of x (first moment)
μ_x^3	skewness of x (third moment)
σ_x	standard deviation of x
σ_x^2	variance of x (second moment)

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