

Efficient methods for the lot sizing problem

Ayşe Akbalık



21/09/2020

HdR defense in Computer Science

Outline

1 Background

2 My research activities

- Overview on the single-item lot sizing problem (LSP)
- My main contributions to the literature
- LSP under capacity reservation contract

3 Projects

CV

B.Sc. Industrial Engineering
Galatasaray University
Istanbul / Turkey



2002

2003

2006

2007

2008

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2011

2018

2019

CV

MSc. Industrial Engineering
Grenoble INP, ENSGI
Grenoble / France



2002

2003

2006

2007

2008

2009

2010

2011

2018

2019

CV

Ph.D Industrial Engineering
Grenoble INP, ENSGI
Grenoble / France



« Lot sizing problem for
integrated supply chains »
Supervised by B. Penz and V.D. Cung



2002

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2018

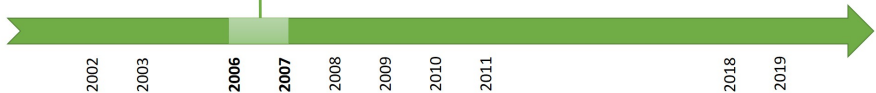
2019

CV

Post-Doc, CORE
 Université Catholique de Louvain
 Louvain-la-Neuve / Belgium



Integer Programming
 Polyhedral approach for LSP
 (Facets, convex hulls, valid ineq.)
 In the team of Y. Pochet & LA. Wolsey



CV

Lecturer, Polytech'Grenoble
Université Joseph Fourier
Grenoble / France



2002

2003

2006

2007

2008

2009

2010

2011

2018

2019

CV

Post-Doc, CEA / Minatec
 Lab. des Technologies de la
 Microélectronique
 Grenoble / France



« Non-linear inverse
 problem for optical
 index determination »
 In the team of P. Schiavone



2002

2003

2006

2007

2008

2009

2010

2011

2018

2019

CV

Visiting researcher
TOBB University of Economics
and Technology
Ankara / Turkey



TOBB ETÜ
Ekonomi ve Teknoloji Üniversitesi

2002

2003

2006

2007

2008

2009

2010

2011

2018

2019

CV

Assistant Professor
Université de Metz
Laboratoire LGIPM
Metz / France



2002

2003

2006

2007

2008

2009

2010

2011

2018

2019

CV



Visiting Researcher
University of Porto
Porto / Portugal



Universidade do Porto
Faculdade de Engenharia
FEUP

2002

2003

2006

2007

2008

2009

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2011

2018

2019

CV



Assistant Professor
Université de Lorraine
Laboratoire LCOMS
Metz / France



2002

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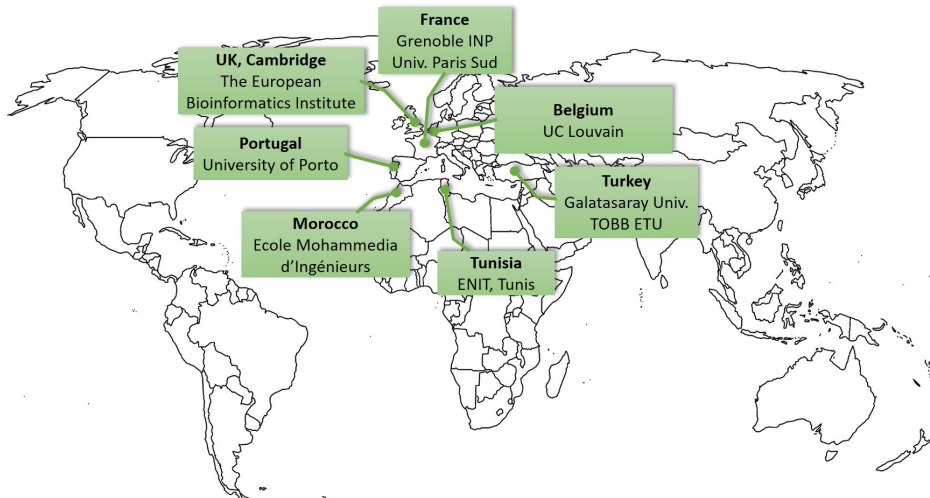
2018

2019

My research topics



International collaborations



Supervisions

Ph.D supervision Mlouka Farhat (Defense : 2019)

Co-supervised with N. Sauer and A. Hadj-Alouane.

“Lot sizing problem with batch replenishment under buyback contract”.

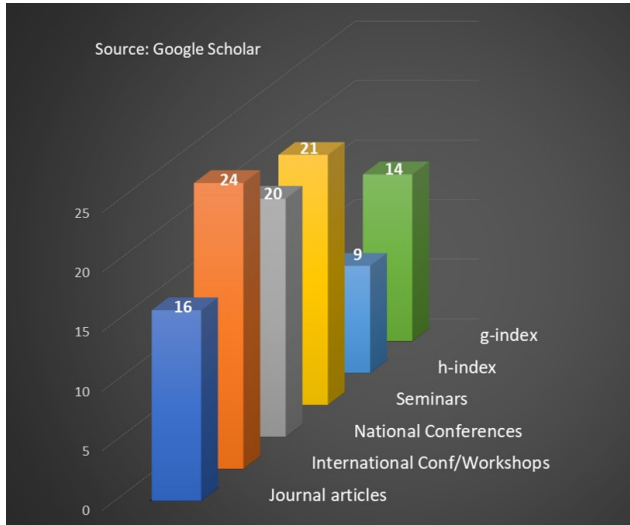
M.S. supervisions 7 master students

“Fleet sizing, lot sizing, replenishment planning and supply chain optimization topics”.

Industrial projects Master 1 and Master 2 levels

“Industrial engineering common topics”.

Publication indicators



Teaching activities (1)

Teaching activities in several engineering schools and universities

Grenoble INP – ENSGI, France (2004-06, 2007-08)

Polytech'Grenoble, Université Joseph Fourier, France (2007-08)

TOBB ETU-Ankara, Turkey (2010-11)

EMSI-Casablanca, Morocco (2015, 2016)

IULT Wroclaw, Poland (2014, 2015)

Ecole des Mines de Nancy, France (since 2011)

ENSAM-Campus Metz, France (since 2011)

UFR - Math Info Méca (Since 2011)

Teaching activities (2)

Teaching topics	Student level
Operations research	Licence 3 – Indus. Eng.
Combinatorial optimization	Master 1 – Comp. Sci.
Decision Making Tools	Master 2 – Indus. Eng.
Integer programming	Master 2 – Indus. Eng.
Production management	Master 2 (Eng. 3A)
Supply chain management	Master 2 (ENSAM)
Design and modeling of industrial systems	Professional Licence
Software and tools to simulate and optimize sys.	Professional Licence
Simulation with Arena	L3, M1, M2
Quality Control	Master 1 – Indus. Eng.

Other activities

- Co-president of ROADEF'2017 Conference organization committee (380 participants)



Other activities

- Co-president of ROADEF'2017 Conference organization committee (380 participants)
- Member of epiSTEM Türkiye, a volunteer science communication organization



Other activities

- Co-president of ROADEF'2017 Conference organization committee (380 participants)
- Member of epiSTEM Turkiye, a volunteer science communication organization
- Erasmus responsible for Turkish universities
- Referee for 15 inter. journals (EJOR, IJPE, JORS, C&OR, POM, etc.)

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LSP inside ERP

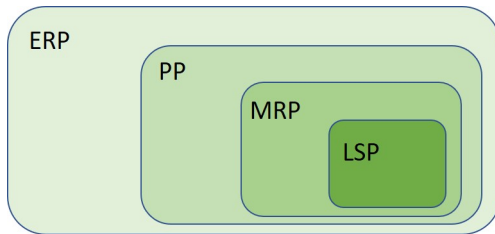
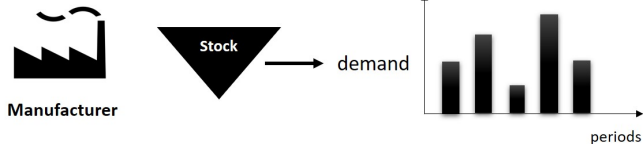


FIGURE – ERP : Enterprise Resource Planning, PP : Production planning, MRP : Material Requirements Planning, LSP : Lot sizing problem

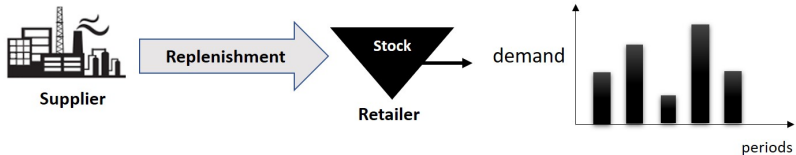
Source : Y. Pochet, LA. Wolsey, Production Planning for MIP.

LSP for production/replenishment

Production planning problem



Replenishment planning problem



LSP for production/replenishment

Production planning problem

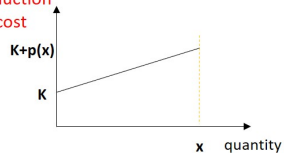


Manufacturer



Holding cost (h)

Production cost



Replenishment planning problem



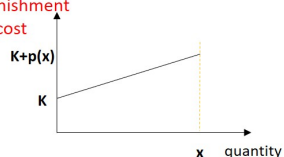
Supplier



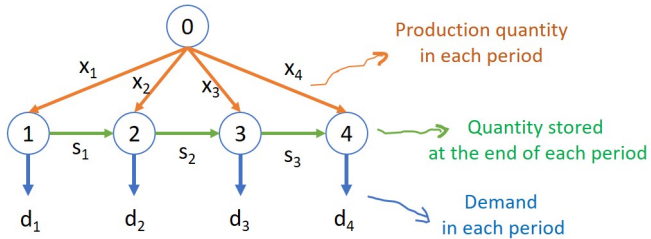
Retailer

Holding cost (h)

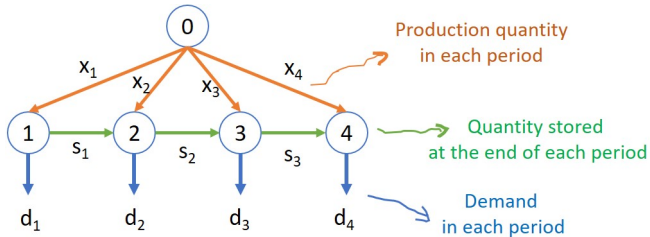
Replenishment cost



Network representation of LSP



Network representation of LSP



For instance, in period $t=2$ we have the material balance « $s_1 + x_2 = d_2 + s_2$ »

Lot sizing problem

The aim

To satisfy a deterministic demand over a finite horizon, while minimizing the total cost.

Several extensions...

Single or multi-item, uncapacitated or capacitated, with or without backlogging/lost sales, time windows, special cost structures, etc.

Important references...

- Pochet and Wolsey (2006), Production planning by MIP
- Brahimi et al. (2017), EJOR, Updated review on LSP

Different tools to model and solve LSP

- Polyhedral approach, extended formulations
- Dynamic programming
- Network flows
- Heuristics, matheuristics, etc.

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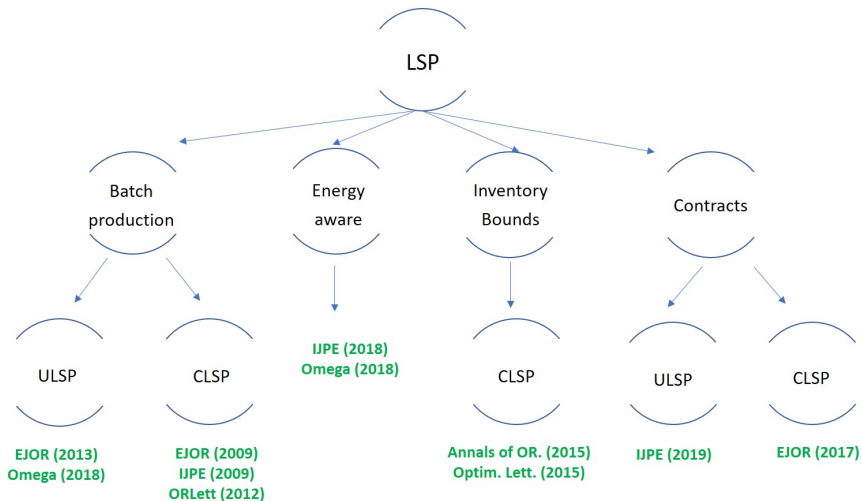
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- My main contributions to the literature
- LSP under capacity reservation contract

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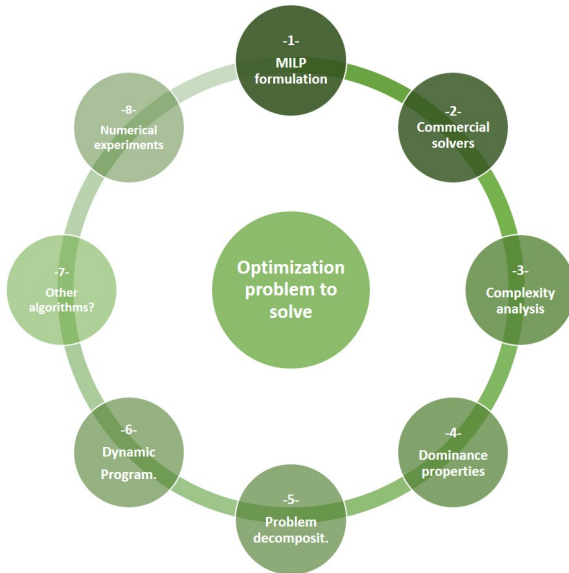
My topics : LSP integrated with other constraints



My contributions to the LSP literature



Our methodology



My theoretical contributions to the LSP literature

Class/subclass	Complexity	Dynamic programming	Polyhedral/MIP/B&C	B&B and dual
Constraints on resources				
Production capacity	(Akbalik & Penz, 2009), Agra and Constantino (1999)*, Baciarello, D'Avino, Onori, and Schiraldi (2013)*,	(Akbalik & Penz, 2009; Akbalik & Rapine, 2012; Berk, Toy, & Hazir, 2008; Chen, Feng, & Lin, 2008), Akbalik and Penz (2009)*, (Chubanov, Kovalyov, & Pesch, 2006; 2008; Chubanov & Pesch, 2012), Akbalik and Rapine (2012)*, Akbalik and Rapine (2013)*, (Feng, Chen, Kumar, & Lin, 2011b), Bahl, Ritzman, and Gupta (1987)*, (Kovalyov & Pesch, 2014), Chan, Muriel, Shen, and Simchi-Levi (2002)*, (Merzifonluoglu, Geunes, & Romeijn, 2007; Ng, Kovalyov, & Cheng, 2010;	(Akbalik & Penz, 2009; Akbalik & Pochet, 2009; Atamtürk & Muñoz, 2004), Adulyasak, Cordeau, and Jans (2015b)*, (Brahimi & Khan, 2014; Coleman & McKnew, 1995; Di Summa & Wolsey, 2010; Hardin, Nemhauser, & Savelsbergh, 2007), Brahimi, Dauzère-Pérès, Najid, and Nordli (2006)*, (Loparic, Marchand, & Wolsey, 2003), Chu, Chu, Zhong, and Yang (2013)*, (Pochet & Wolsey, 1993), (van Vyve, 2006; Yilmaz & Çatay, 2006; Zhang, Jiang, & Pan, 2012b)	Absi, Dauzère-Pérès, Kedad-Sidhoum, Penz, and Rapine (2013)*, Akbalik and Rapine (2013), (Erenguc & Aksoy, 1990; Hardin, Nemhauser, & Savelsbergh, 2007), Chan, Muriel, Shen, and Simchi-Levi (2002)*,

Source : Brahimi et al. (2017), EJOR, Single-item dynamic LSP, An updated survey

My main contributions to the LSP literature

Class/subclass	Complexity	Dynamic programming	Polyhedral/MIP/B&C
Perishable inventories		Bahl and Neelam (2009)*, Bitran and Yanasse (1982)*, (Önal, Romeijn, Sapra, & van den Heuvel, 2015), [86*]	
Constraint on lot sizes	(Absi, Dauzère-Pérès, Kedad-Sidhoum, Penz, & Rapine, 2016; Akbalik & Rapine, 2013)	(Akbalik & Rapine, 2012), (Anderson & Cheah, 1993; Okhrin & Richter, 2011b; Pochet & Wolsey, 1993; van Vyve, 2007)	(Akbalik & Pochet, 2009; Park & Klabjan, 2015; Pochet & Wolsey, 1993)
Outsourcing		(Chu, Chu, Zhong, & Yang, 2013; Huang, Zhong, Ni, & Yang, 2008; Merzifonluoglu, Geunes, & Romeijn, 2007; Wang, He, Sun, Xie, & Shi, 2011)	(Merzifonluoglu, Geunes, & Romeijn, 2007)
Complex Structure			
Multi-echelon	(Arkin, Joneja, & Roundy, 1989)	(Denizel, Solyalı, & Süral, 2010; Kaminsky & Simchi-Levi, 2003), Brahimi and Dauzère-Pérès (2015)*, (van Hoesel, Romeijn, Morales, & Wagelmans, 2005; Melo & Wolsey, 2010; Zangwill, 1969; Zhang, Kucukyavuz, & Yaman, 2012a)	(Brahimi & Khan, 2014; Egri, Kis, Kovács, & Váncza, 2014; Senoussi, Mouss, Penz, Brahimi, & Dauzère-Pérès, 2016),(Yang, Wee, Chung, & Ho, 2010), (Yilmaz & Çatay, 2006)
Multi-sourcing	(Absi, Dauzère-Pérès, Kedad-Sidhoum, Penz, & Rapine, 2013; Akbalik & Penz, 2009)	(Absi, Dauzère-Pérès, Kedad-Sidhoum, Penz, & Rapine, 2013), (Akbalik & Penz, 2009; Akbalik & Rapine, 2013), (de Toledo & Shiguemoto, 2005)	(Akbalik & Penz, 2009)

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Capacity Reservation Contracts (CRC)



- Reservation of any desired quantity of the capacity at supplier, in exchange of an advantageous price for the buyer : a risk sharing mechanism.
- Once this capacity is exceeded, the purchase price increases : convex cost function
- Fluctuating and uncertain demand, products having short lifecycles, important capacity investments, ex. high-tech industry, Wu *et al.* (2005).

Illustration of LSP with batch replenishment under CRC

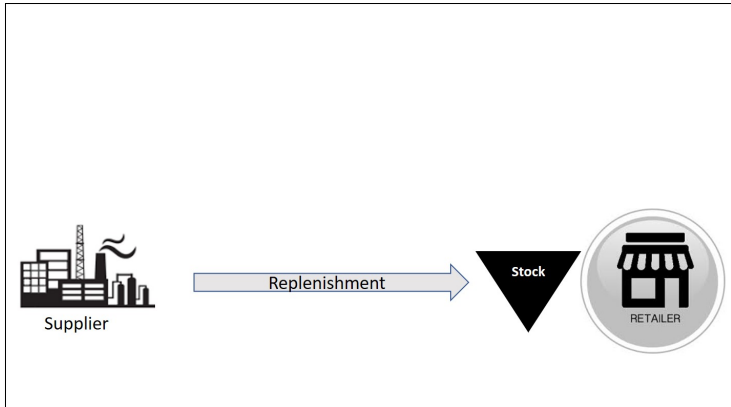


Illustration of LSP with batch replenishment under CRC

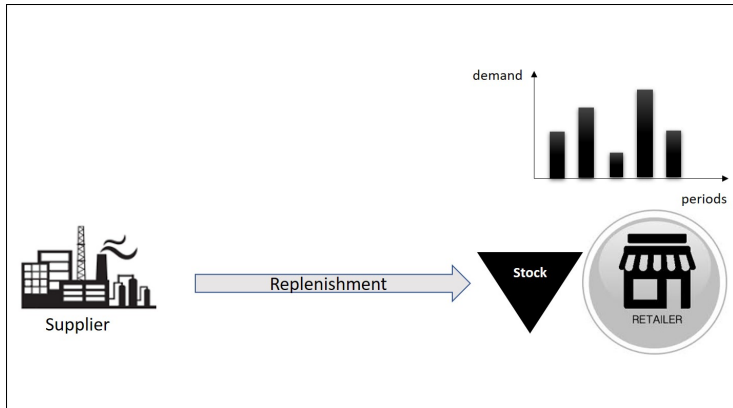


Illustration of LSP with batch replenishment under CRC

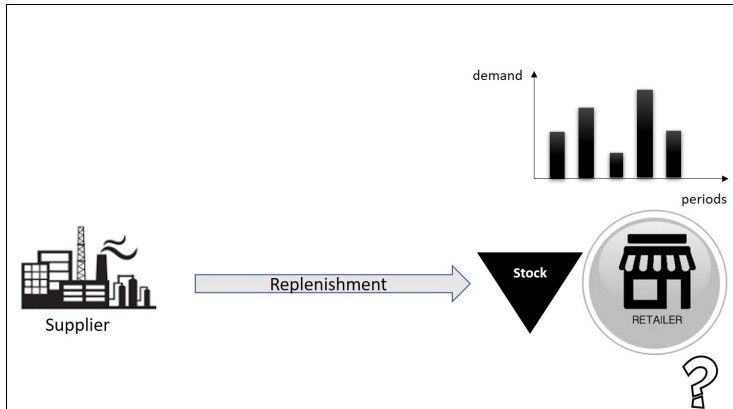


Illustration of LSP with batch replenishment under CRC

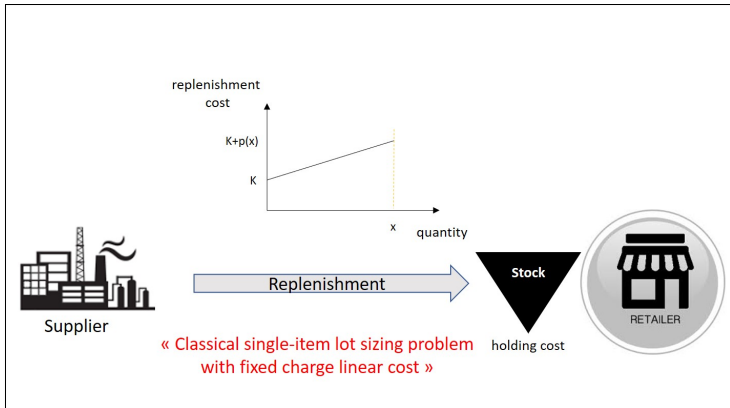


Illustration of LSP with batch replenishment under CRC

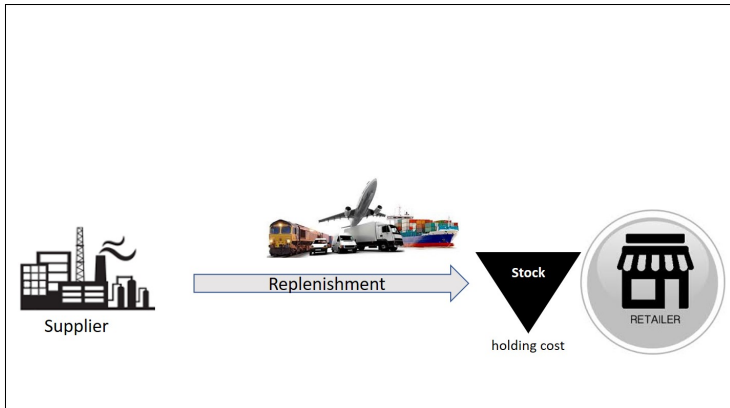


Illustration of LSP with batch replenishment under CRC

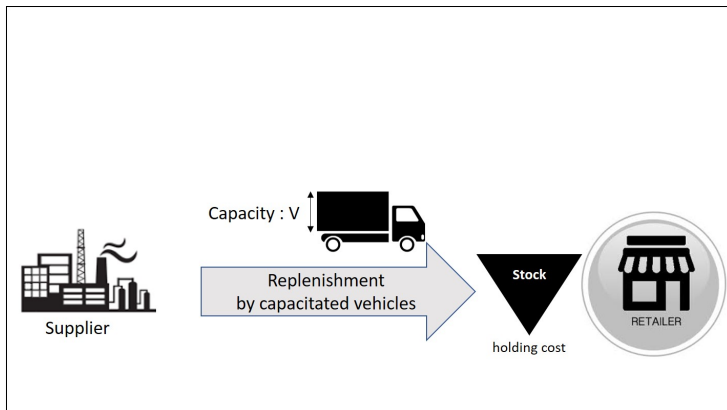


Illustration of LSP with batch replenishment under CRC

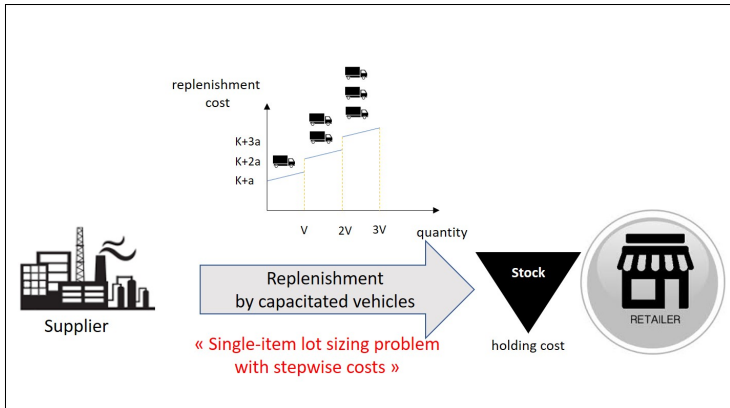


Illustration of LSP with batch replenishment under CRC

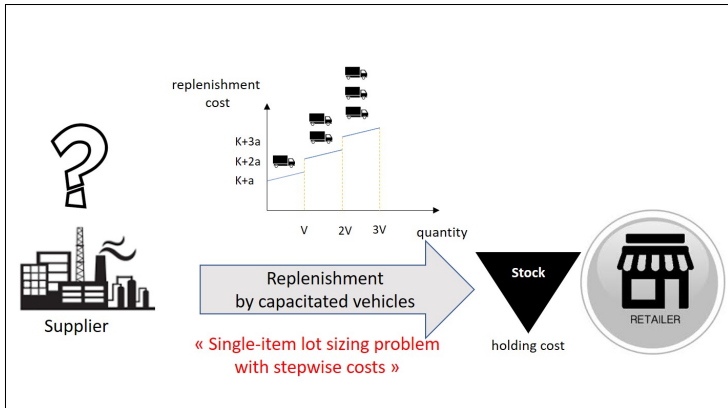
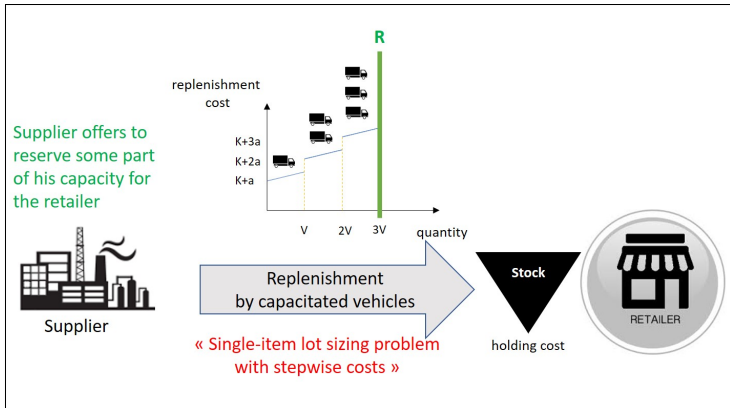


Illustration of LSP with batch replenishment under CRC

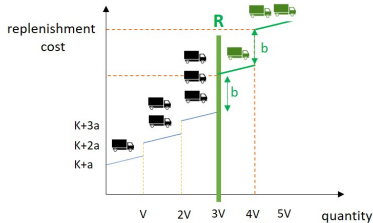


Supplier offers to reserve some part of his capacity for the retailer



Replenishment by capacitated vehicles

« Single-item lot sizing problem
under the capacity reservation contract
with stepwise costs »



Stock

holding cost



Literature review

Parameters	Fixed charge cost		Batch ordering	
	AH2001	LL2013	NV2005	Our study
Number of items	mono	mono	multi	mono
Reserved capacity	constant	constant / ND	constant	constant/arbitrary
Batch production	-	-	yes	yes
Batch size	-	-	constant	constant/arbitrary
Setup cost	✓	✓	✓	✓
Unit production cost	✓	✓	-	✓
Unit holding cost	✓	✓	✓	✓
Fixed cost per batch a_t	-	-	a	a_t
Fixed cost per batch b_t	-	-	b	b_t

AH2001 : Atamturk and Hochbaum (2001)

LL2013 : Lee and Li (2013)

NV2005 : van Norden and van de Velde (2005)

Formulation of LSP-BCR without inventory variables

$$\min C_0 + \sum_{t=1}^T (K_t y_t + a_t A_t + b_t B_t + p_t' x_t - h_t \sum_{i=1}^t d_i)$$

$$\text{s.t. } \sum_{i=1}^t x_i \geq \sum_{i=1}^t d_i, \forall t = 1, \dots, T$$

$$x_t \leq \sum_{i=t}^T d_i y_t, \forall t = 1, \dots, T$$

$$x_t \leq V_t(A_t + B_t), \forall t = 1, \dots, T$$

$$A_t \leq R_t, \forall t = 1, \dots, T$$

$$x_t \in \mathbb{R}_+, A_t, B_t \in \mathbb{N}, y_t \in \{0, 1\}, \forall t = 1, \dots, T$$

The notation $(K_t, a_t, b_t, p'_t, R_t, V_t)$

The notation $(K_t, a_t, b_t, p'_t, R_t, V_t)$ is used for parameters : (setup cost, fixed cost per batch under the reserved capacity, fixed cost per batch over the reserved capacity, unit modified procurement cost, reserved capacity, batch capacity). The field for a parameter α will take either the value :

- '—' if α is null,
- ' α ' if it is assumed stationary,
- and ' α_t ' if it is allowed to be time-dependent.

NP-hardness of $(K/a_t/ + \infty/ - /R_t/V)$

- Florian *et al.* (1980) show that the single item CLSP with constant demand and null storage cost is NP-hard.
- By considering $b_t = +\infty$, our problem is transformed into a CLSP.
- Furthermore, by setting $K = 1$ and $V = 1$, the fixed cost per batch a_t will replace the unit procurement cost.
- A special case of our problem is thus equivalent to the instance considered in Florian *et al.* (1980).

NP-hardness of $(K_t, -, b, -, -, V_t)$ or $(K_t, +\infty, b, -, +\infty, V_t)$

- With the assumption of $b_t \leq a_t, \forall t$, our problem becomes an ULSP.
- We obtain an equivalent problem either assuming ($a_t = \infty$ and $R_t = +\infty$) or ($R_t = 0$ and $a_t = 0$).
- In Akbalik and Rapine (2013) the ULSP with batch production with arbitrary batch sizes and arbitrary setup costs is shown to be NP-hard.

Main assumptions

- The batch sizes are assumed to be stationary.
- We assume arbitrary costs a_t and b_t to generalize our methods.
- The reservation capacities R_t are considered as a multiple of the batch size V for a given period t .

ZIO (zero-inventory-ordering) is not dominant

ZIO property is not dominant for LSP-BCR, even with null setup costs, null unit procurement and holding costs, and stationary capacities, stationary batch sizes.

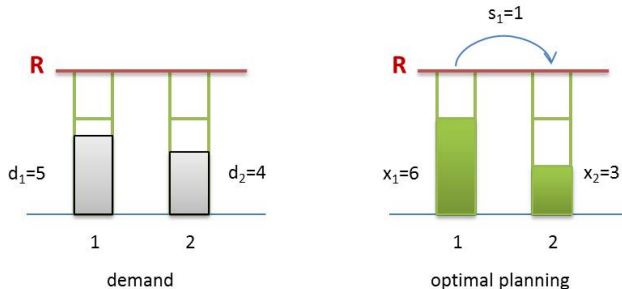


FIGURE – An illustrative example for the non-dominant ZIO property for LSP-BCR. $R = 9$, $V = 3$, $d_1 = 5$, $d_2 = 4$, $a_1 > a_2$, b_1 and b_2 are higher than costs a .

Case 1. $(-, a_t, b_t, p'_t, R_t, V) : \text{Algorithm in } O(T^2 \log(T))$

We double the number of periods as in Akbalik and Rapine (2013) and Helmrach *et al.*(2015) to reduce the instance of LSP-BCR into an instance of CLSP-B with time dependent capacities.

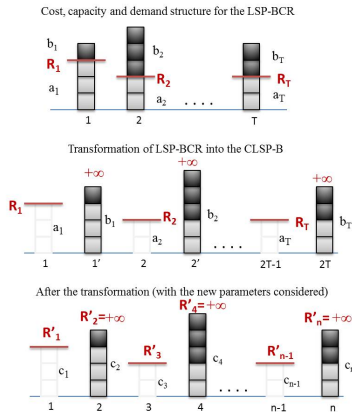


FIGURE – Transformation of LSP-BCR into CLSP-B with $2T$ periods.

Case 1. $(-, a_t, b_t, p'_t, R_t, V)$: Algorithm in $O(T^2 \log(T))$

van Vyve (2007) proposes an algorithm in $O(T^2 \log(T))$ for the CLSP-B with time-dependent capacities, without setup cost, without backlogging and under the WW cost structure.

Case 2. $(-, a_t, b_t, p', R_t, V)$: Algorithm in $O(T \log(T))$

The idea of the algorithm is to produce in the periods with the least c_t costs, while satisfying demands without backlogging. The Insertion Sort algorithm is used for ordering periods in non-decreasing (ND) order of their fixed costs per batch c_t and in each step saturating the least cost periods. The overall algorithm takes $O(T \log(T))$ time.

Case 3. $(K, a, +\infty, -, R_t, V)$: Algorithm in $O(T \log(T))$

- Note that with infinite spot market costs, the problem becomes CLSP-B with time-dependent capacities.
- The algorithm is based on ordering units in periods with the largest remaining capacity.
- We use the well known heap sort algorithm with an $O(T \log(T))$ time complexity to choose the largest value among all existing capacities in the heap.

Case 4. $(K_t, a, +\infty, -, R, V)$: Algorithm in $O(T \log(T))$

- This time the sorting is done over setup costs rather than the capacities.
- A positive quantity is ordered on periods with the lowest setup cost first.

Our contributions : Polynomial time algorithms

TABLE – Polynomial time algorithms proposed in this study.

K_t	a_t	b_t	p'_t	R_t	V_t	Complexity results
-	a_t	b_t	p'_t	R_t	V	$O(T^2 \log(T))$
-	a_t	b_t	p'	R_t	V	$O(T \log(T))$
K	a	$+\infty$	-	R_t	V	$O(T \log(T))$
K_t	a	$+\infty$	-	R	V	$O(T \log(T))$
K_t	a_t	$+\infty$	p'_t	R	V	$O(T^4), R \bmod V = 0$
K_t	a_t	$+\infty$	p'_t	R	V	$O(T^6)$

Our contributions : NP-hardness results

TABLE – NP-hardness results proposed in this study.

K_t	a_t	b_t	p'_t	R_t	V_t	Complexity results
K	a_t	$+\infty$	-	R_t	V	NP-hard
K_t	-	-	-	R_t	V	NP-hard
K_t	-	b	-	-	V_t	NP-hard
K_t	$+\infty$	b	-	$+\infty$	V_t	NP-hard
-	-	b_t	-	-	V_t	NP-hard
-	$+\infty$	b_t	-	$+\infty$	V_t	NP-hard

Perspectives and open cases can be found in the following publication : Akbalik, Hadj-Alouane, Sauer, Ghribi (2017), NP-hard and polynomial cases for the single-item lot sizing problem with batch ordering under capacity reservation contract, EJOR

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My current research projects

Project Title	Partners
Energy-aware LSP	Université Paris Sud (LRI) Grenoble INP (G-SCOP) Université de Lorraine
Multi-item LSP	University of Porto Université de Lorraine
Cutting Stock & LSP	University of Porto Université de Lorraine
Multi compartment VRP	University of Porto Université de Lorraine
Semi Fluid Packing Problem	University of Porto Université de Lorraine

My current research projects on LSP

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Energy-aware LSP	Université Paris Sud (LRI) Grenoble INP (G-SCOP) Université de Lorraine
Multi-item LSP	University of Porto Université de Lorraine
Cutting Stock & LSP	University of Porto Université de Lorraine
Multi compartment VRP	University of Porto Université de Lorraine
Semi Fluid Packing Problem	University of Porto Université de Lorraine

Project “Energy aware LSP”

Renewable energy sources :
Free but limited in each period



If more energy needed:
Not free, but unlimited



Manufacturer

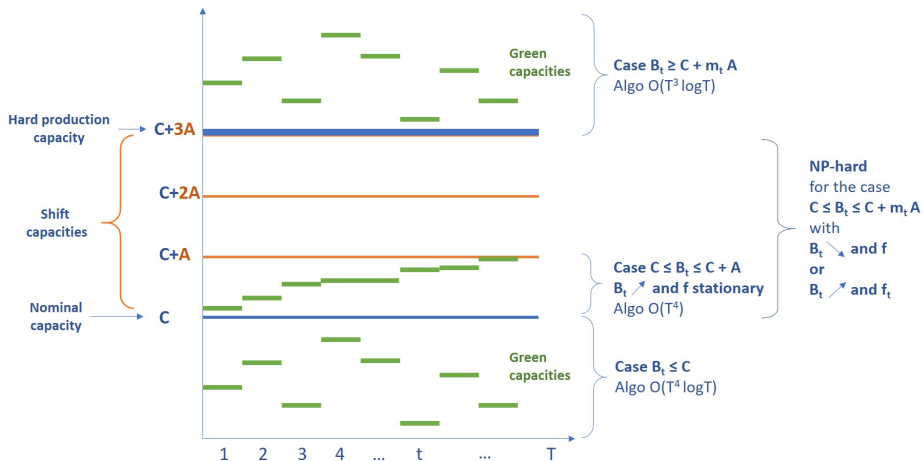
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The manufacturer can
decide to add additional
production capacities

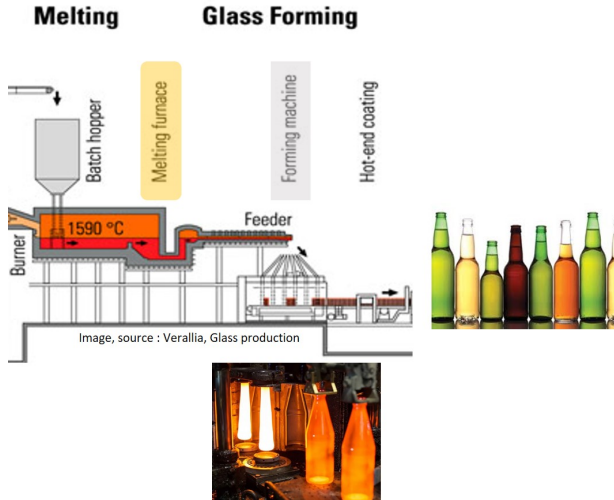
Project members : C. Gicquel, B. Penz, C. Rapine

Project “Energy aware LSP”



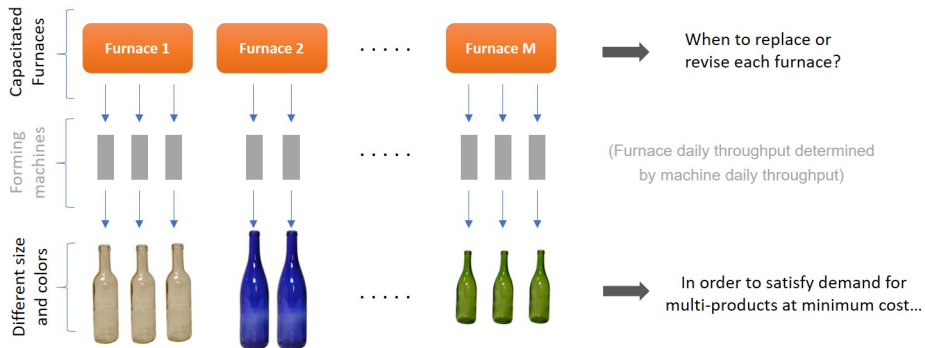
Project members : C. Gicquel, B. Penz, C. Rapine

Project “LSP for glass container industry”



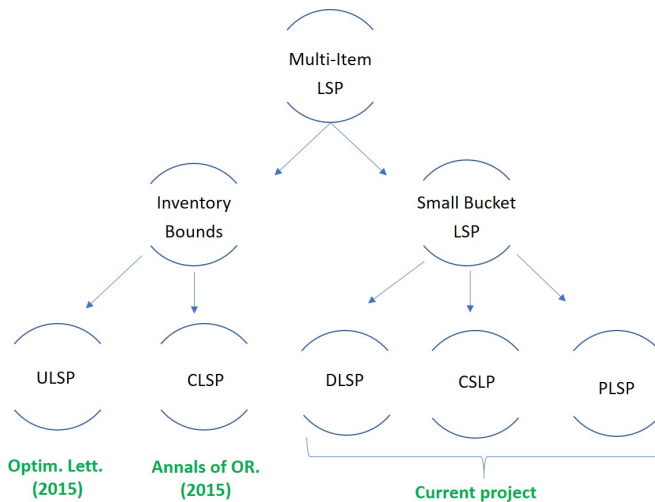
Project members : B. Almada-Lobo, L. Guimarães, C. Rapine

Project “LSP for glass container industry”

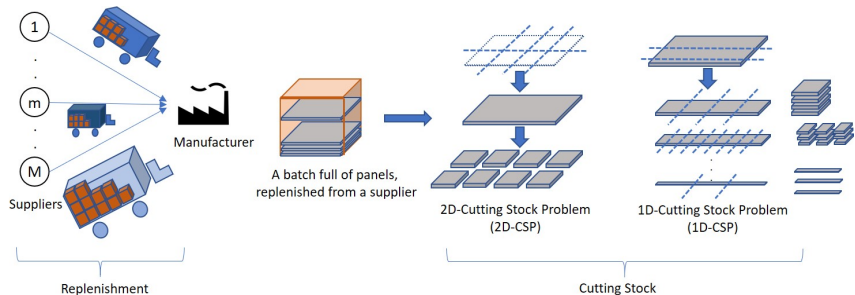


Project members : B. Almada-Lobo, L. Guimarães, C. Rapine

Our contributions : Multi-item LSP



Project “Cutting Stock & LSP”



Project members : M.A. Caravilla, J.F. Oliveira, C. Rapine, E. Silva

Other projects

Project Title	Partners
Energy-aware LSP	Université Paris Sud (LRI) Grenoble INP (G-SCOP) Université de Lorraine
Multi-item LSP	University of Porto Université de Lorraine
Cutting Stock & LSP	University of Porto Université de Lorraine
Multi compartment VRP	University of Porto Université de Lorraine
Semi Fluid Packing Problem	University of Porto Université de Lorraine

Project “Multi-compartment multi-commodity VRP”

Our problem is motivated by a major Portuguese grocery retailer

Food transport

-  Frozen
-  Chilled
-  Ambient



One-commodity

Multi-compartment vehicles
(MCV)



One-commodity

Multi-compartment vehicles
(MCV)



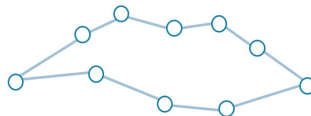
Multi-commodity

Project members : S. Martin, C. Rapine

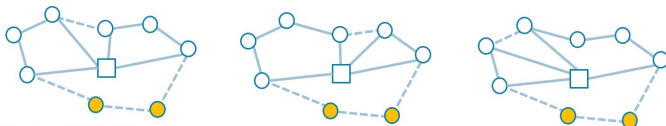
Project “Multi-compartment multi-commodity VRP”

Our approach : “Route-First Cluster-Second Heuristic”

1. Relax the capacity of the vehicle,
Construct a giant tour
visiting all the customers (TSP)
(Heuristically or given by Cplex)



2. Reject some no-good-neighbour customers (MC-CPTP : multi-commodity capacitated profitable tour pb)
Split the tour for each commodity, into routes for capacitated vehicles, leaving some of the stores aside



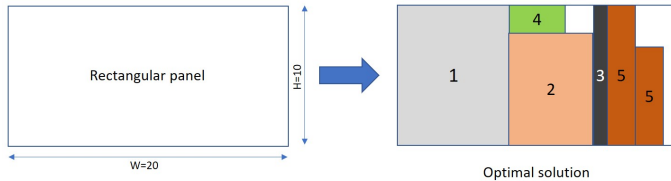
DISCARD & SPLIT

Project “Semi-Fluid Packing”

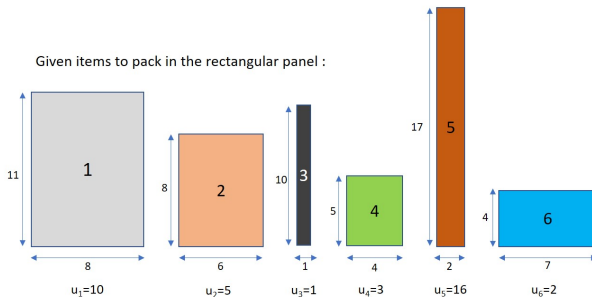


Products that are non-deformable in one direction
But adopt the form of the container in the other direction

Project “Semi-Fluid Packing”



Given items to pack in the rectangular panel :



Project members : J.P. Pedroso, C. Rapine

Perspectives

- Many interesting open cases for each LSP studied.
- Robustness to take into account for several of them.
- Multi-item LSP : use efficient algorithms proposed for single-item LSP.
- Integration of the LSP with other interesting optimization problems.



Efficient methods for the lot sizing problem

Ayşe Akbalık



21/09/2020

HdR defense in Computer Science