

16th ESICUP Meeting

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Solving routing problems with realistic packing constraints

Ramón Alvarez-Valdés
Universitat de València, España



(with many collaborations: Francisco Parreño, Maite Alonso, David Alvarez, José Fernando Oliveira, António Ramos, Manuel Iori,.....)

Why is (good) packing so important?



ENVIRONMENT

The contribution of transport for the total of CO₂ emissions in the EU27 is around 30%, being 75% due to road transportation.



ENERGY

EU transport still depends on oil and oil products for 96 % of its energy needs.



ENERGY PRICES

Increasing energy prices



CONGESTION

Congestion is a major concern, in particular on the roads and in the sky, and compromises accessibility.

Why is (good) packing so important?



SAFETY

New European Cargo
Safety best practices



LEGISLATION

New EU roadside
inspection directive



SHIPPING AIR

Outbound - 60% of
volume occupation

Inbound - 25%
empty trucks



EFFICIENT TOOLS

Transportation
companies need
cargo planning tools
focusing in space
optimization that
can be effectively
used in practice

This story started back in 1995.....



Pergamon

Omega, Int. J. Mgmt Sci. Vol. 23, No. 4, pp. 377-390, 1995

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0305-0483(95)00015-1

Issues in the Development of Approaches to Container Loading

EE BISCHOFF

MSW RATCLIFF

University of Wales, Swansea

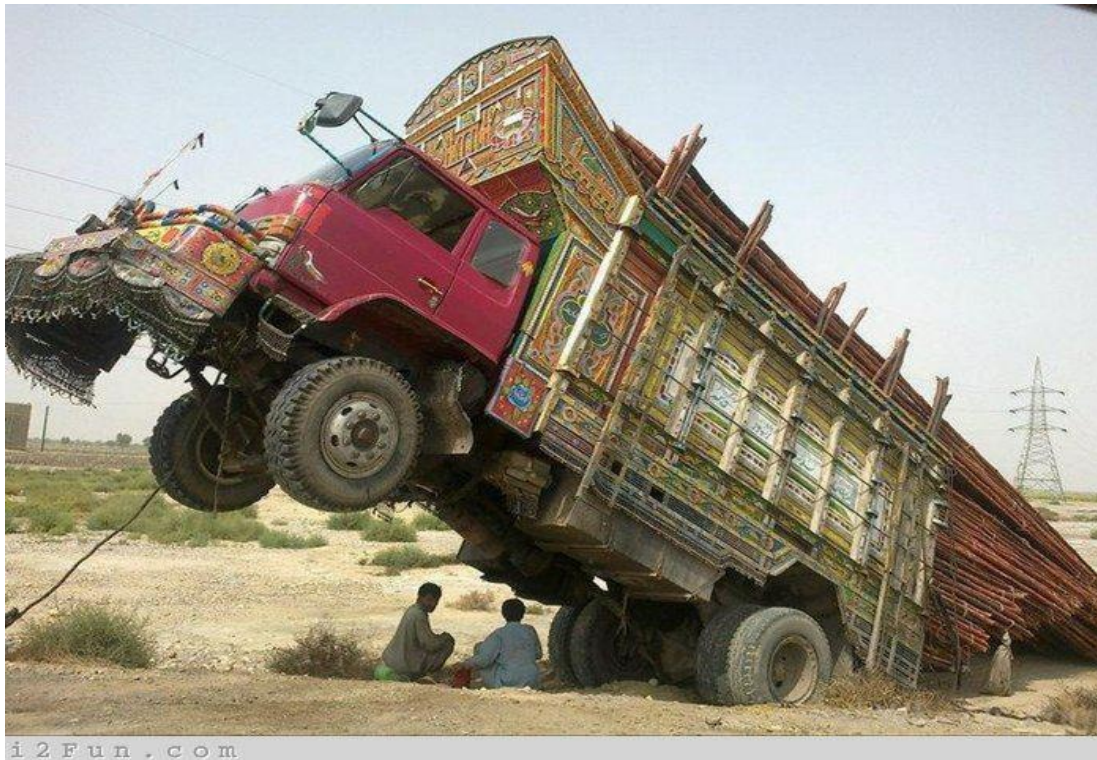
(Received October 1994; accepted after revision March 1995)

Bischoff & Ratcliff list of requirements

- Orientation
- Weight limit
- Weight distribution
- Load bearing strength
- Stability
- Grouping of items
- Separation of items
- Multi-drop
- Complete shipment
- Shipment priorities
- Complexity of loading arrangement
- Handling

Why do we need these practical constraints?

- When we load containers, trucks, or ships, we do it to **move** products
- Cutting problems and Packing problems differ in their applications



Bischoff & Ratcliff (1995) list of requirements

- Orientation
- Weight limit
- Weight distribution
- Load bearing strength
- Stability
- Grouping of items
- Separation of items
- Multi-drop
- Complete shipment
- Shipment priorities
- Complexity of loading arrangement
- Handling

Almost 20 years later...

European Journal of Operational Research 229 (2013) 1–20



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European Journal of Operational Research

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Invited Review

Constraints in container loading – A state-of-the-art review

Andreas Bortfeldt, Gerhard Wäscher*

Otto-von-Guericke University Magdeburg, Faculty of Economics and Management, Department of Management Science, Germany



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ABSTRACT

Container loading is a pivotal function for operating supply chains efficiently. Underperformance results in unnecessary costs (e.g. cost of additional containers to be shipped) and in an unsatisfactory customer service (e.g. violation of deadlines agreed to or set by clients). Thus, it is not surprising that container loading problems have been dealt with frequently in the operations research literature. It has been claimed though that the proposed approaches are of limited practical value since they do not pay enough attention to constraints encountered in practice.

In this paper, a review of the state-of-the-art in the field of container loading will be given. We will identify factors which – from a practical point of view – need to be considered when dealing with container loading problems and we will analyze whether and how these factors are represented in methods for the solution of such problems. Modeling approaches, as well as exact and heuristic algorithms will be reviewed. This will allow for assessing the practical relevance of the research which has been carried out in the field. We will also mention several issues which have not been dealt with satisfactorily so far and give an outlook on future research opportunities.

Did we follow the agenda of Bischoff and Ratcliff?

Constraint type	Papers (1980-2011): 163	
	Absolute	Relative (%)
No constraints	36	22.1
Orientation	115	70.6
Weight limit	23	14.1
Weight distribution	19	11.7
Load bearing	25	15.3
Stability	61	37.4
Allocation	13	8.0
Positioning	28	17.2
Complete shipment	1	0.6
Shipment priorities	3	1.8
Complexity	15	9.2

Did we follow the agenda of Bischoff and Ratcliff?

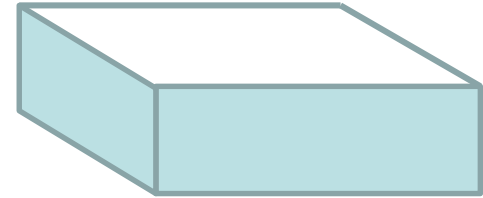
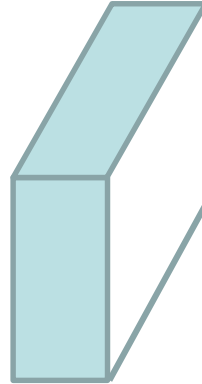
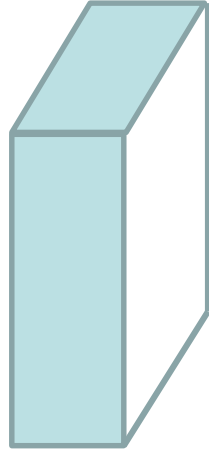
Number of constraints	Papers (1980-2011): 163	
	Absolute	Relative (%)
0	36	22.1
1	51	31.3
2	35	21.5
3	15	9.2
4	6	3.7
5	9	5.5
6	9	5.5
7	2	1.2

Since 2011... has the situation improved?

(this slide was intentionally left blank)

Orientation

Theoretically:



In practice:



Most papers consider the orientation constraints on the items

Weight limit

Most papers consider the limit on the total weight of the cargo

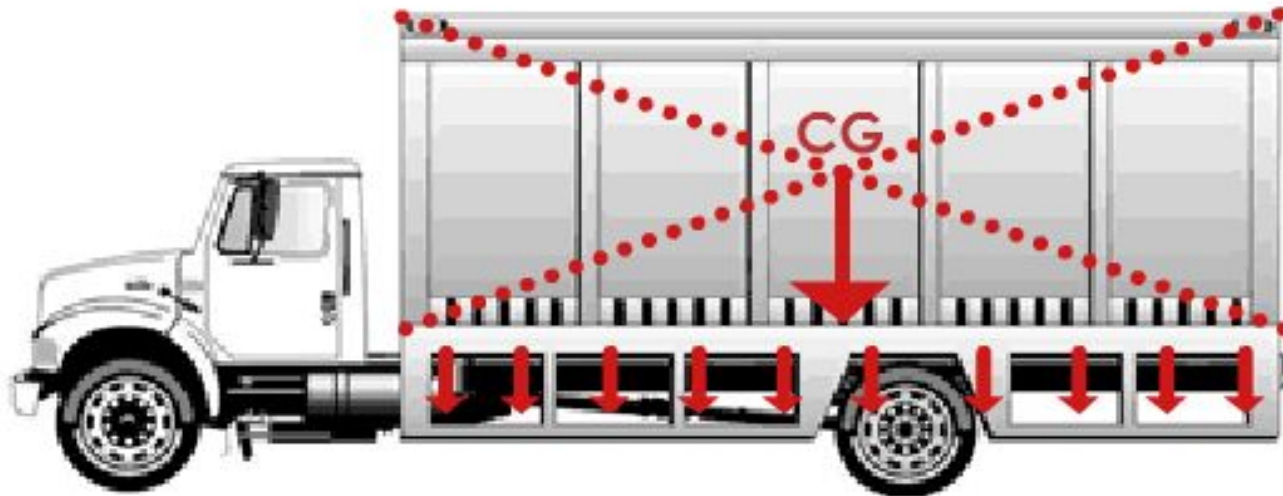


<https://constative.com/lifestyle/overloaded-truck-sahara-desert/>

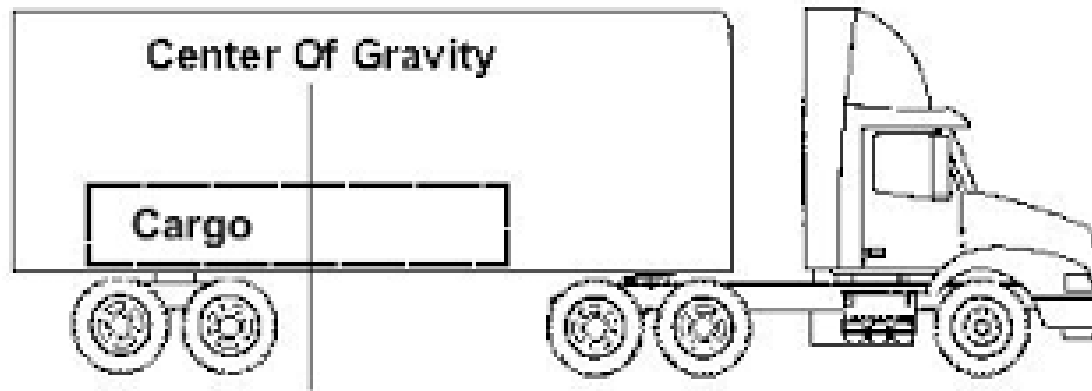
Weight distribution

SIMPLE APPROACH:

Control the position of the centre of gravity



Weight distribution



Wrong



Wrong



Right

Controlling the position of the centre of gravity

Weight distribution

MORE REALISTIC APPROACH:

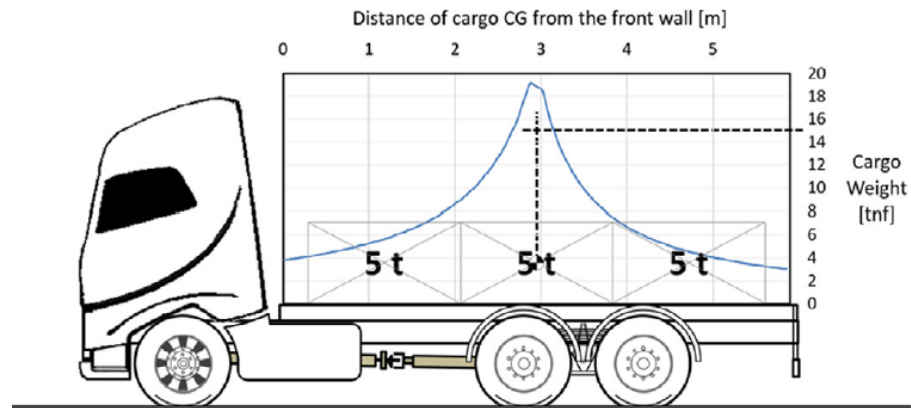
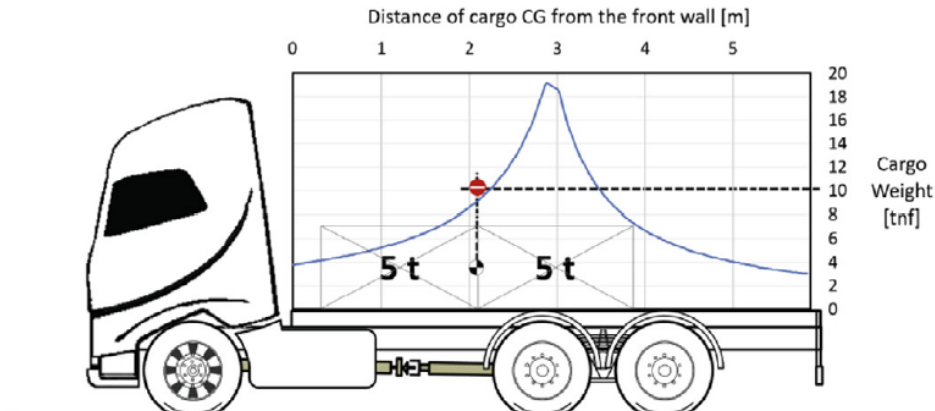


Fig. 1. (a) LDD example of a regulation compliant load arrangement

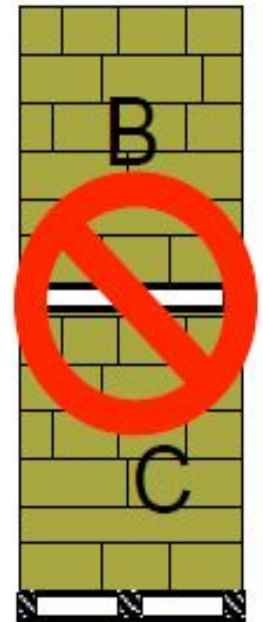
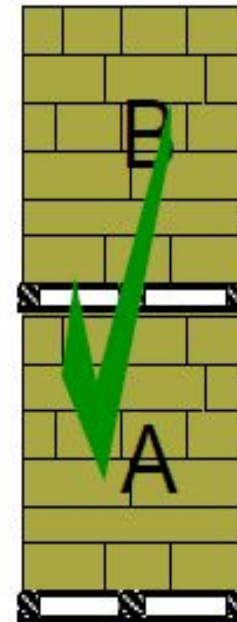
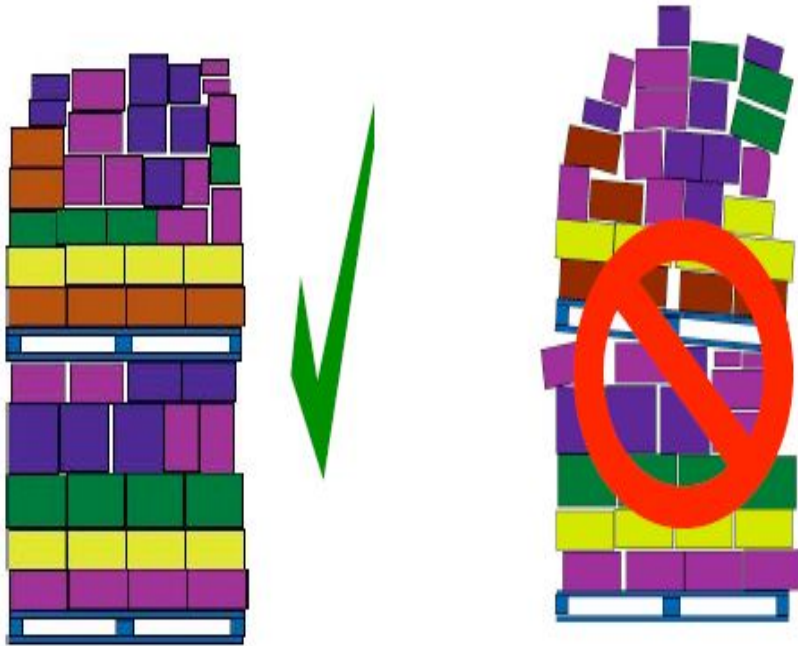


(b) LDD example of a regulation noncompliant load arrangement.

Load bearing



Load bearing





Heuristic algorithms for a three-dimensional loading capacitated vehicle routing problem in a carrier[☆]



Leonardo Junqueira^a, Reinaldo Morabito^{b,*}

C1 – Orientation constraints	C6 – Weight limit constraints
C2 – Cargo stability constraints	C7 – Time windows constraints
C3 – Multi-drop constraints	C8 – Time-constrained routes
C4 – Load bearing/fragility constraints	C9 – Pickup and delivery points
C5 – Boxes in pallets first, pallets in vehicles second	C10 – Split deliveries

References in alphabetical order	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10
Bortfeldt (2012)	X	X	X	X		X				
Bortfeldt and Homberger (2013)	X	X	X				X			
Ceschia et al. (2013)	X	X	X	X		X				X
Fuellerer et al. (2010)	X	X	X	X		X				
Gendreau et al. (2006)	X	X	X	X		X				
Junqueira, Oliveira, Carravilla, and Morabito (2013)	X	X	X	X						
Lacomme et al. (2013)	X					X				
Moura and Oliveira (2009)	X	X	X				X			
Ruan et al. (2013)	X	X	X	X		X				
Tao and Wang (2013)	X	X	X	X		X				
Tarantilis et al. (2009)	X	X	X	X		X				
Zachariadis et al. (2012)	X	X			X		X	X		
Zachariadis et al. (2013)	X	X			X		X		X	
Zhu et al. (2012)	X	X	X	X		X				

Load bearing: integer linear models

Computers & Operations Research 39 (2012) 74–85



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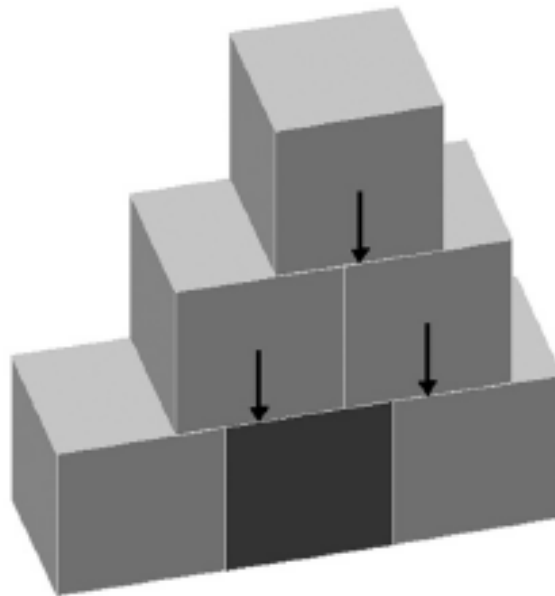
Computers & Operations Research

journal homepage: www.elsevier.com/locate/caor



Three-dimensional container loading models with cargo stability and load bearing constraints

Leonardo Junqueira, Reinaldo Morabito*, Denise Sato Yamashita



Load bearing: integer linear models

Computers & Operations Research 39 (2012) 74–85



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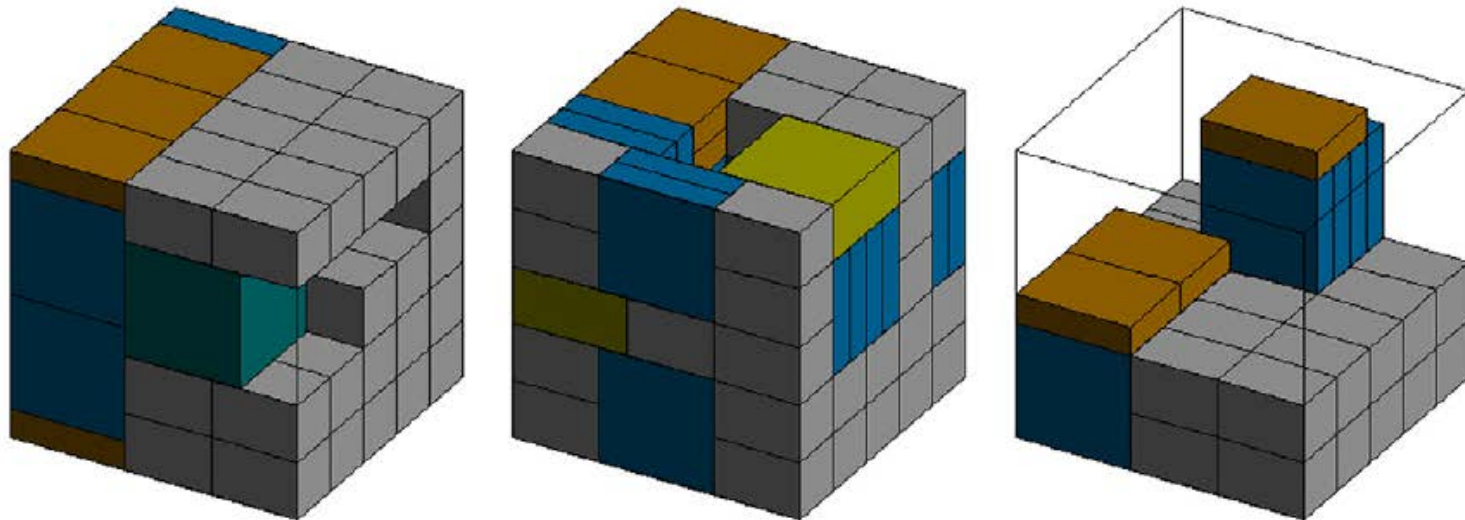
Computers & Operations Research

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Three-dimensional container loading models with cargo stability and load bearing constraints

Leonardo Junqueira, Reinaldo Morabito*, Denise Sato Yamashita



Load bearing: metaheuristic algorithms



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European Journal of Operational Research 168 (2006) 952–966

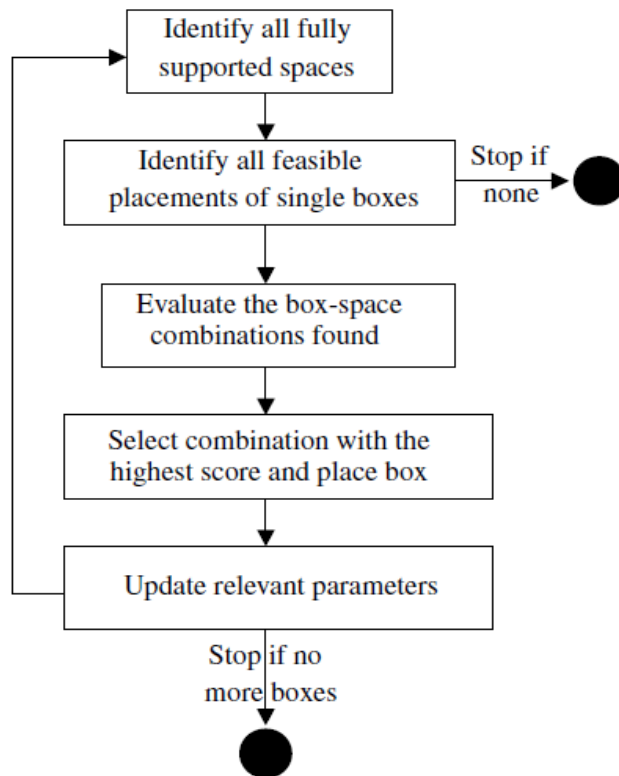
EUROPEAN
JOURNAL
OF OPERATIONAL
RESEARCH

www.elsevier.com/locate/ejor

Discrete Optimization

Three-dimensional packing of items with limited load bearing strength

E.E. Bischoff *



$$E = \frac{v_1}{r_1} C_1 + \frac{v_2}{r_2} C_2 - \frac{v_3}{r_3} C_3 + \frac{v_4}{r_4} C_4 - \frac{v_5}{r_5} C_5$$

C1: Relation between box size and position of loading surface

C2: Match between box and space dimensions

C3: Unusable space generated

C4: Potential for building columns of identical boxes

C5: Relative loss in load bearing capacity

Update of parameters: Nelder-Mead procedure

Load bearing: metaheuristic algorithms

European J. Industrial Engineering, Vol. 8, No. 5, 2014

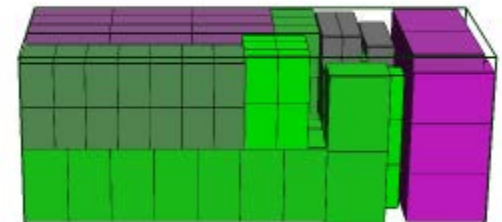
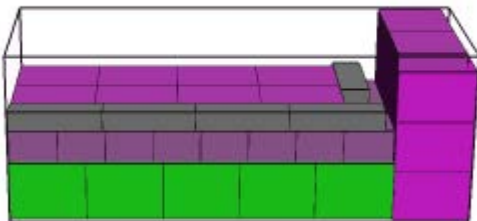
669

A reactive GRASP algorithm for the container loading problem with load-bearing constraints

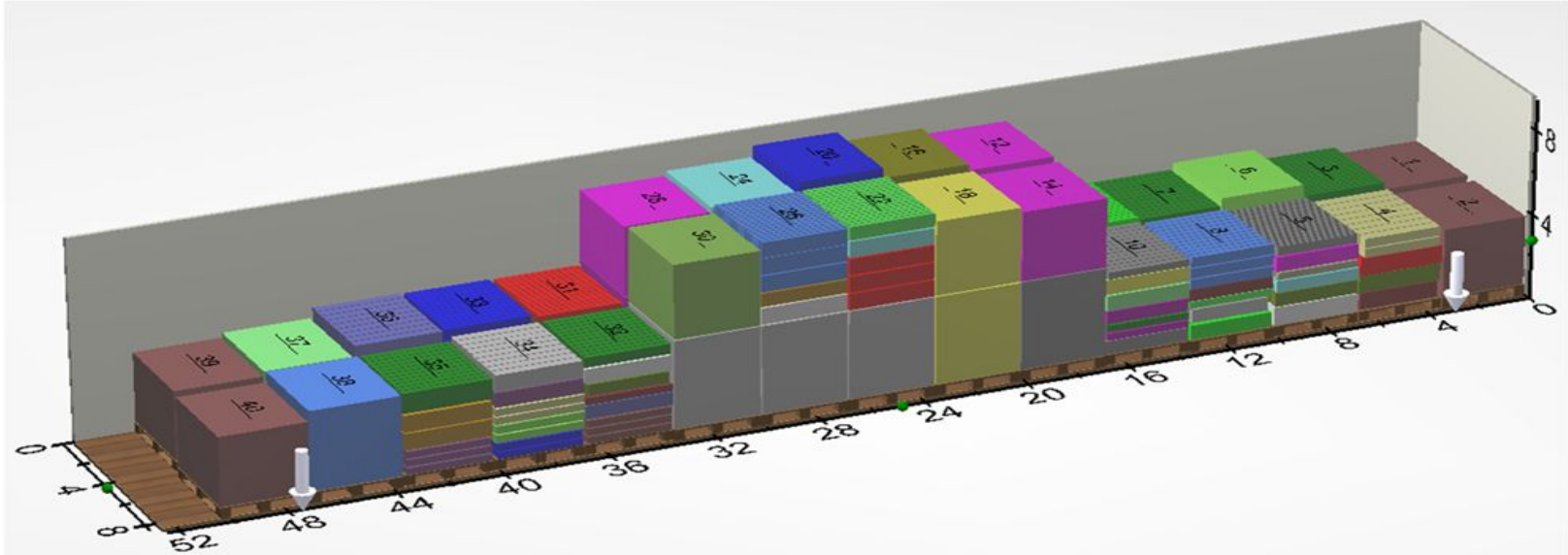
Maria Teresa Alonso*
Francisco Parreño

Ramon Alvarez-Valdes
Jose Manuel Tamarit

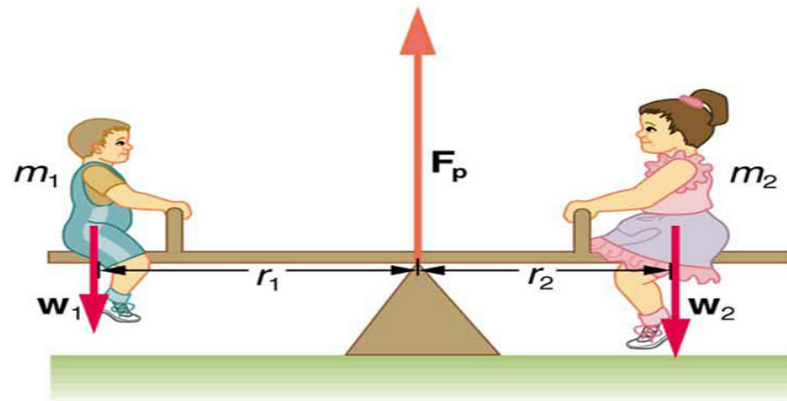
- Several constructive algorithms selected according to a reactive random strategy
- Some improvements moves tailored to the problem



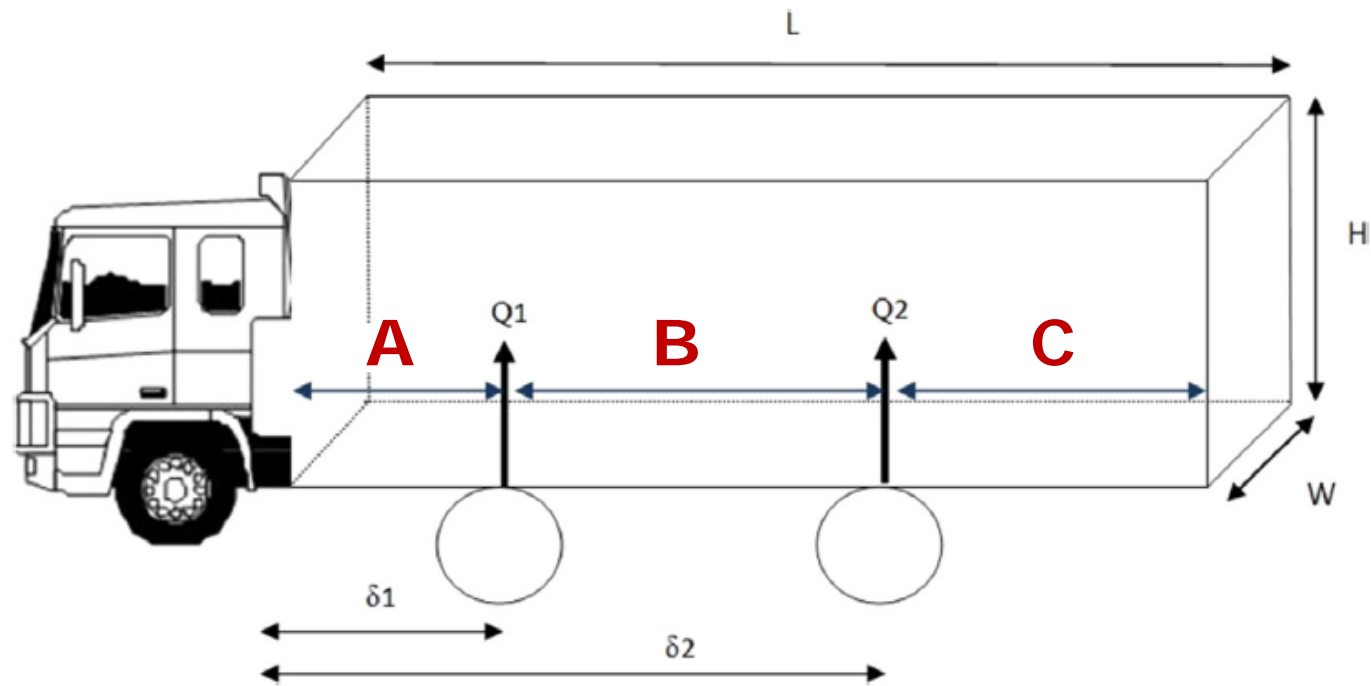
Axle weight constraints



<https://ortec.com>



Axle weight constraints



Axle forces per section.

Sections	Position	Force on axle 1	Force on axle 2
Section A	$0 \leq p_i^x \leq \delta_1$	$q_i(\delta_2 - p_i^x)$	$-q_i(\delta_1 - p_i^x)$
Section B	$\delta_1 < p_i^x \leq \delta_2$	$q_i(\delta_2 - p_i^x)$	$q_i(p_i^x - \delta_1)$
Section C	$\delta_2 < p_i^x \leq L$	$-q_i(p_i^x - \delta_2)$	$q_i(p_i^x - \delta_1)$

Axle weight constraints: heuristics

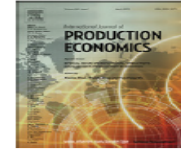
Int. J. Production Economics 144 (2013) 358–369



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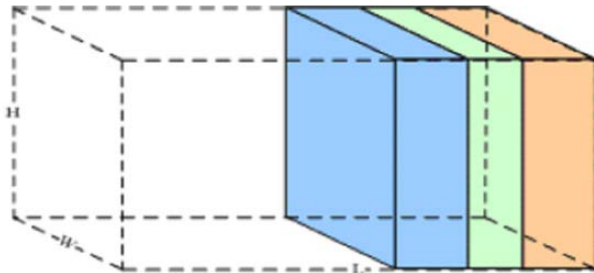
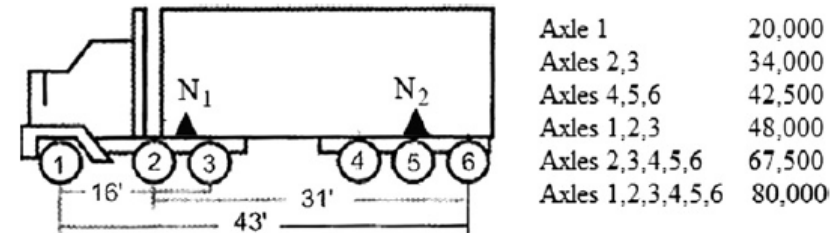
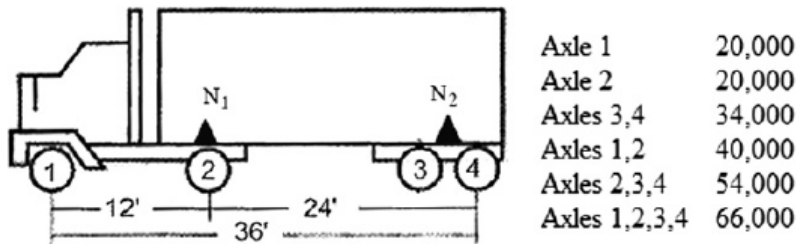
Int. J. Production Economics

journal homepage: www.elsevier.com/locate/ijpe



The single container loading problem with axle weight constraints

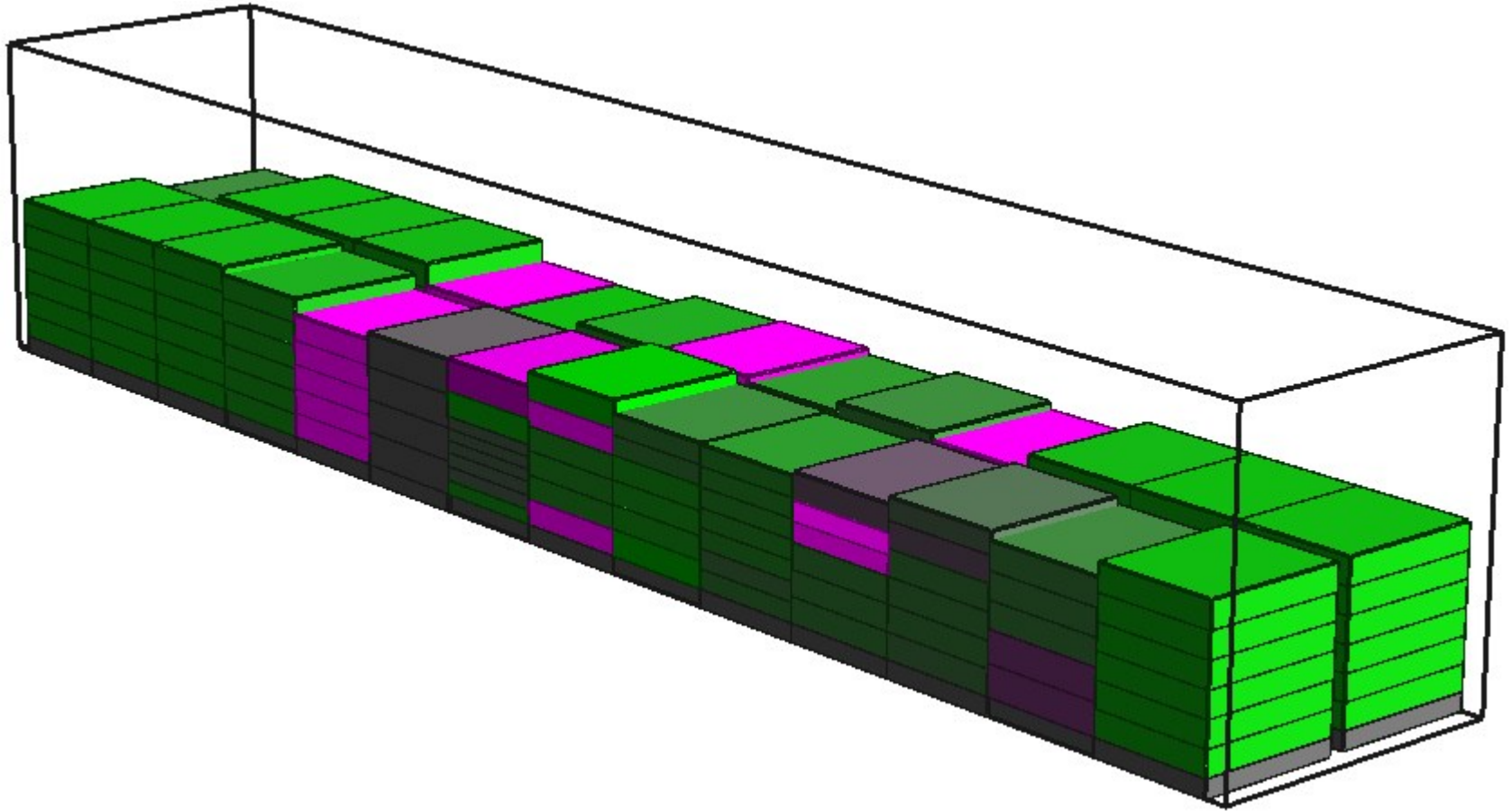
Andrew Lim^a, Hong Ma^{b,*}, Chaoyang Qiu^c, Wenbin Zhu^a



+ MIP model for rearranging walls

GRASP Wall building
(Moura & Oliveira, 2005)

Axle weight constraints: heuristics



Axle weight constraints: models

$$\min \sum_{k \in K} y_k$$

$$\sum_{k \in K} \sum_{i \in I} x_{kij} \geq n_j \quad j \in J$$

Demands must be satisfied

$$\sum_{j \in J} h_j x_{kij} \leq H y_k \quad k \in K, i \in I$$

Not exceeding the truck height

$$\sum_{i \in I} \sum_{j \in J} q_j x_{kij} \leq Q^{\max} y_k \quad k \in K$$

Not exceeding the maximum truck weight

$$\sum_{i \in I} \sum_{j \in J} q_j x_{kij} (\delta_2 - p_i^x) \leq Q_1 (\delta_2 - \delta_1) y_k \quad k \in K$$

Not exceeding the axle weight limits

$$\sum_{i \in I} \sum_{j \in J} q_j x_{kij} (p_i^x - \delta_1) \leq Q_2 (\delta_2 - \delta_1) y_k \quad k \in K$$

$$\sum_{j \in J} \sum_{i \in I} q_j x_{kij} \geq \sum_{j \in J} \sum_{i \in I} q_j x_{k+1ij} \quad k \in K : k \leq lb$$

$$y_k \geq y_{k+1} \quad k \in K : k < |K|$$

Keep the trucks ordered

$$y_k = 1 \quad k \in K : k \leq lb$$

$$x_{kij} \geq 0, \text{ integer} \quad k \in K, i \in I, j \in J$$

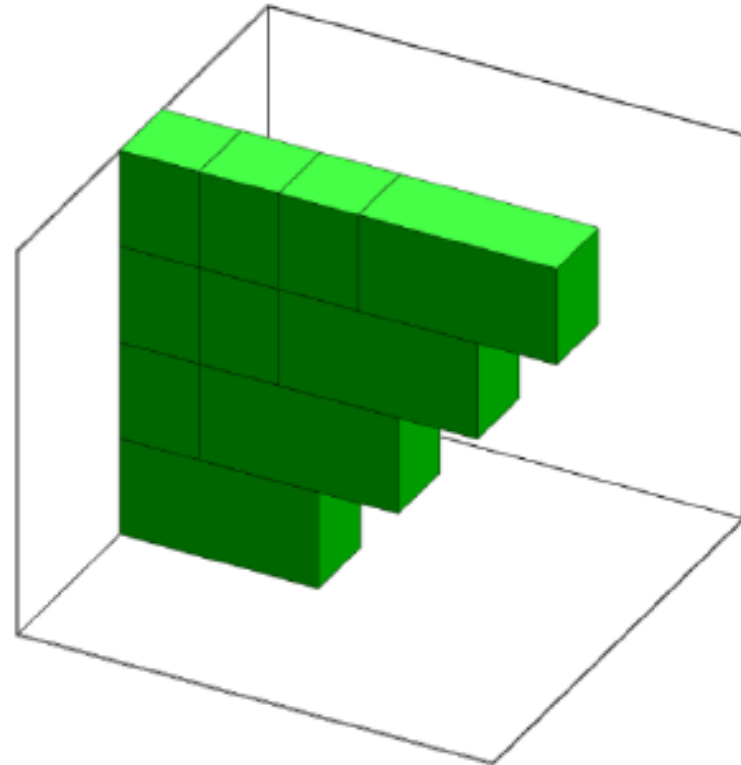
$$y_k \in \{0,1\} \quad k \in K$$

Static stability: simple approach

Full support



Partial support



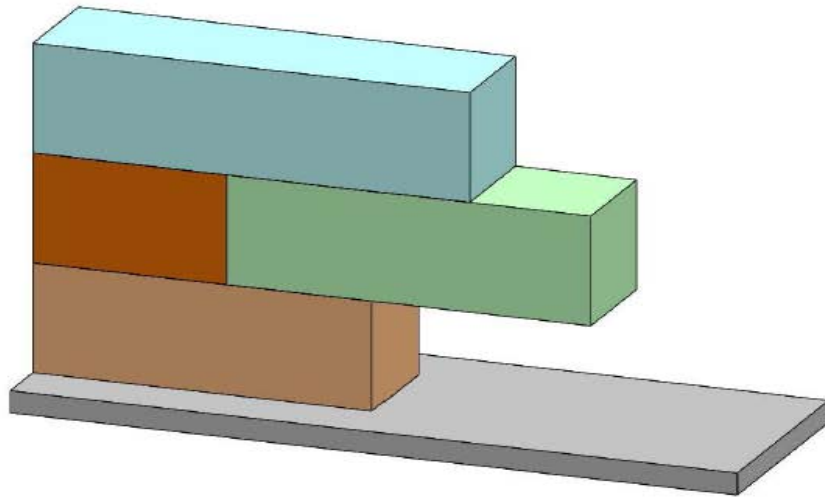
Static stability: more elaborated approach

- Stability of the cargo during the loading operation.
- Stacking and standing of the cargo in the container floor.
- Closely related with the actual packing sequence of boxes inside the container.



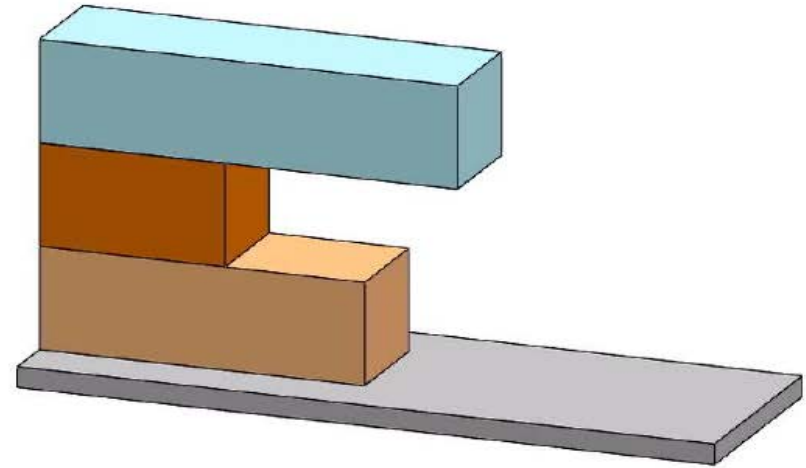
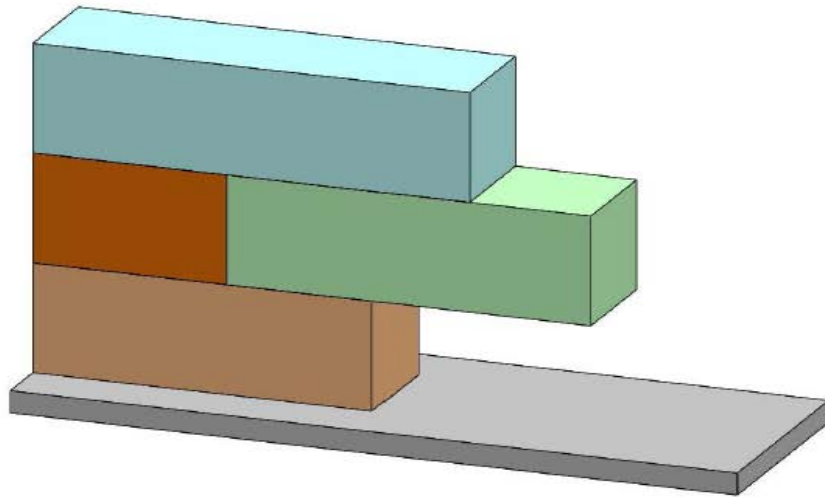
Static stability: more elaborated approach

Evaluate whether building an arrangement of boxes is feasible



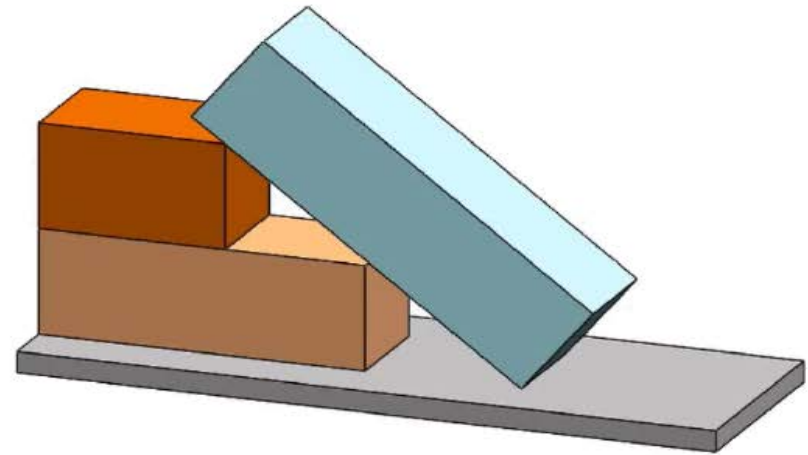
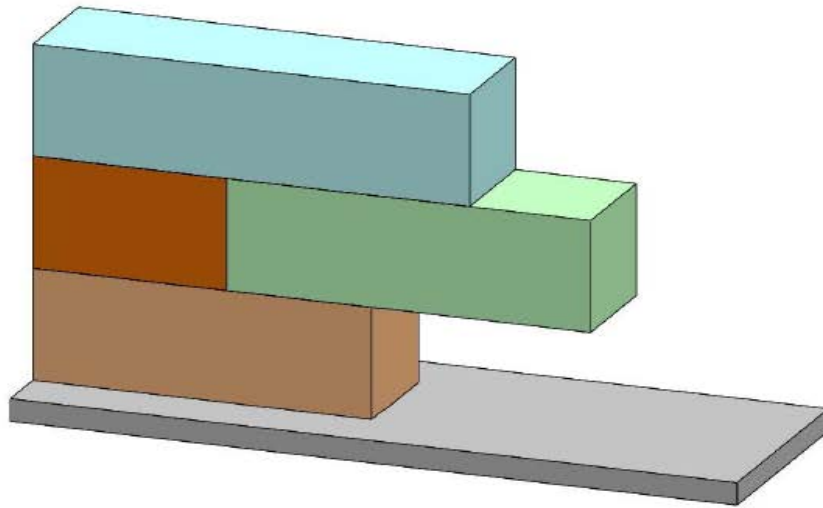
Static stability: more elaborated approach

Evaluate whether building an arrangement of boxes is feasible



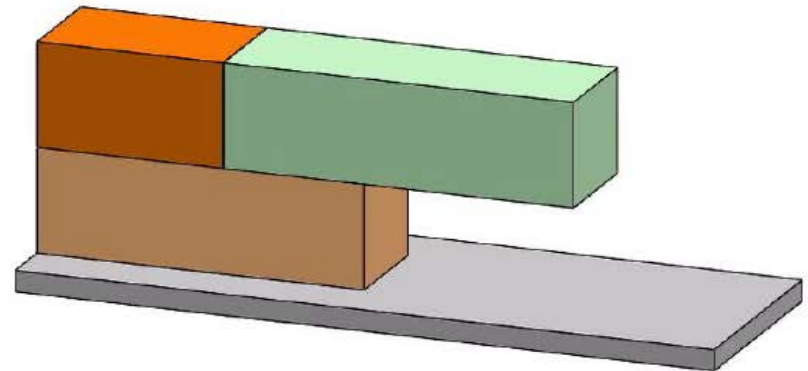
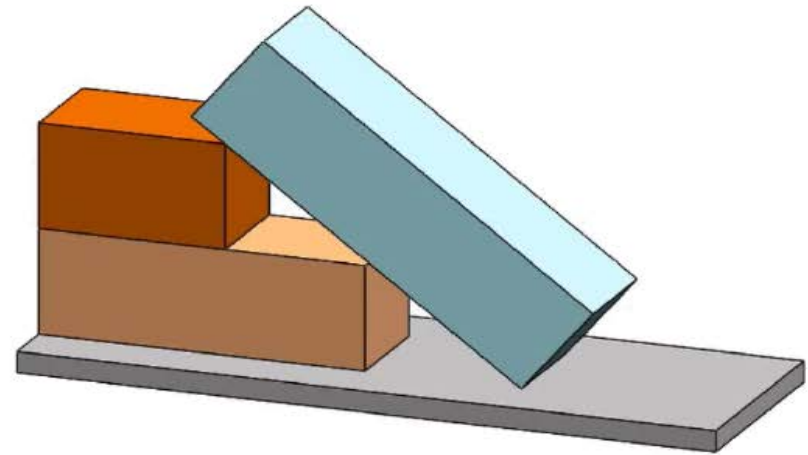
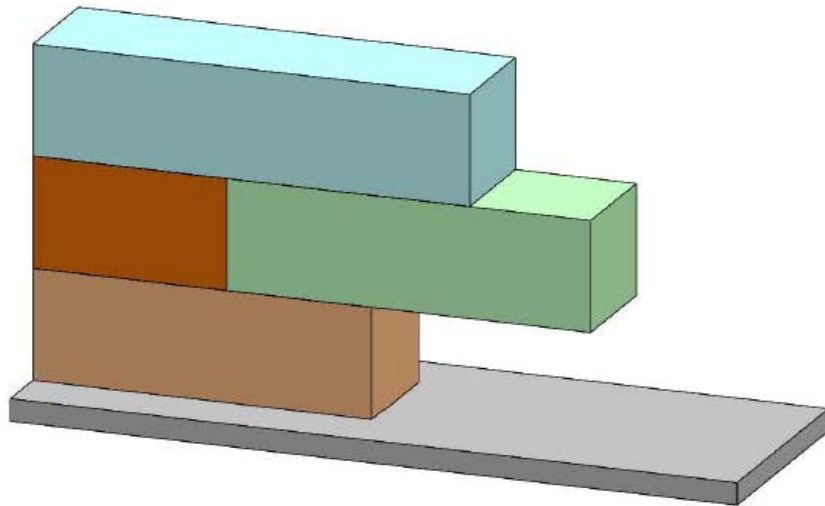
Static stability: more elaborated approach

Evaluate whether building an arrangement of boxes is feasible



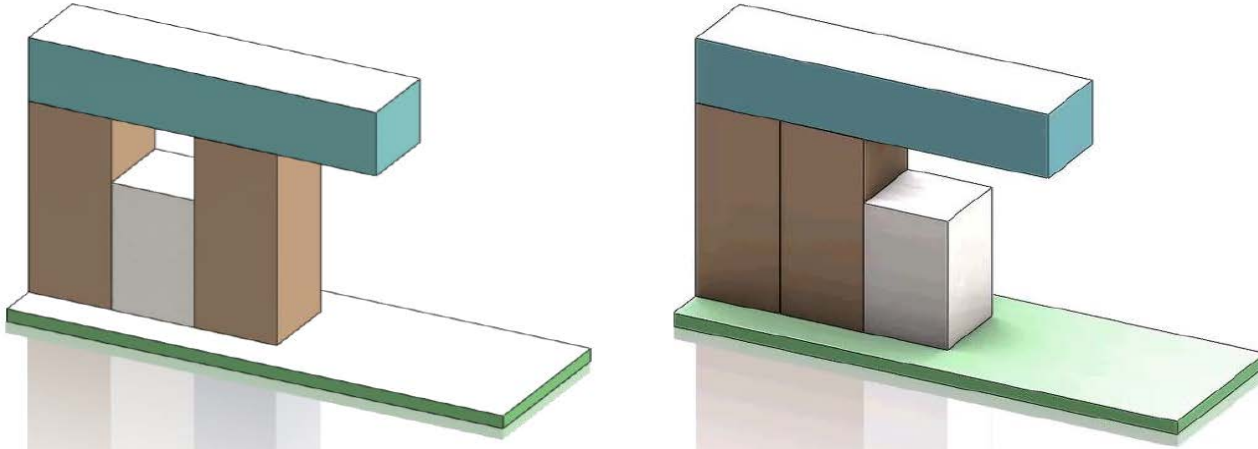
Static stability: more elaborated approach

Evaluate whether building an arrangement of boxes is feasible



Static stability: more elaborated approach

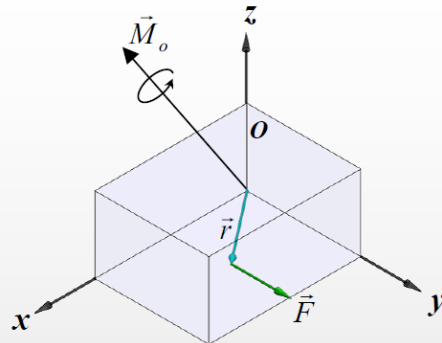
Evaluate stability independently of base support



Based on static mechanical equilibrium conditions applied to rigid bodies

$$\sum \vec{F} = 0$$

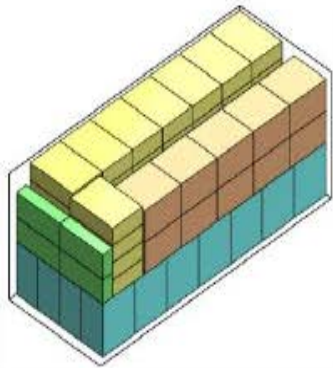
$$\sum \vec{M}_o = \sum (\vec{r} \times \vec{F}) = 0$$



Dynamic Stability



Dynamic stability



Cargo
arrangement



Transportation
scenario



Outcome

Some examples of outcomes



Some examples of outcomes



Some examples of outcomes



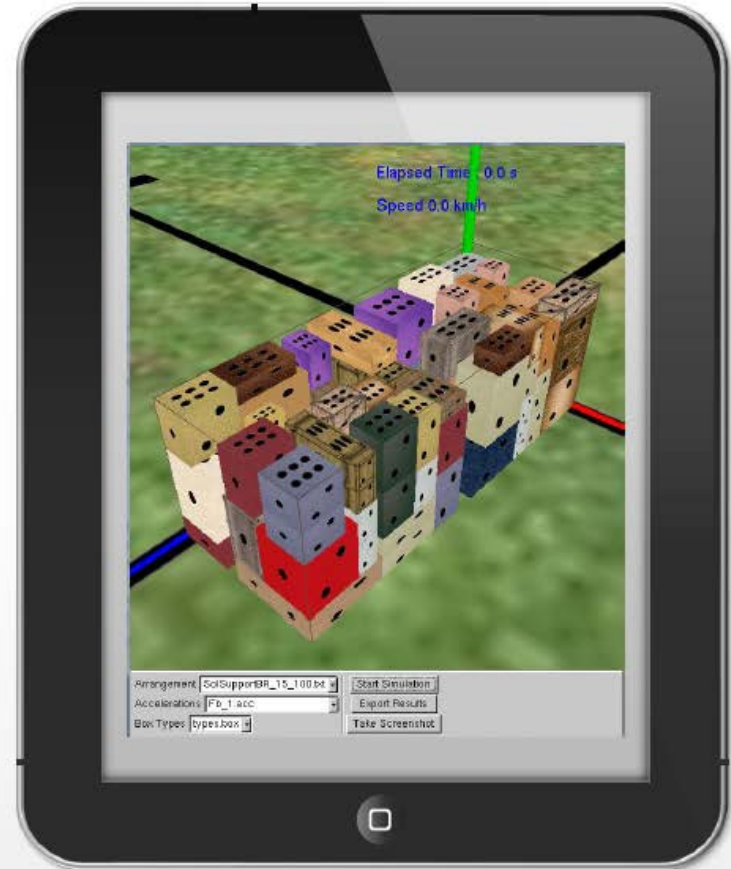
Some examples of outcomes



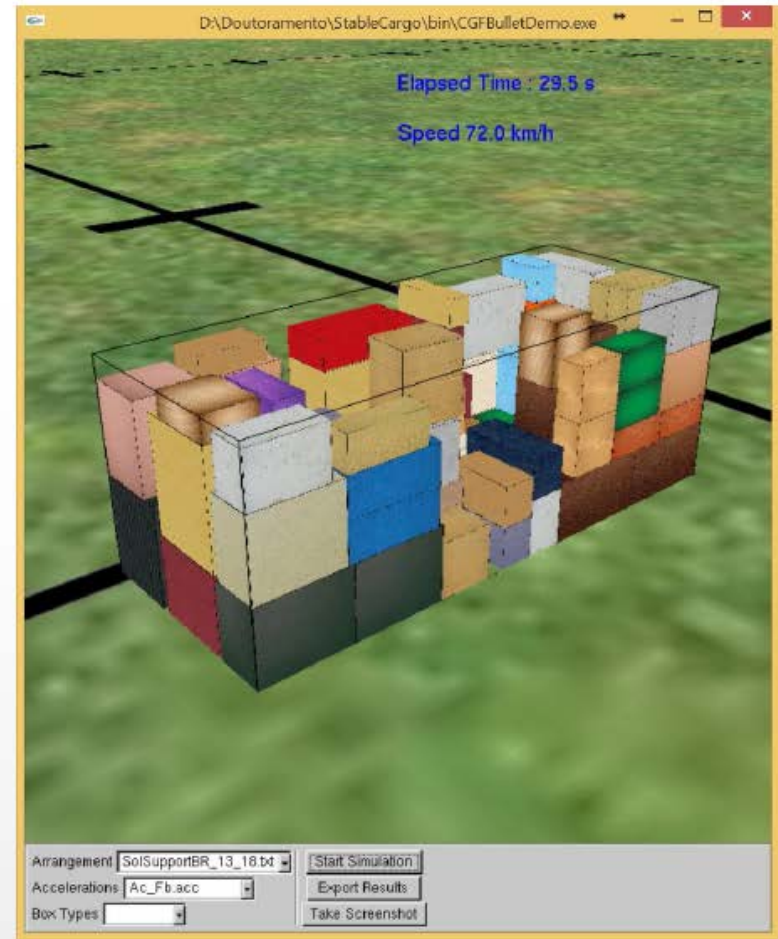
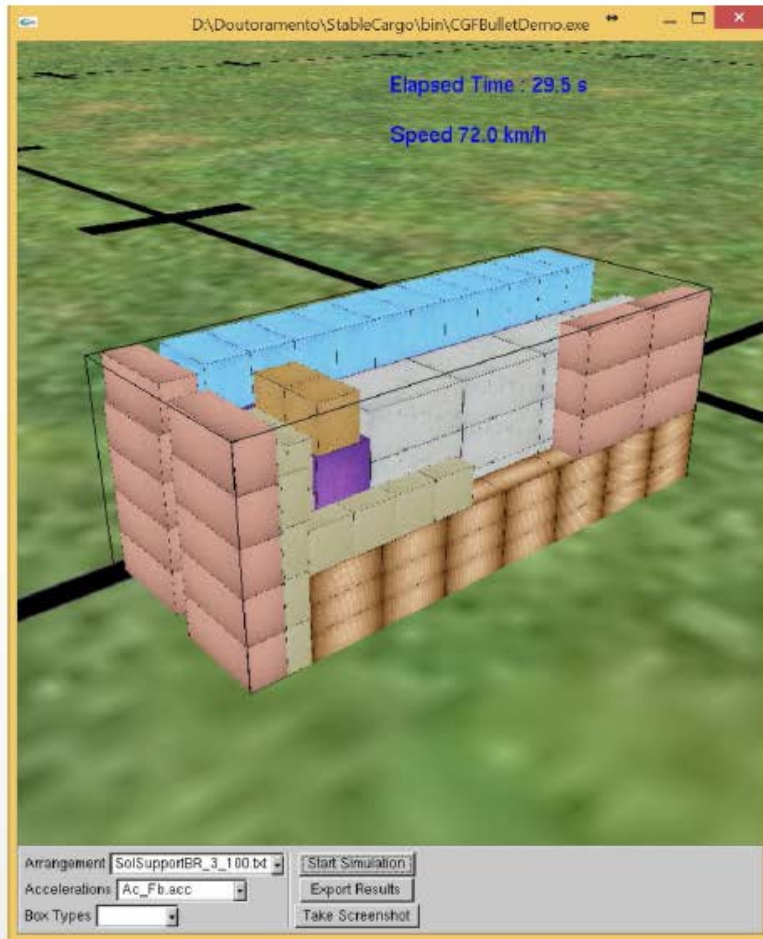
Simulation of dynamic stability

Physics engine

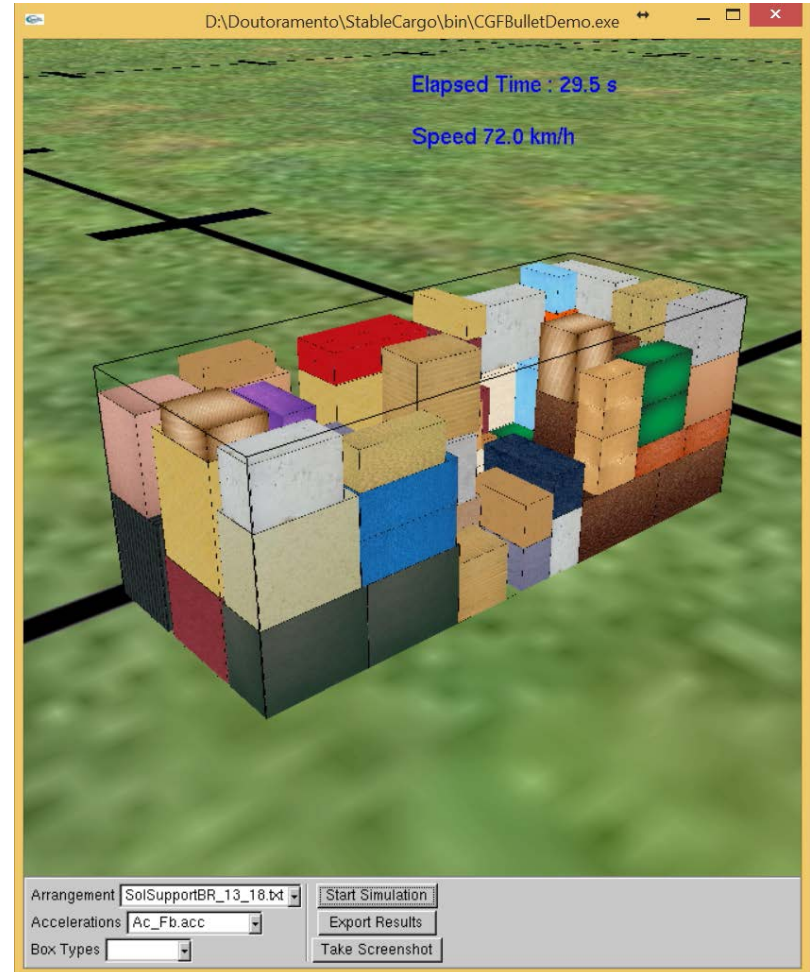
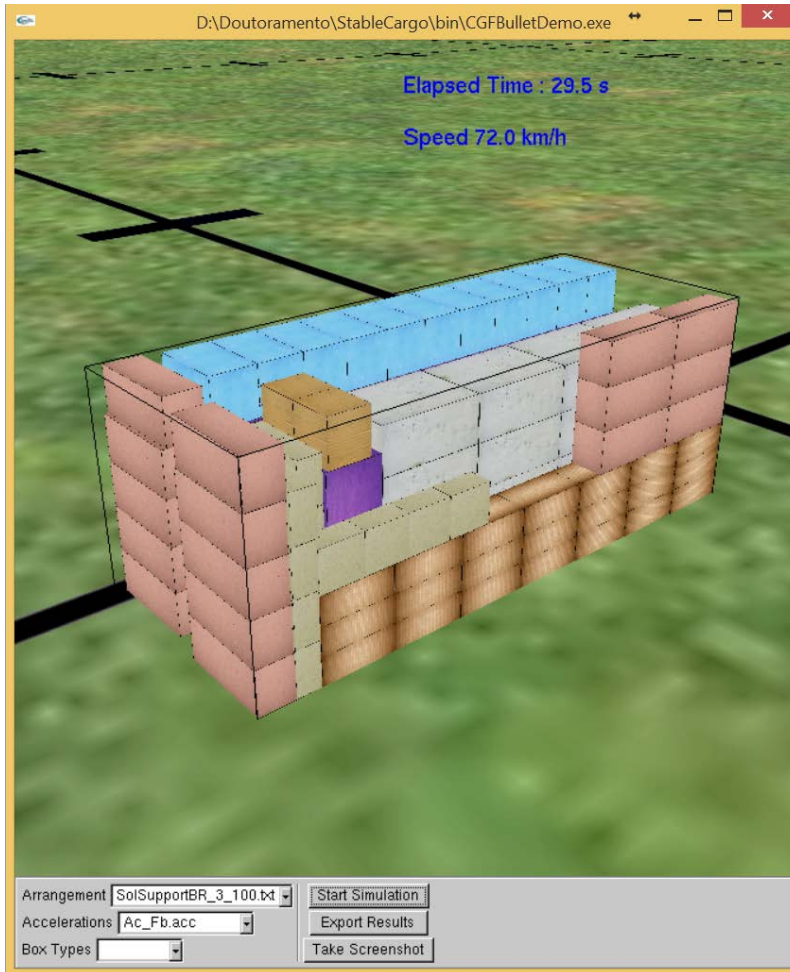
- Software system that simulates Newtonian physics in a simulated environment.
- Bullet Collision Detection and Physics Library3D (v 2.81)
 - collision detection,
 - rigid body dynamics,
 - soft body dynamics.



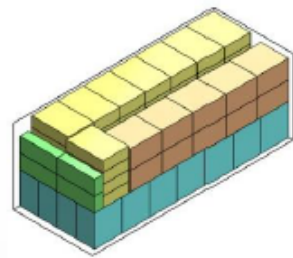
Simulation of dynamic stability



Examples



Approach to dynamic stability



Cargo arrangement



Transportation scenario



Outcome



Dynamic stability metrics



Multiple linear regression analysis

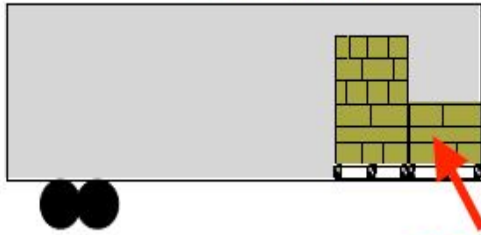


Dynamic stability performance indicators



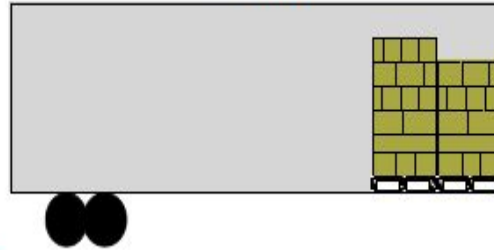
A simpler approach when packing pallets

Undesirable

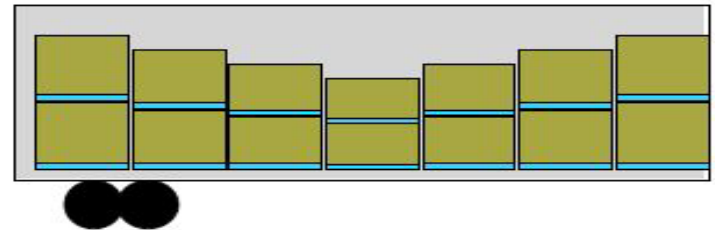
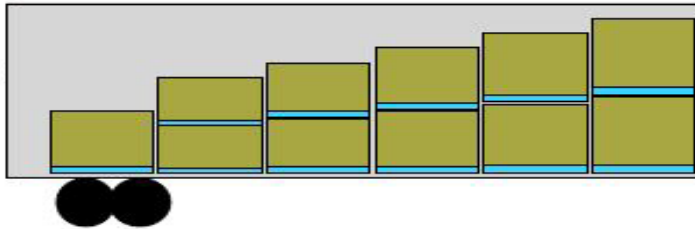
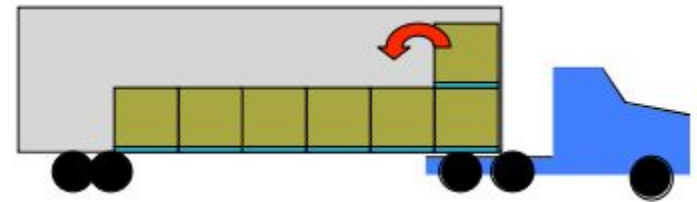
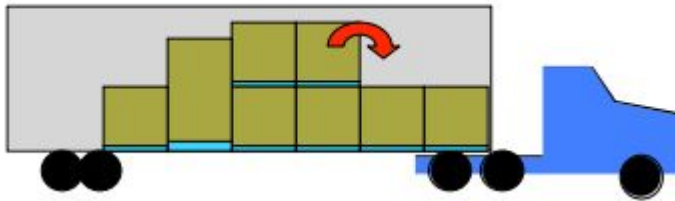
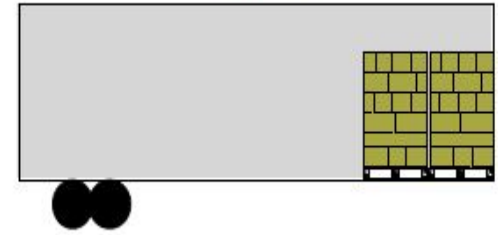


Too short

Better

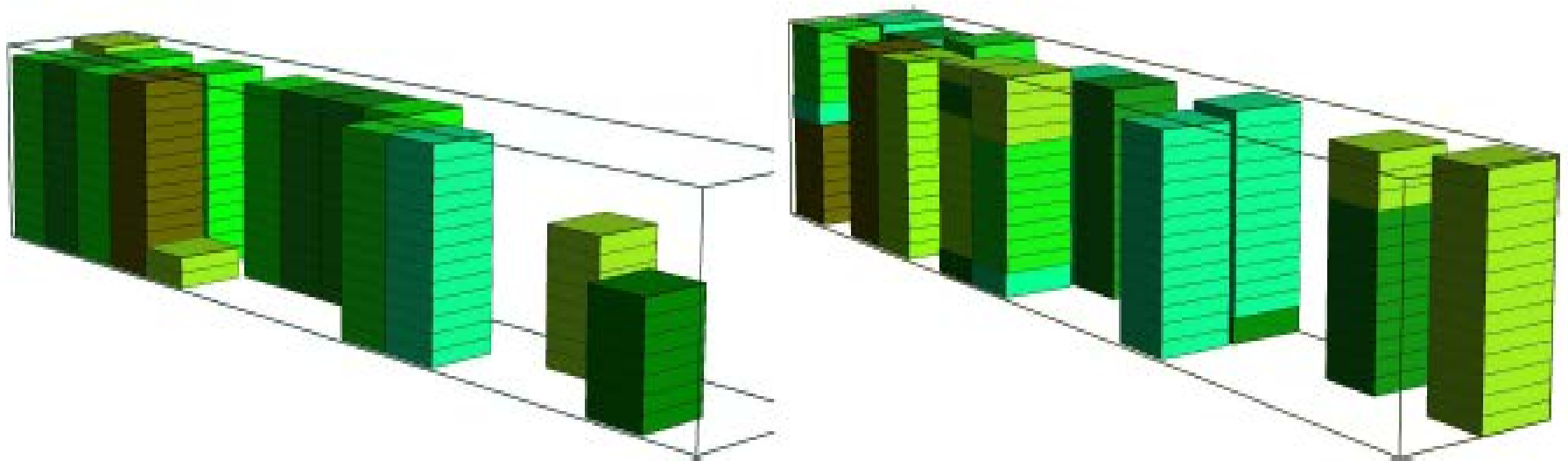


Best



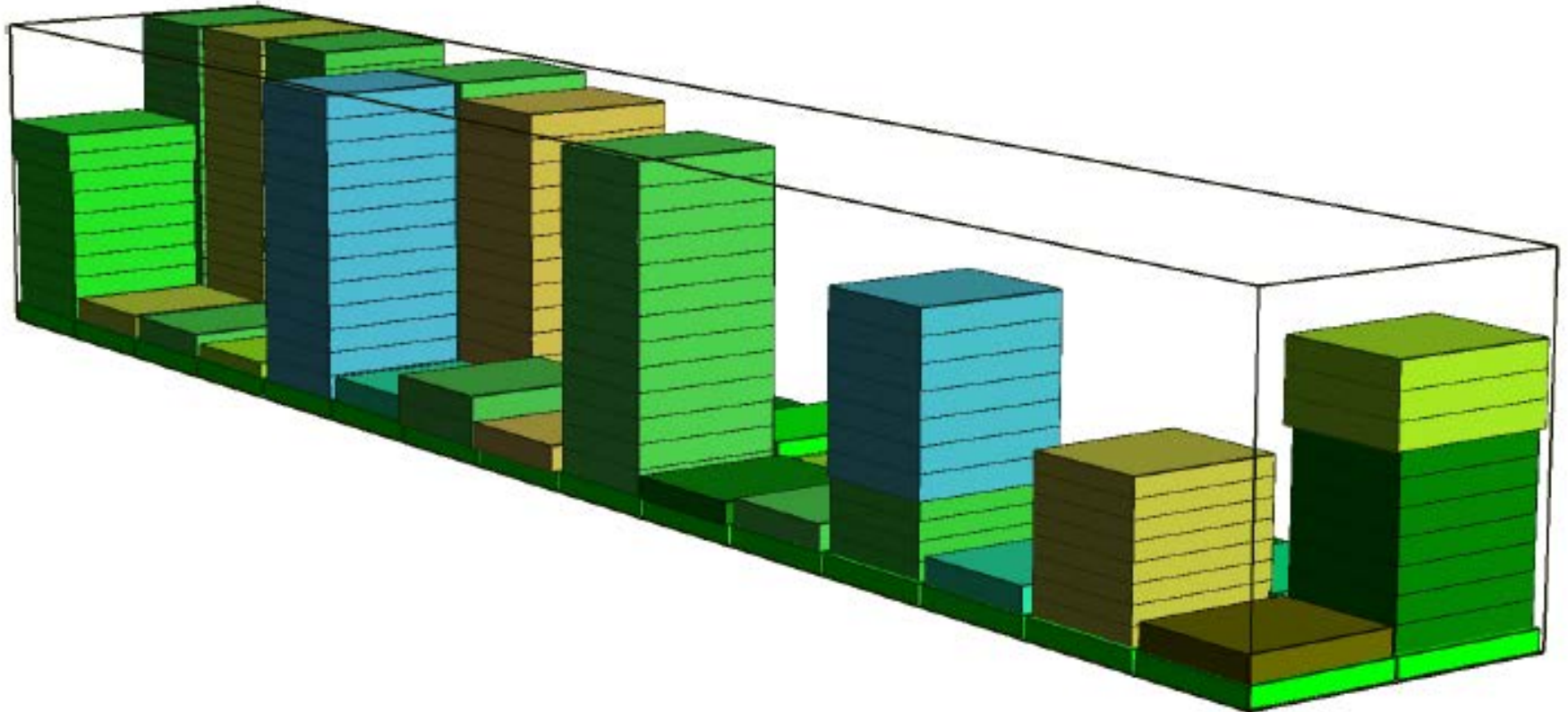
Possible outcomes of the basic model

Considering weight limit and axle weight constraints

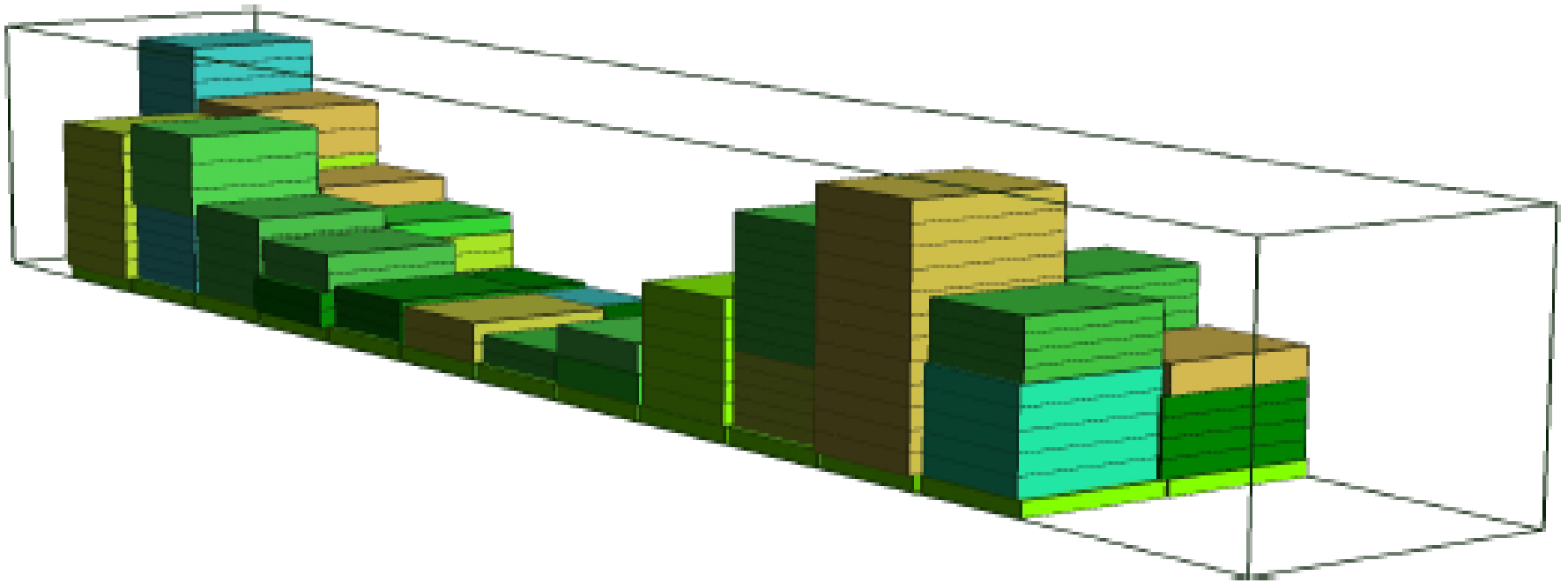


and the stability?

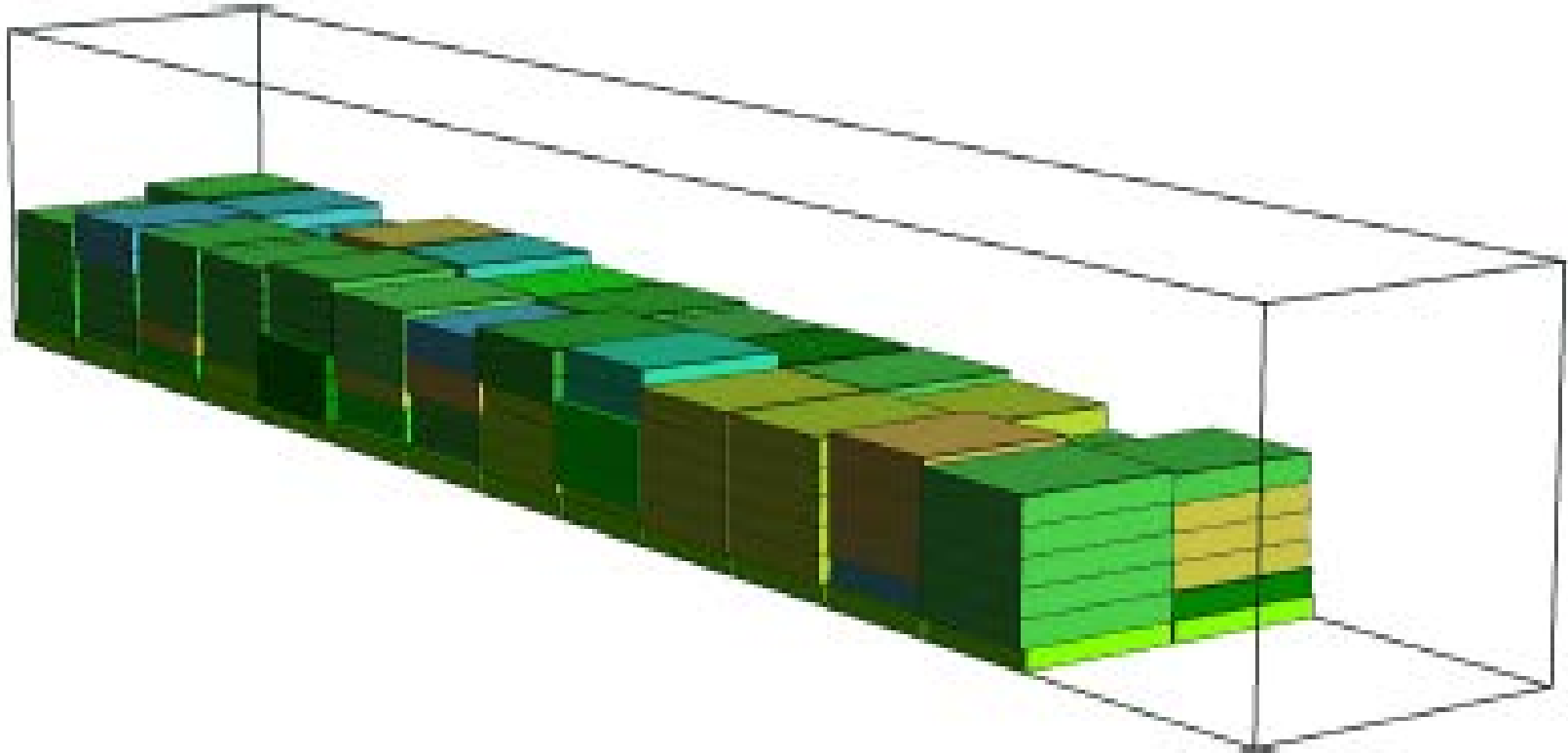
Preventing empty spaces between pallets



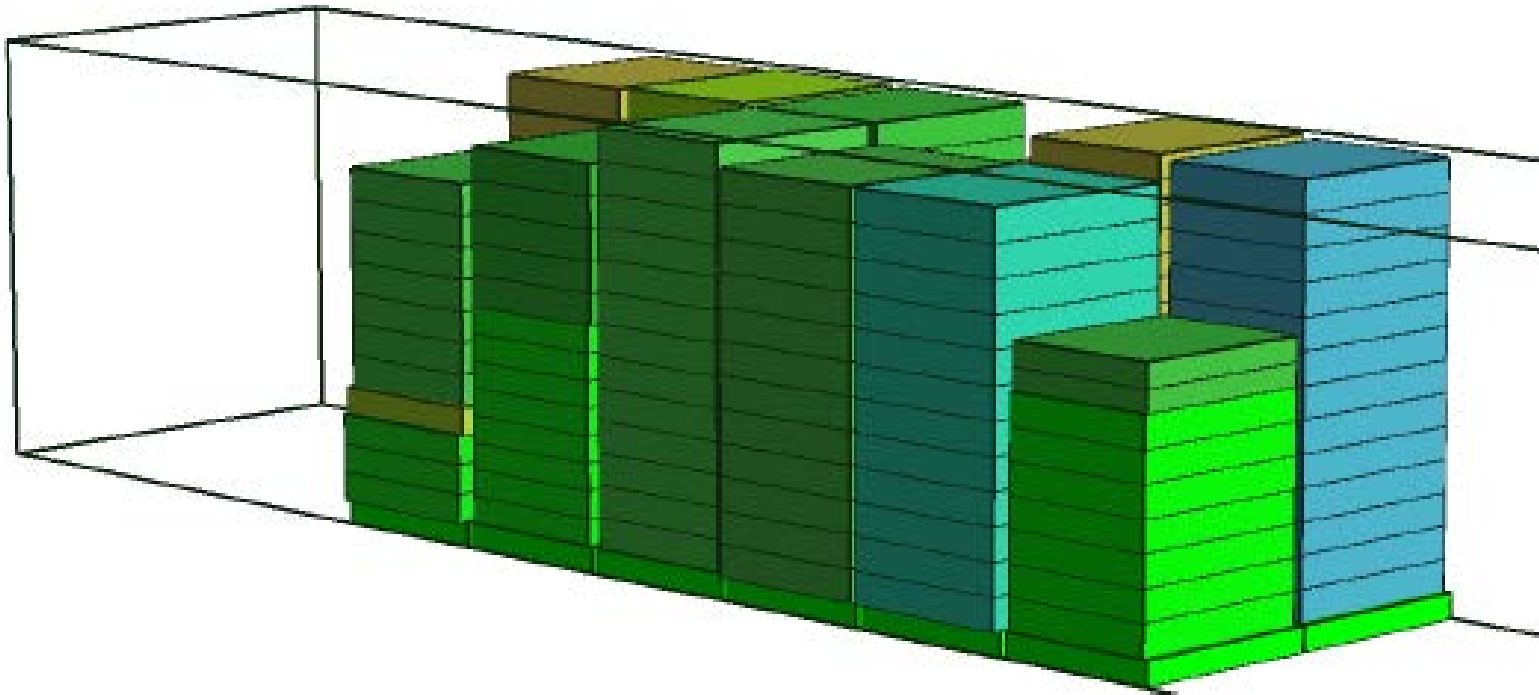
Controlling height differences between adjacent pallets



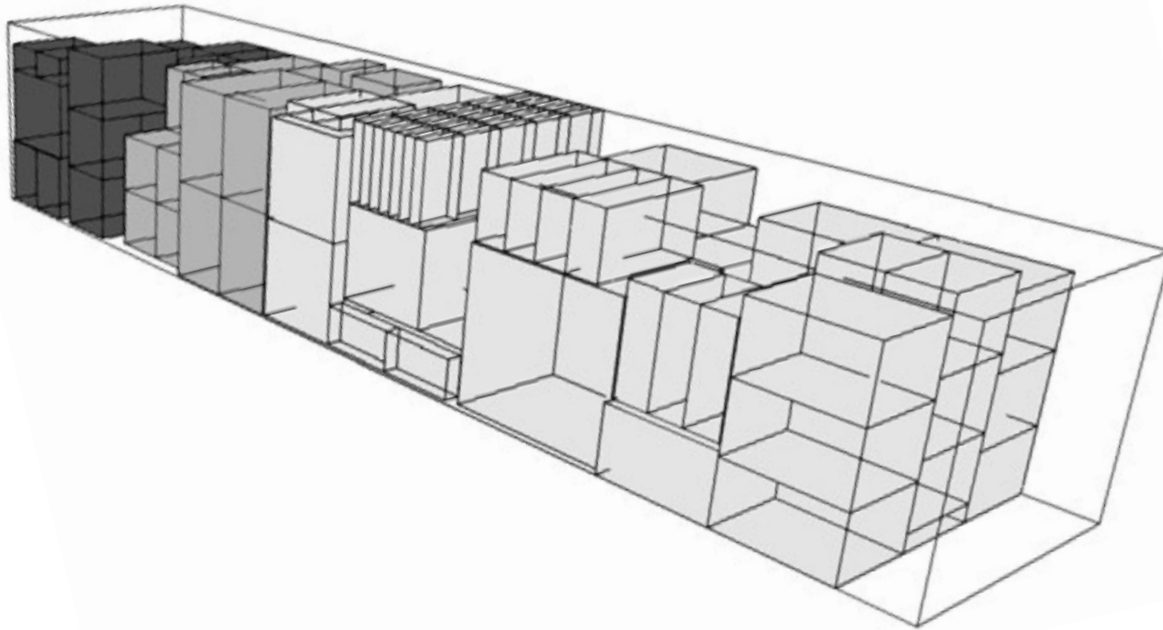
Looking for a global balance in pallet heights



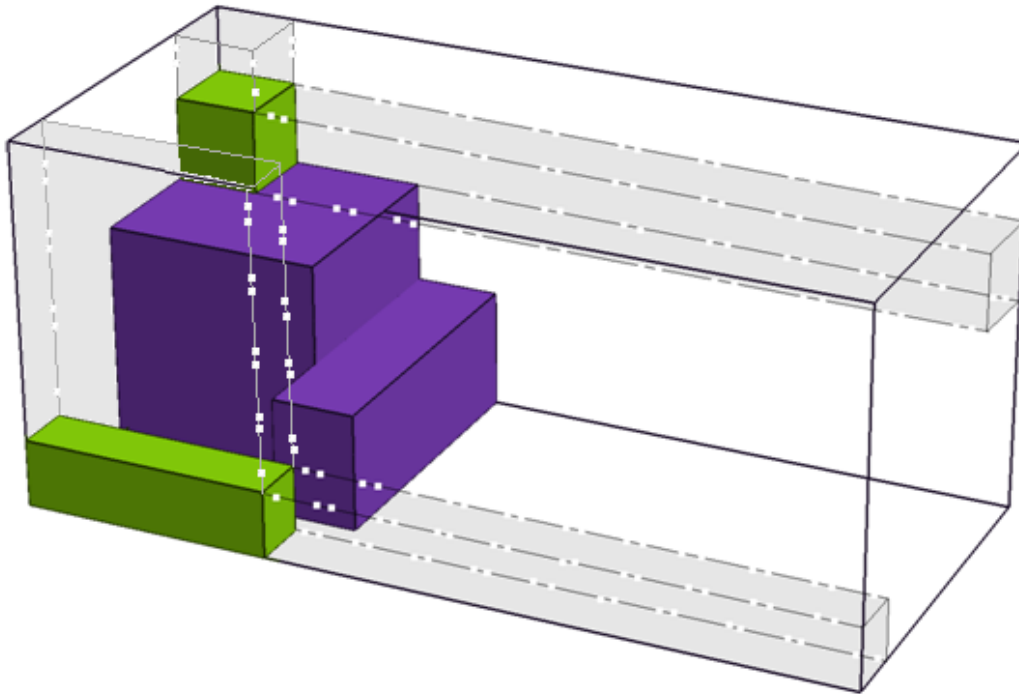
Imposing a minimum height ($H/2$)



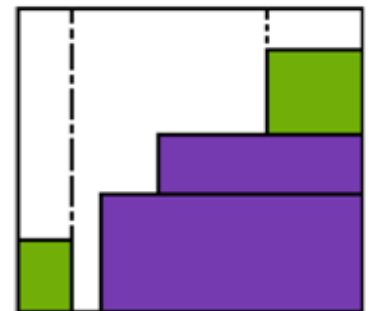
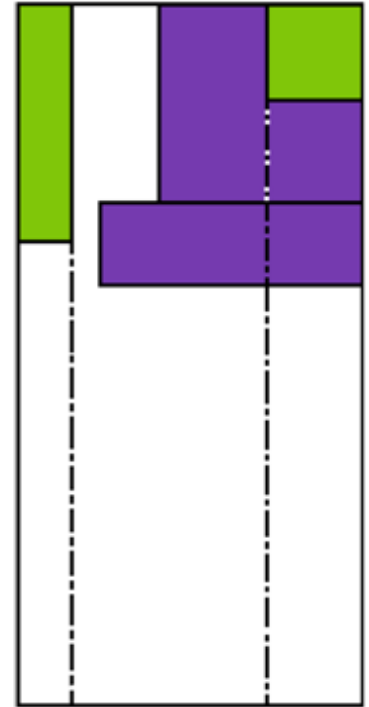
Positioning: Multi-drop



Approaches to multi-drop: **Boxes visible**

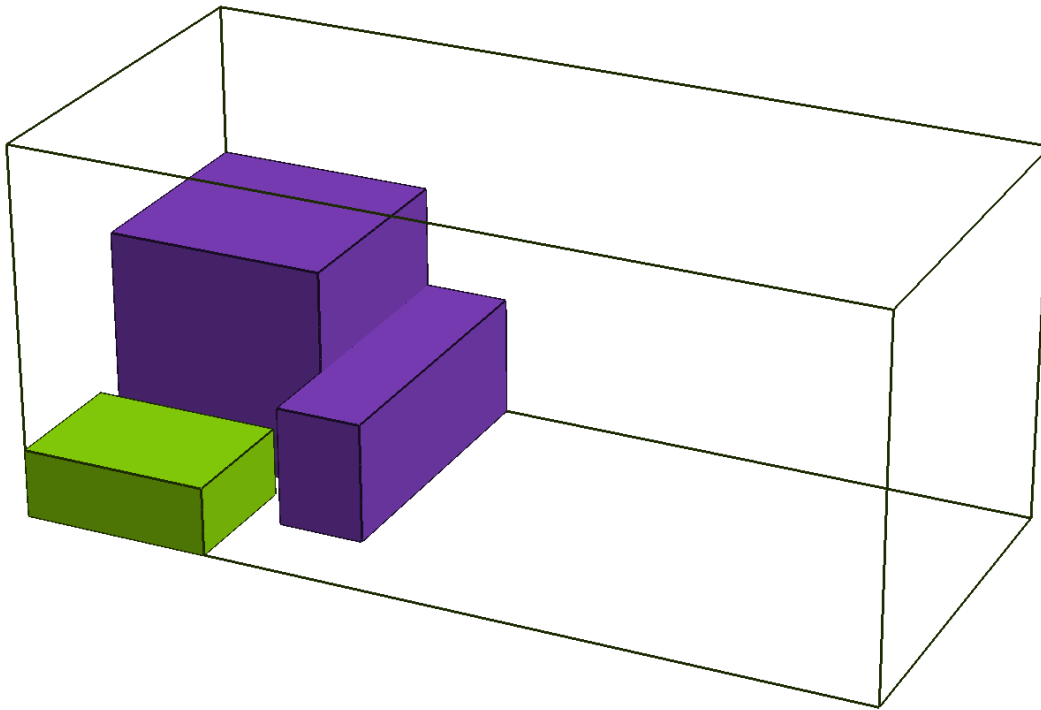


VISIBLE

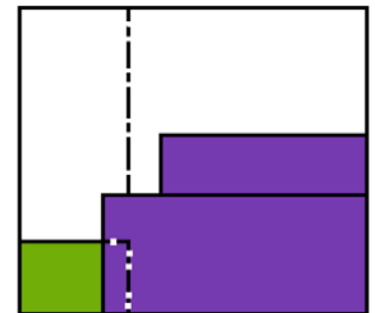
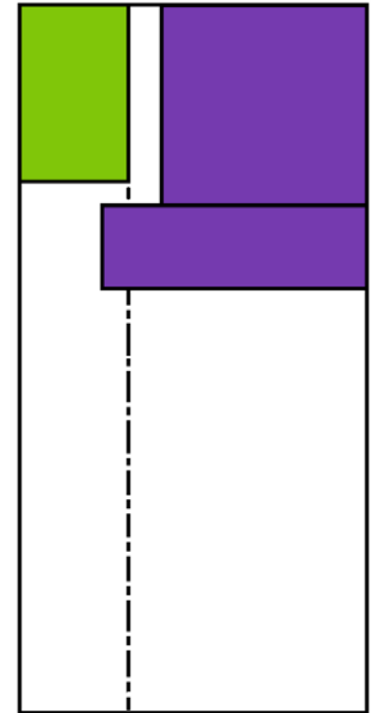


Gendreau et al. (2006), Fuellerer et al. (2010), Bortfeldt et al. (2012),
Ceschia and Schaerf (2011), Christensen and Rousee (2009)

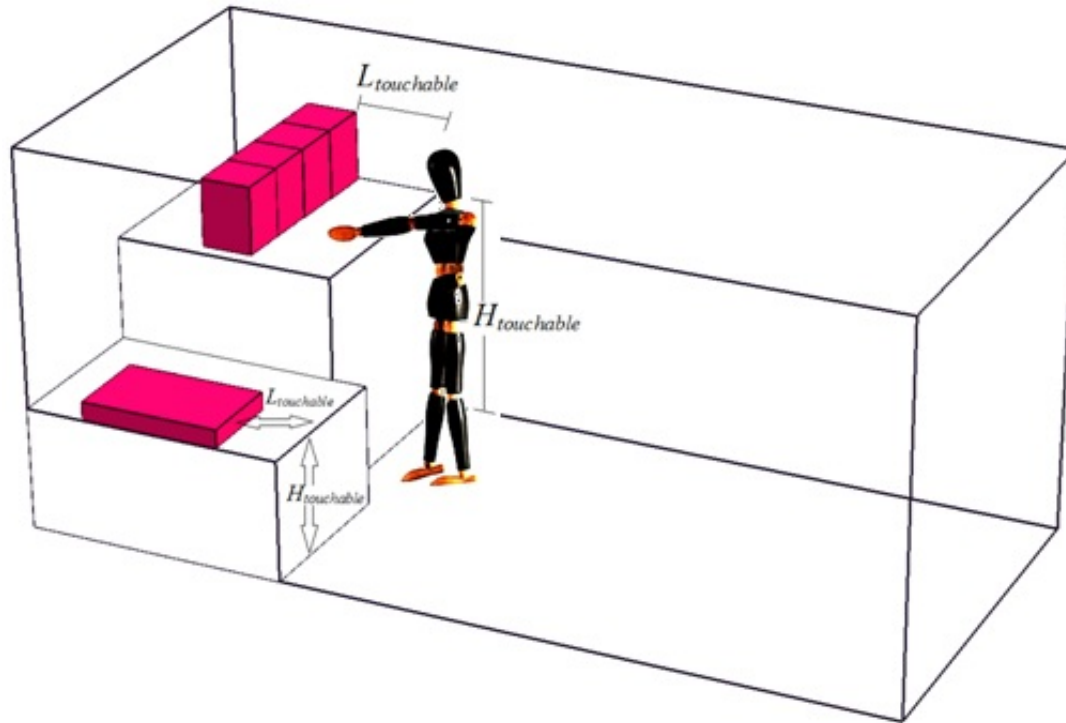
Approaches to multi-drop: **Boxes visible**



NOT VISIBLE

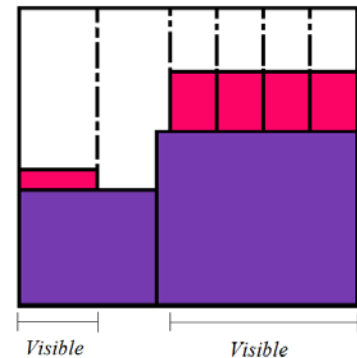
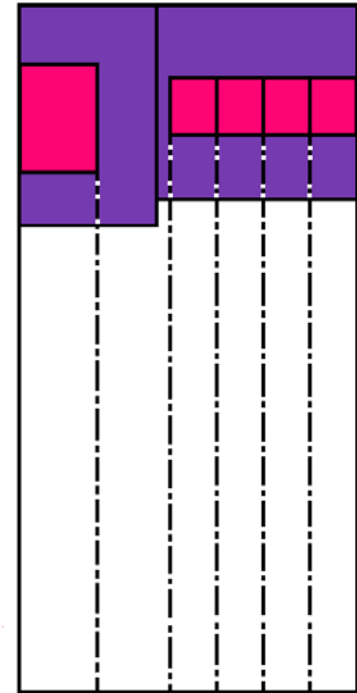


Approaches to multi-drop: Boxes touchable

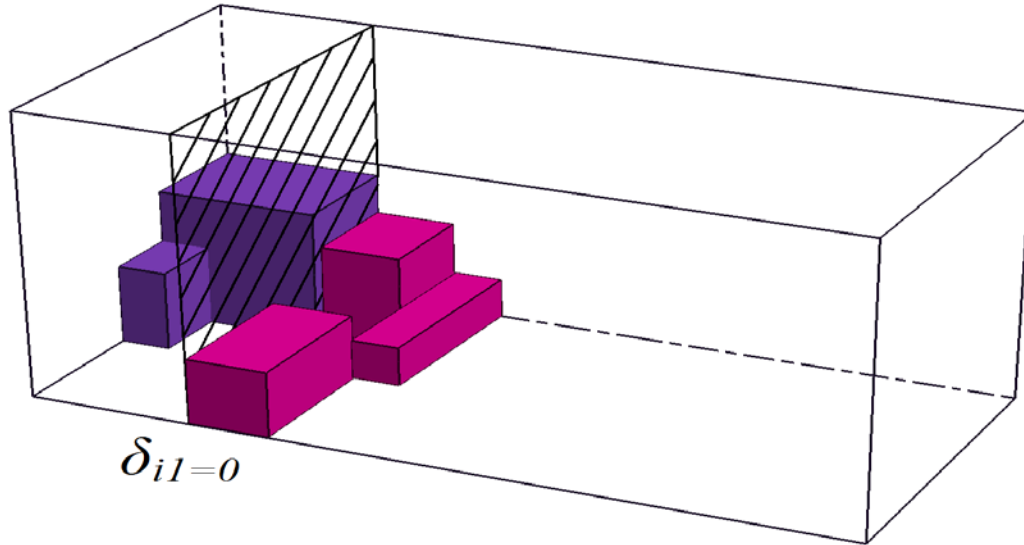


$$L_{touchable} + H_{touchable} \leq 200$$

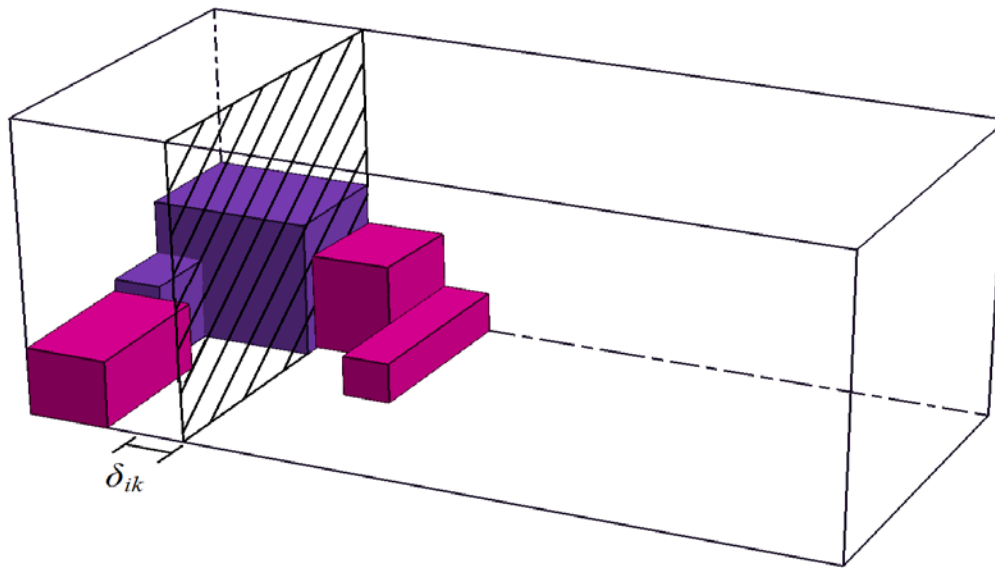
Liu et al. (2011)



Approaches to multi-drop: Boxes separated

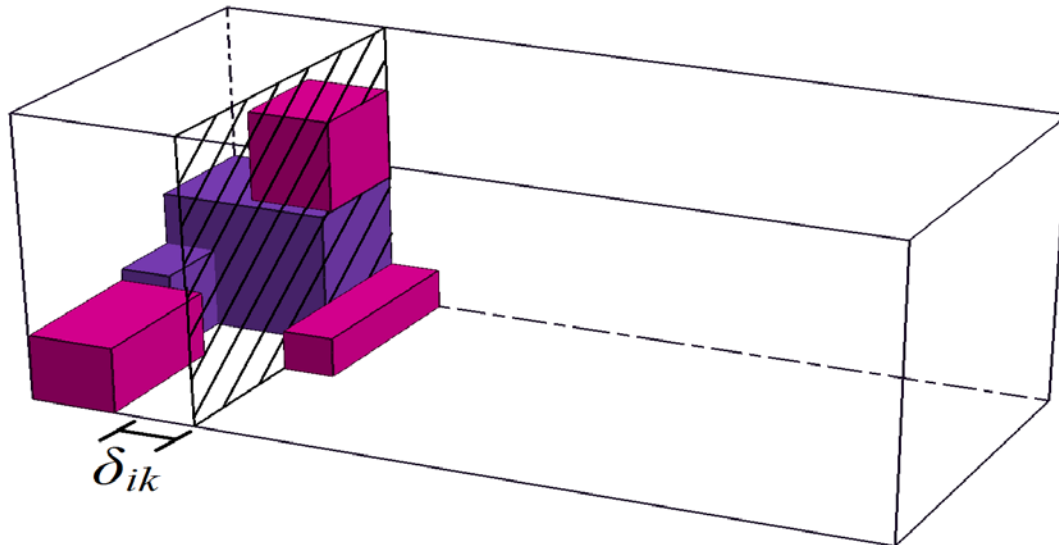
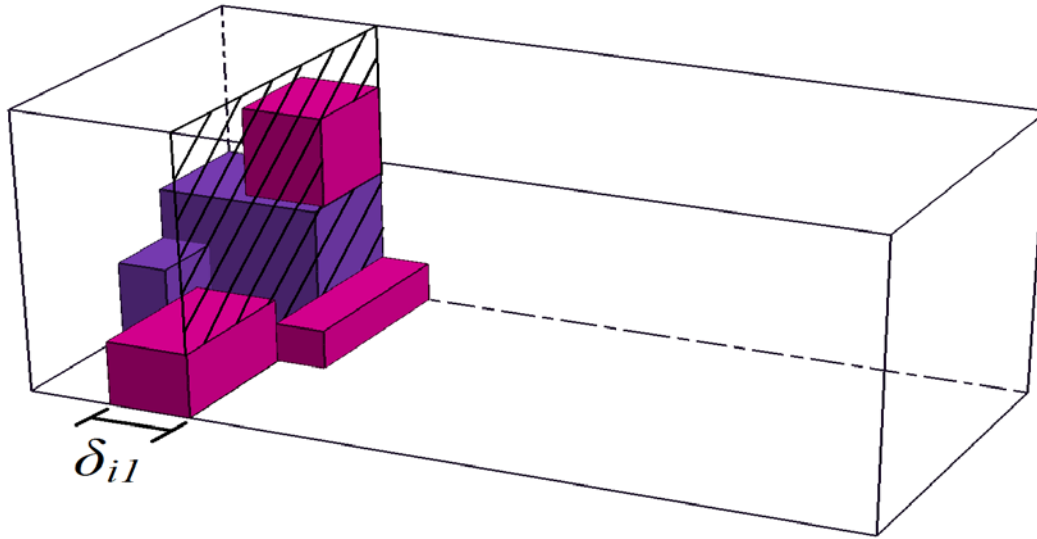


$$\delta = 0$$

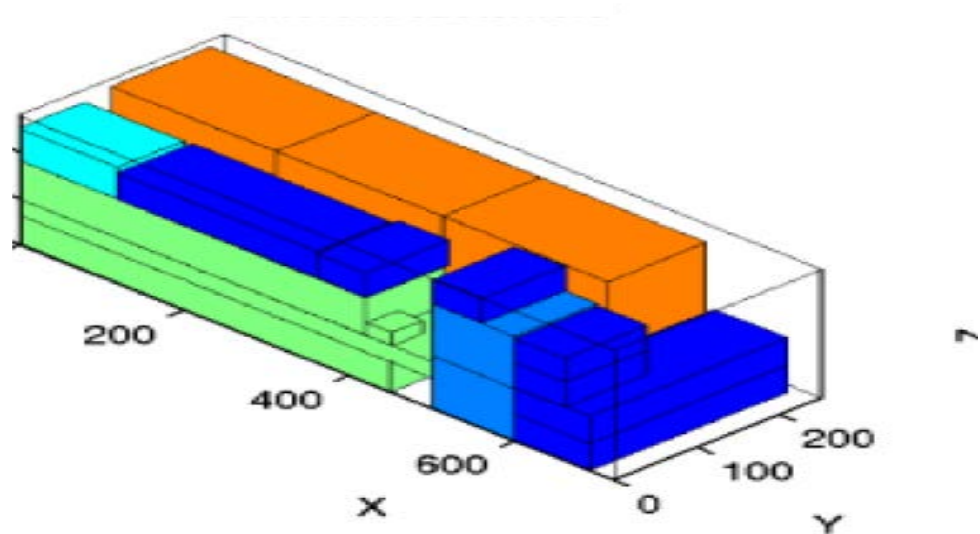


Approaches to multi-drop: Boxes separated

$$\delta = l_k$$



Depends on the way the cargo is accessed



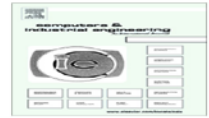
Complete shipment

Computers & Industrial Engineering 108 (2017) 149–164

Contents lists available at ScienceDirect

Computers & Industrial Engineering

journal homepage: www.elsevier.com/locate/caie

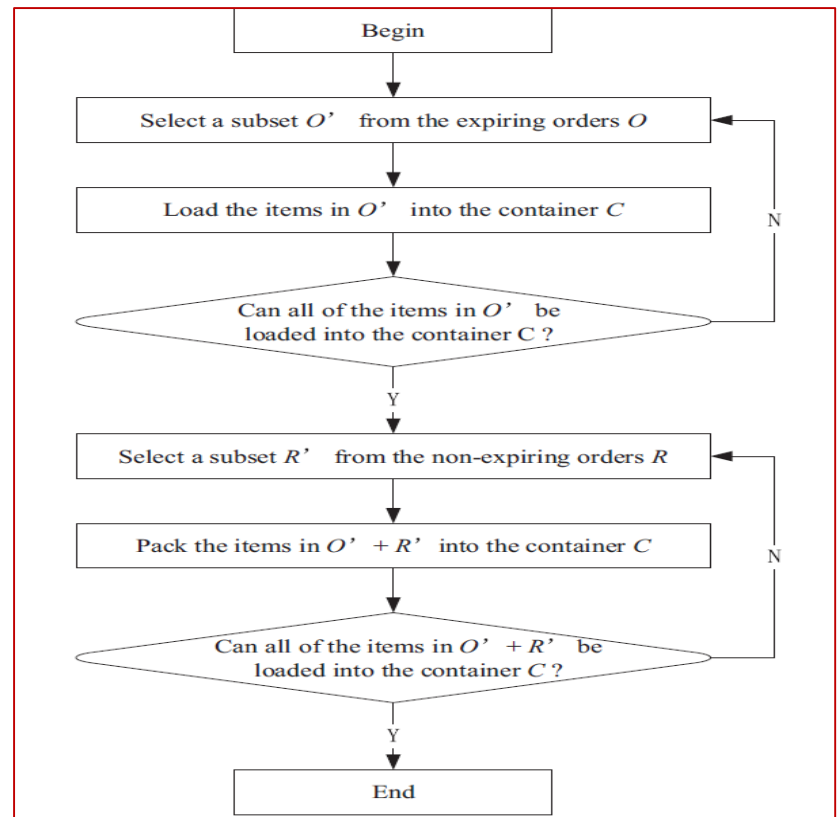


Heuristic algorithm for the container loading problem with multiple constraints



Liu Sheng^{a,*}, Shang Xiuqin^a, Cheng Changjian^b, Zhao Hongxia^a, Shen Dayong^c, Wang Feiyue^a

- C1: orientation
- C2: stability
- C3: guillotine cutting
- C4: complete shipment
- C5: item priority

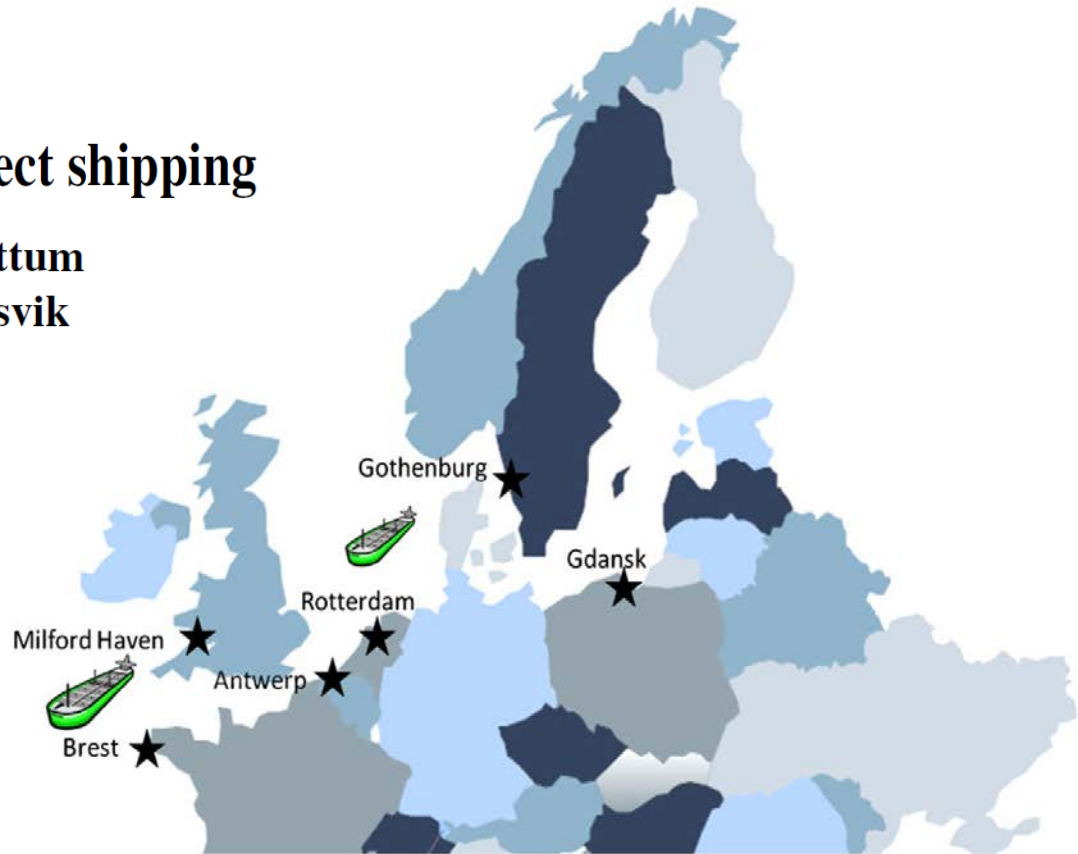


Complete shipment

Ann Oper Res (2013) 207:67–81
DOI 10.1007/s10479-011-0888-1

Routing and scheduling in project shipping

Kjetil Fagerholt · Lars Magnus Hvattum
Trond A.V. Johnsen · Jarl Eirik Korsvik



Cargo	Cargo set	Load port	Discharge port	Quantity [m ³ /m ²]	Time window
1	1 = {1,2}	Gdansk	Milford Haven	3000/450	4/11/10 – 11/11/10
2		Antwerp	Milford Haven	2000/500	4/11/10 – 11/11/10
3	2 = {3}	Gothenburg	Antwerp	NA/600	8/11/10 – 16/11/10
4	3 = {4,5}	Rotterdam	Brest	3000/300	24/11/10 – 07/12/10
5		Gdansk	Brest	2500/NA	23/11/10 – 06/12/10

Separation of items

Computers & Operations Research 36 (2009) 3041 – 3050



Contents lists available at ScienceDirect

Computers & Operations Research

journal homepage: www.elsevier.com/locate/cor



An adaptive guidance approach for the heuristic solution of a minimum multiple trip vehicle routing problem

M. Battarra^a, M. Monaci^b, D. Vigo^{a,*}

Three commodities are considered:

- vegetables (V),
- fresh products, as milk and meat(F)
- non-perishable items(N).

These commodities are ***incompatible*** with each other, i.e., they may not be transported together in a vehicle.

Shipment priorities

Int. J. Production Economics 145 (2013) 531–540



Contents lists available at ScienceDirect

Int. J. Production Economics

journal homepage: www.elsevier.com/locate/ijpe

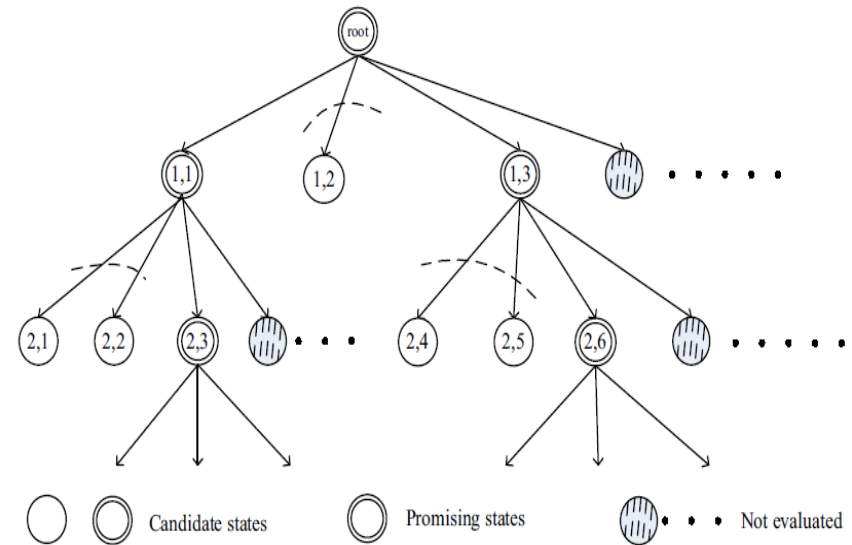


A multi-round partial beam search approach for the single container loading problem with shipment priority



Ning Wang, Andrew Lim, Wenbin Zhu*

- *orthogonal packing*: Boxes must be placed with faces parallel to the faces of the container;
- *loading constraint*: Any pair of boxes inside the container is interior-disjoint;
- *orientation constraint*: Some boxes can only be placed in certain orientations;
- *full support constraint*: A box is either placed on the floor of the container or with its base fully supported by the top faces of other boxes,
- *priority constraint*: All boxes of high priority must be loaded.



A case study: the ESICUP/RENAULT competition



Transportation between factories



Very large instances

- Number of required trucks or containers

Instances A	Containers
ARG_BUR_STK_container/	6
AVF_RIR_STK_container/	24
AVF_RIR_STK_truck/	5
AVT_BUR_STK_container/	4
AVZ_RIR_STK_container/	17
AVZ_RIR_STK_truck/	5
CHE_GC_PEX_container/	3
CHE_RIR_STK_container/	12
CME_GC_PEX_container/	5
CVP_GC_PEX_container/	27
CVU_GC_PEX_container/	85
FSI_GC_PEX_container/	27
IND_RIR_STK_container/	5
MED_GC_PEX_container/	13
NSA_BUR_STK_container/	5
NSA_RIR_STK_container/	4
RSM_GC_PEX_container/	5
SOM_BUR_STK_container/	2
SOM_RIR_STK_container/	26
TNG_RIR_STK_container/	4

Instances B	Containers
ACI_RIR_PEX_truck	4
ALG_RIR_PEX_container	28
AVF_RIR_PEX_container	6
AVZ_RIR_PEX_container	11
CHE_GC_PEX_container	5
CHE_RIR_PEX_container	11
CHE_VLD_PEX_container	9
CVP_GC_PEX_container	7
CVU_GC_PEX_container	22
CVU_VLD_PEX_container	7
FSI_GC_PEX_container	10
FSI_VLD_PEX_container	16
IKO_RIR_PEX_truck	4
MED_GC_PEX_container	8
MJV_VLD_PEX_truck	4
NSA_RIR_PEX_container	18
RSM_GC_PEX_container	7
SOM_VLD_PEX_container	42
TAK_RIR_PEX_truck	2

Instances X	Containers
ALG_RIR_PEX_container	11
ARG_BUR_PEX_container	14
AVF_RIR_PEX_container	24
AVT_BUR_PEX_container	15
BAX_COR_PEX_container	20
CHE_RIR_PEX_container	15
CME_GC_EXP_container	8
CVP_GC_EXP_container	27
FSI_GC_EXP_container	35
MED_GC_EXP_container	25
NSA_RIR_PEX_container	7
RSM_GC_EXP_container	7
SOM_GC_EXP_container	19
SOM_RIR_PEX_container	32
TAN_BUR_PEX_container	11
TNG_RIR_PEX_container	54
VAX_COR_PEX_container	5

Two types of containers / trucks

Bin type	Bin dimensions	xMax (mm)	xMax Ratio	weight (kg)	weight Ratio	volume (m3)	volume Ratio
UT12X	5899(L)x2350(l)x2393(H)	5890	99,85 %	12705,20	45,38 %	29,60	89,24 %

1 m	1 m	1 m	1 m	1 m	0,90 m
2,25 T	1,59 T	1,79 T	2,43 T	2,27 T	2,37 T



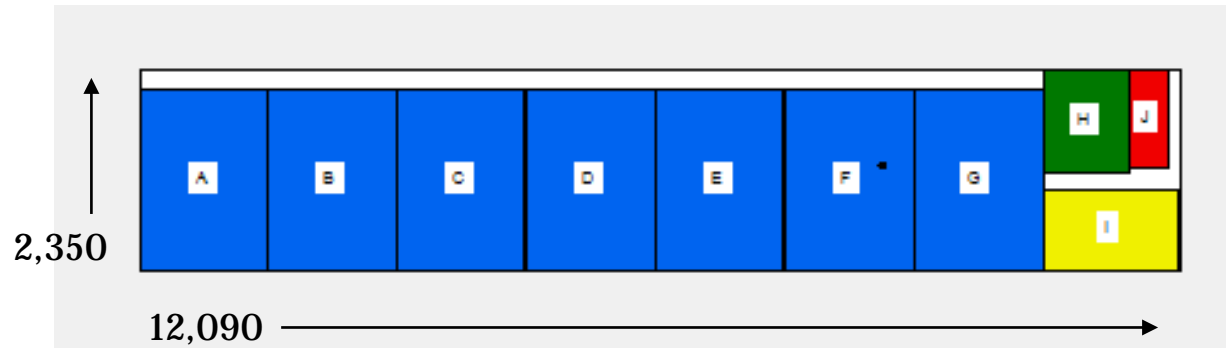
Bin type	Bin dimensions	xMax (mm)	xMax Ratio	weight (kg)	weight Ratio	volume (m3)	volume Ratio
CT40H	12090(L)x2350(l)x2680(H)	11860	98,10 %	24780,39	93,87 %	63,40	83,27 %

1 m	1 m	1 m	1 m	1 m	1 m	1 m	1 m	1 m	1 m	1 m	1 m	0,09 m
2,98 T	2,38 T	2,29 T	2,02 T	2,39 T	1,67 T	1,43 T	1,41 T	1,91 T	2,32 T	2,13 T	1,86 T	0,00 T



Very big and heavy boxes

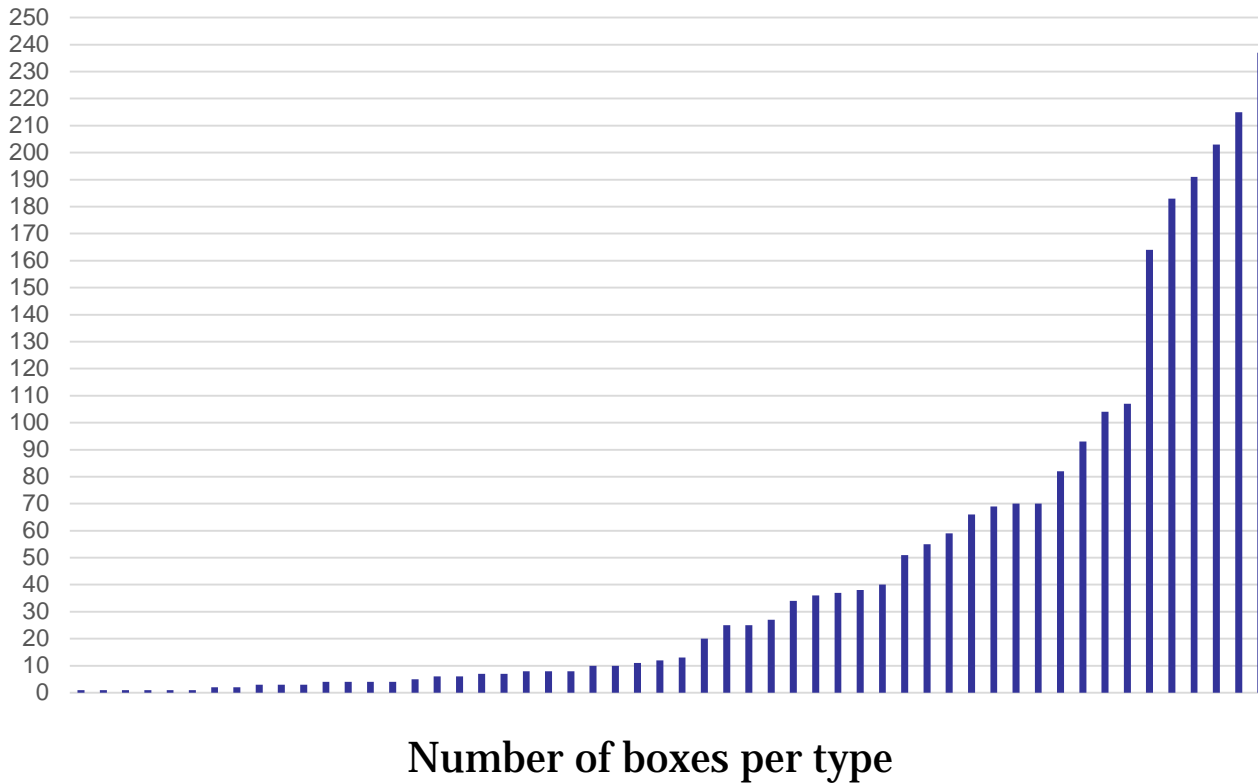
- AVF_RIR_STK_container
 - 1307 kg. 2270x1170x1270
 - 38 boxes with more than 1000 kg.



Extremely varying demand

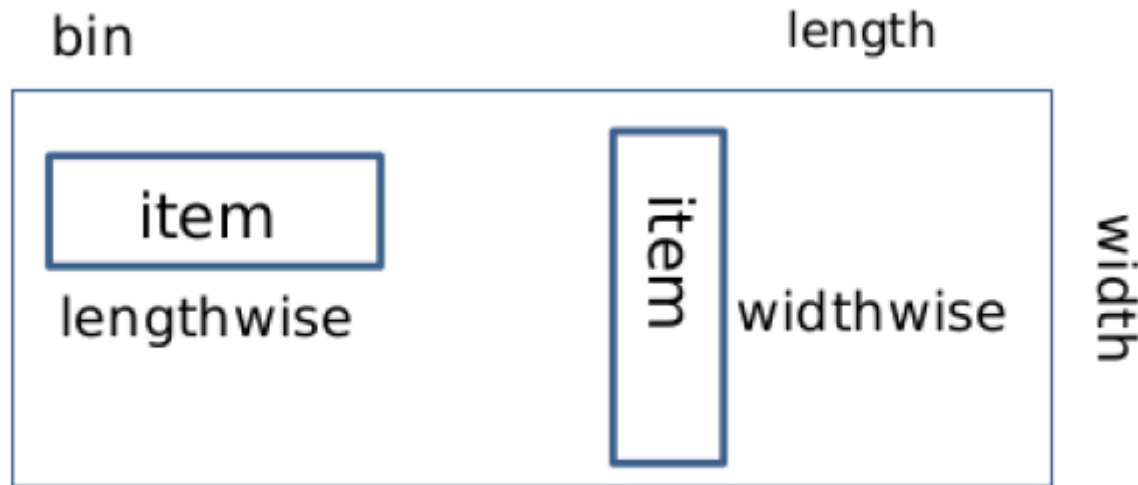
GVU_GC_PEX_container

54 types of boxes



Orientation constraints

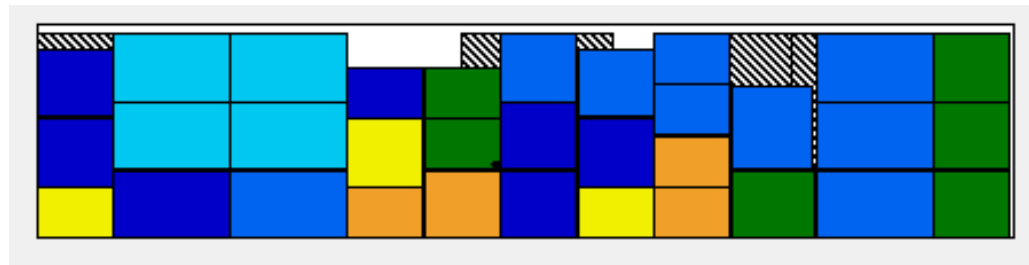
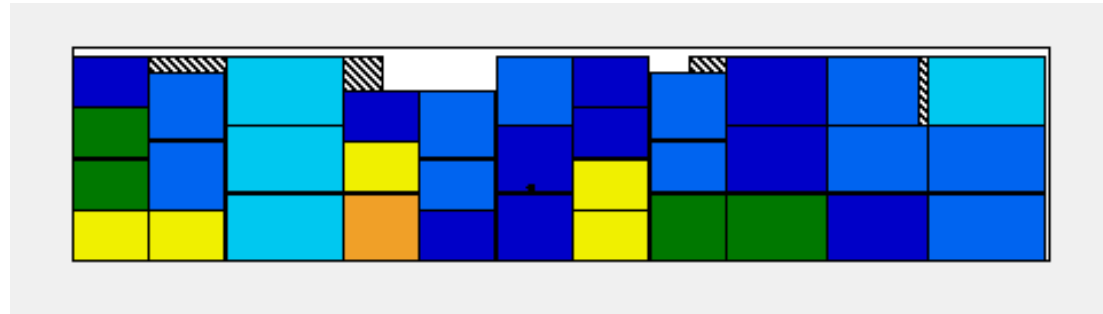
- Items may be rotated only in one dimension (horizontal), so the bottom of a box always remains the bottom.
- Some items cannot be rotated, so they will be fixed lengthwise or widthwise (by convention, length is larger than width)



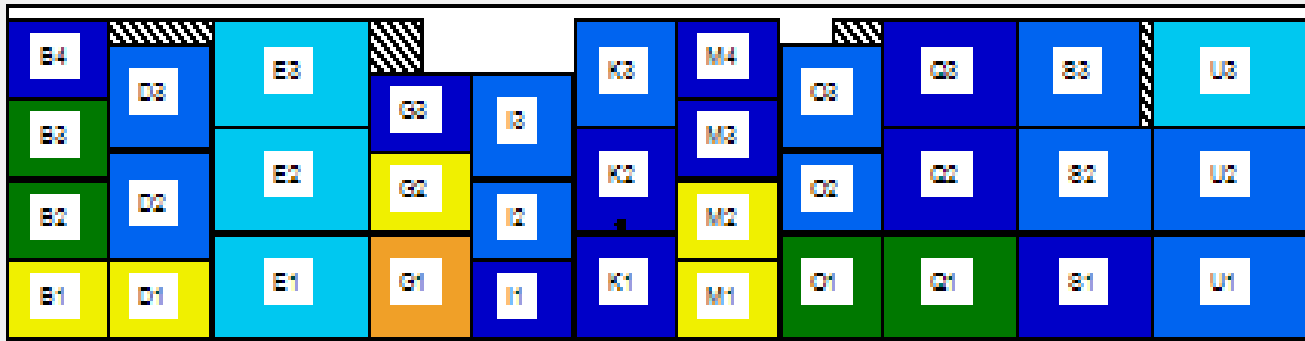
Very strict conditions concerning the weight

- Maximum density for non-metallic stacks
- Layers in a stack have to be sorted by decreasing weight
- Maximum weight supported by the items in the bottom stack

	< 50 Kg/m ²
	50 to 100 Kg/m ²
	100 to 200 Kg/m ²
	200 to 300 Kg/m ²
	300 to 400 Kg/m ²
	400 to 600 Kg/m ²
	600 to 1000 Kg/m ²
	> 1000 Kg/m ²



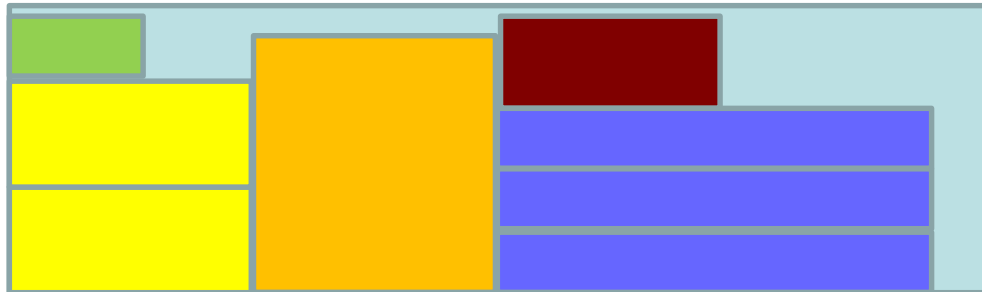
Strict conditions for building layers and stacks



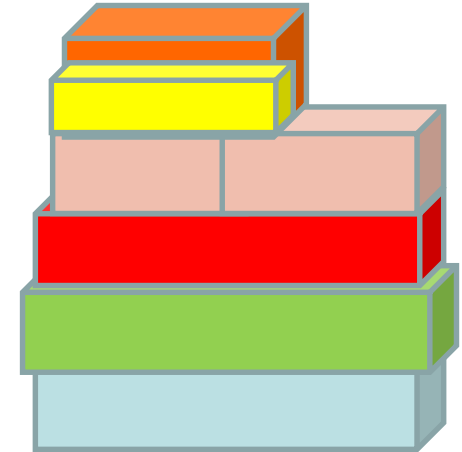
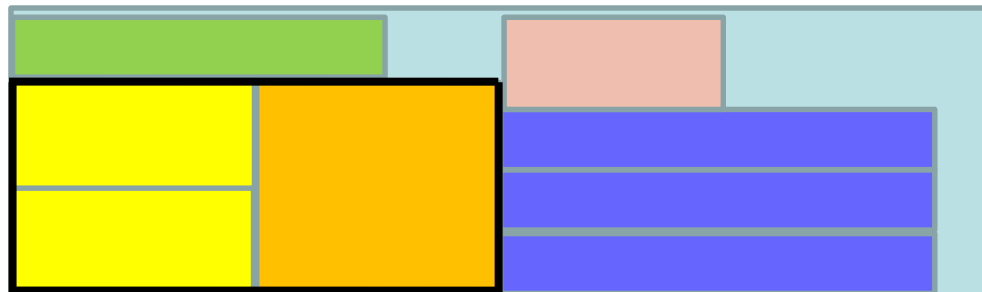
Two layers of the stack must not differ from more than a given ratio δ in the two horizontal dimensions ($\delta = 0.05$)

Special conditions for the top layer





- Built when the stack is finished
- Built when the bin is finished

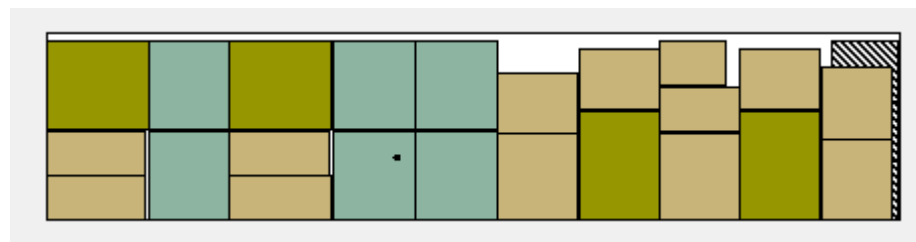
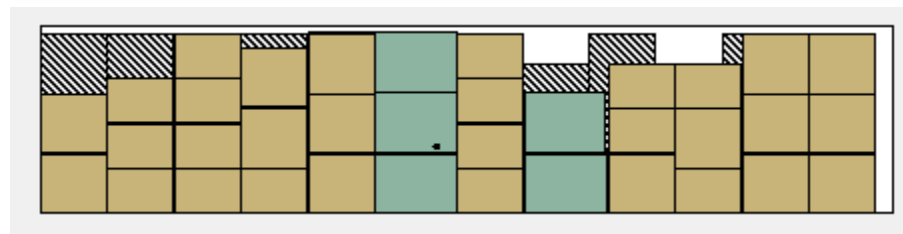
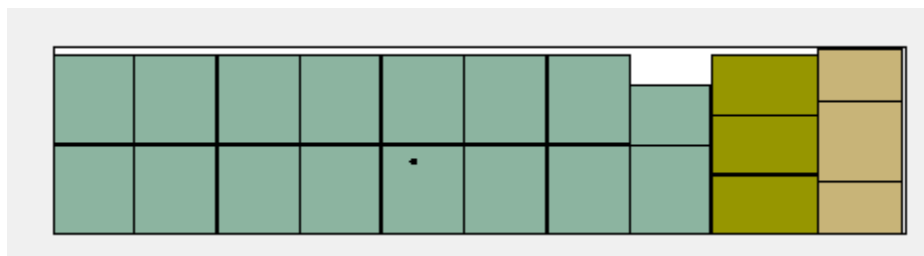


- Merging stacks



Strict separation of metal and cardboard/wood boxes

	wood
	cardboard
	metal
	plastic



Don't send half empty trucks!

- **Bin 0** : Boxes that are not sent
 - For a given product with k items, there cannot be more than
$$\lfloor k * \gamma \rfloor \quad \gamma \in [0,1] \quad (\gamma=0.9)$$
 - Bin 0 defined as the one with the smallest volume used
(known at the end of the loading process)

Routing meets Packing

1.- No packing



Routing meets Packing

2.- No routing: Point-to-point transportation problem

Orders per day



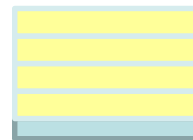
Logistics centre



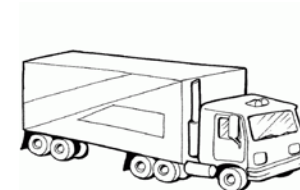
Distribution centre

Day	Product
1	100 beers 200 kg potatoes 50 cereals 100 soap
2	250 cokes 500 sauces 200 rice
...	

Products



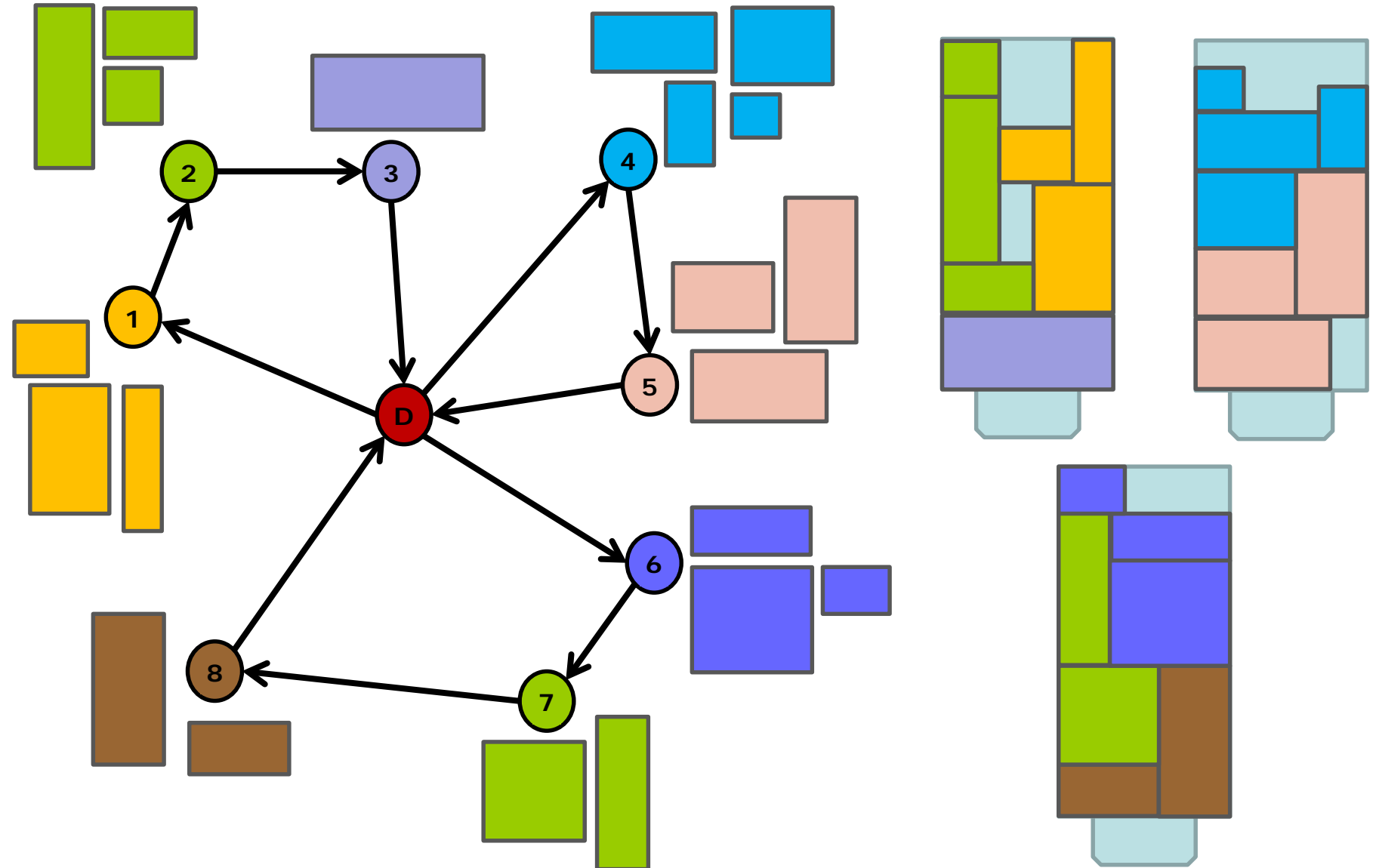
Pallets



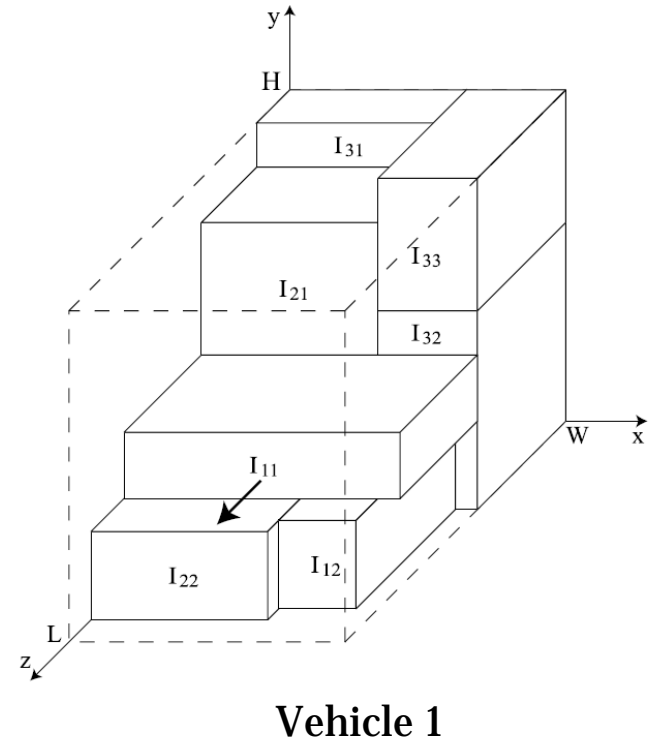
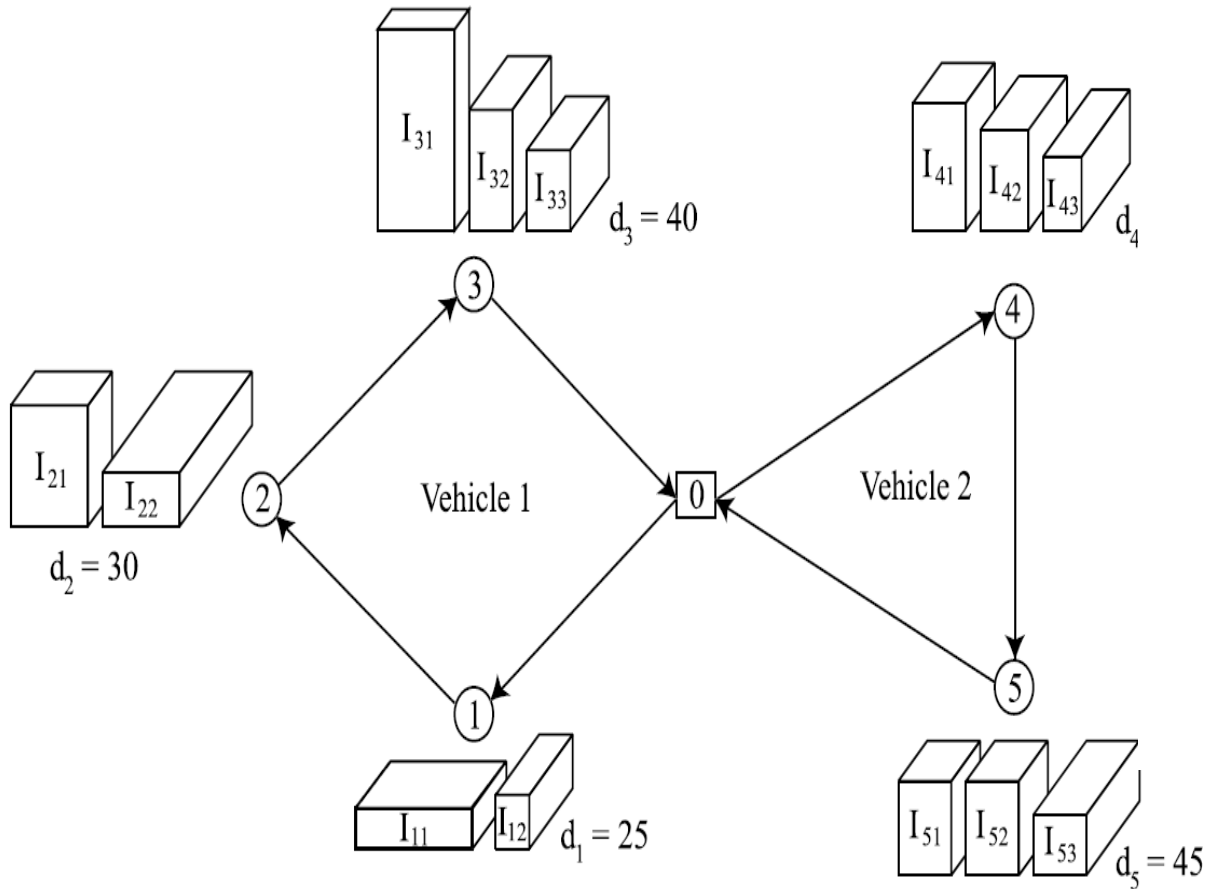
Trucks



Routing meets Packing: 2D

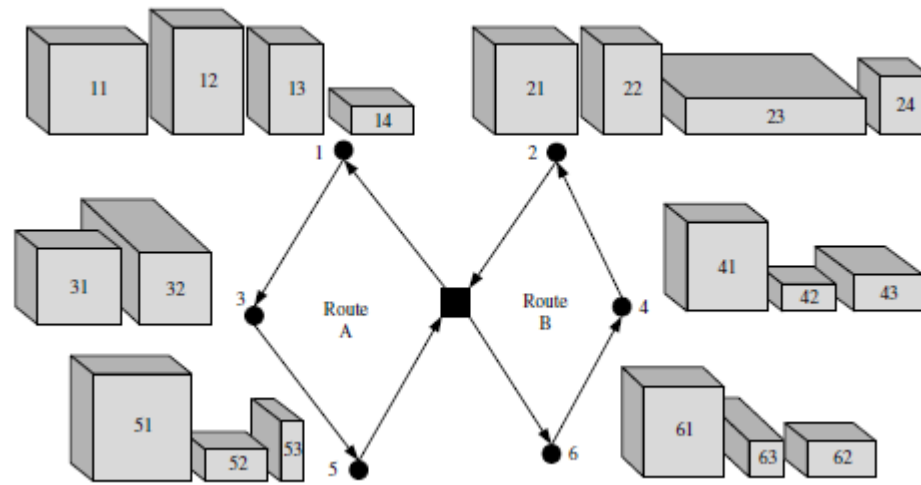


Routing meets Packing: 3D

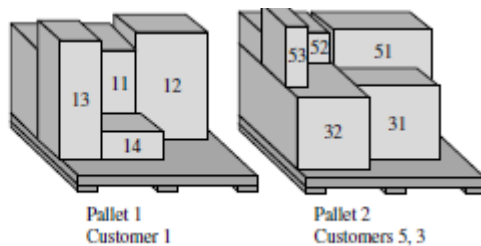


Routing meets Packing: pallet loading

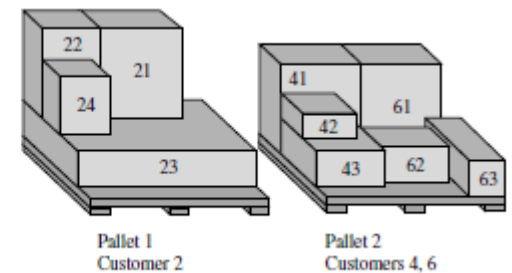
3.- Routing and Packing



Pallet packing route A



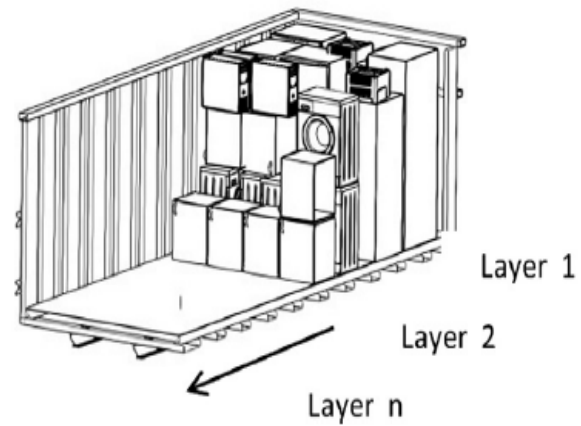
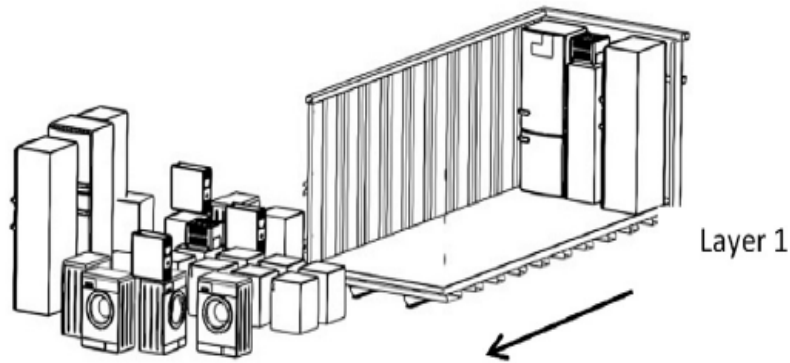
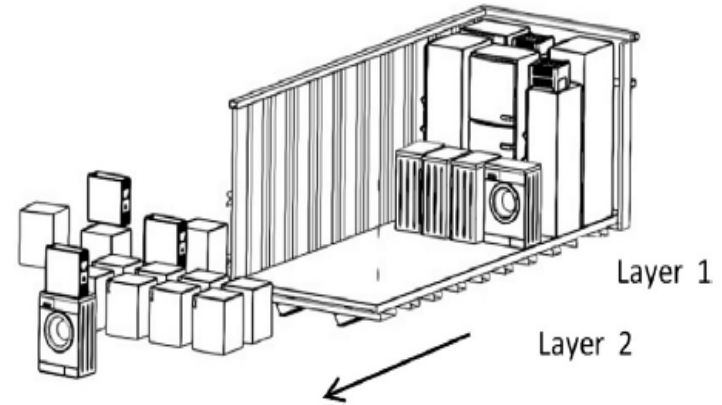
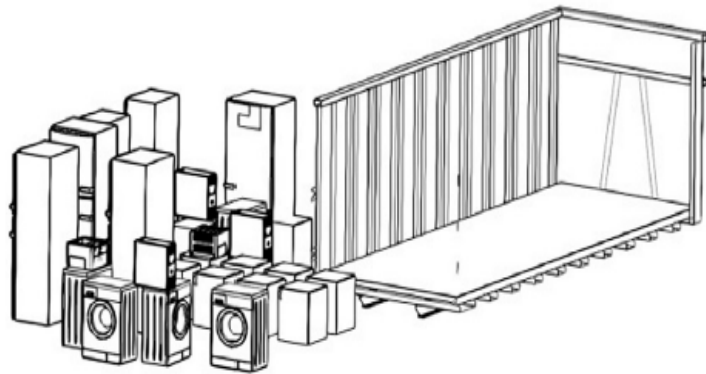
Pallet packing route B



Collecting e-waste: a case study in Poland



Collecting e-waste: proposed procedure



Vehicle routing problems with loading constraints: state-of-the-art and future directions

Hanne Pollaris · Kris Braekers · An Caris ·
 Gerrit K. Janssens · Sabine Limbourg

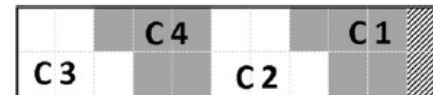
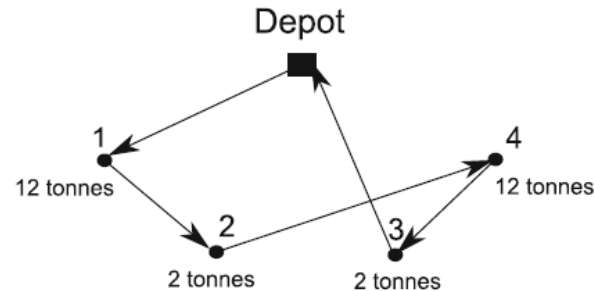
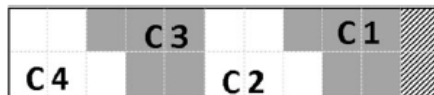
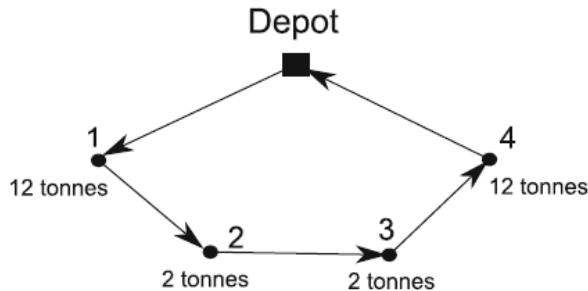
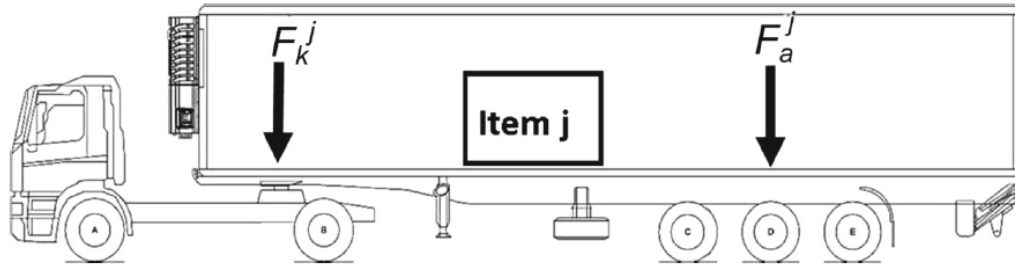
		P	CS	Co	Se	Po(*)	WL	WD	LP	Orth	Or	St	VS	HS
<i>2L-CVRP</i>														
Iori et al. (2007)	B&B	-	X		X	X			-	X	X	-	-	
Attanasio et al. (2007)	Heur+ILP	-	X		X	X			-		X	-	-	
Gendreau et al. (2008)	Tabu	-	X		X	X			-	X	X	-	-	
Fuellerer et al. (2009)	ACO	-	X		X	X			-	X	X	-	-	
Zachariadis et al. (2009)	Tabu	-	X		X	X			-	X	X	-	-	
Strodl et al. (2010)	VNS	-	X			X			-	X	X	-	-	
Leung et al. (2011)	Tabu	-	X		X	X			-	X	X	-	-	
Duhamel et al. (2011)	GRASP	-	X			X			-	X	X	-	-	
Leung et al. (2013)	SA	-	X		X	X			-	X	X	-	-	
Khebbache-Hadji et al. (2013)	Heur	-	X			X			-	X	X	-	-	
Zachariadis et al. (2013b)	ACO	-	X		X	X			-	X	X	-	-	
Martinez and Amaya (2013) (1)	NLP	-	X						-			-	-	
Martinez and Amaya (2013) (2)	Heur	-	X						-			-	-	
Dominguez et al. (2014)	B Rand	-	X			X			-	X	X	-	-	
Pollaris et al. (2014)	ILP	-	X		X	X			-	X	X	-	-	

RESEARCH PAPER

Capacitated vehicle routing problem with sequence-based pallet loading and axle weight constraints

Hanne Pollaris • Kris Braekers • An Caris •

Gerrit K. Janssens • Sabine Limbourg



Ex	HV	TW	CP	CS	Co	Se	Po(*)	WL	WD	LP	Orth	Or	St	VS	HS
----	----	----	----	----	----	----	-------	----	----	----	------	----	----	----	----

3L-CVRP

Gendreau et al. (2006)	TS		x	-	x		x	x	↑	-	x	x	x	x	↑
Aprile et al. (2007)	SA		x	-	x					-					
Moura (2008)	GA		x	-	x		x			-	x	x	x		
Moura and Oliveira (2009)	Seq+Hierar		x	-	x		x			-	x	x	x		
Tarantilis et al. (2009)	TS+GLS		x	-	x		x	x		-	x	x	x	x	
Fuellerer et al. (2010)	ACO		x	-	x		x	x		-	x	x	x	x	
Ren et al. (2011)	Hierarch		x	-	x		x	x		-	x	x	x	x	
Massen et al. (2012)	Heur		x	-	x		x	x		-	x	x	x	x	
Bortfeldt (2012)	TS		x	-	x		x	x		-	x	x	x	x	
Wisniewski et al. (2012)	TS		x	-	x		x	x		-	x	x	x	x	
Zhu et al. (2012)	GA+TS		x	-	x		x	x		-	x	x	x	x	
Miao et al. (2012)	Hierarch		x	-	x		x	x		-	x	x	x	x	
Ruan et al. (2013)	Bee		x	-	x		x	x		-	x	x	x	x	
Bortfeldt and Homberger (2012)	PF-RS		x	-	x		x	x		-	x	x	x	x	
Ceschia et al. (2013)	SA+LNS		x	-	x		x	x		-	x	x	x	x	
Tao and Wang (2013)	TS		x	-	x		x	x		-	x	x	x	x	
Junqueira et al. (2013)	ILP		x	-	x			x	↓	-	x	x	x	x	↓

Ex = exact solution method, HV = heterogeneous vehicles, TW = time windows, CP = classical packing, CS = complete shipment, Co = connectivity, Se = separation constraint, Po = positioning, WL = weight limits, WD = weight distribution, LP = loading priorities, Orth = orthogonality, Or = orientation, St = Stacking (fragility), VS = vertical stability, HS = horizontal stability

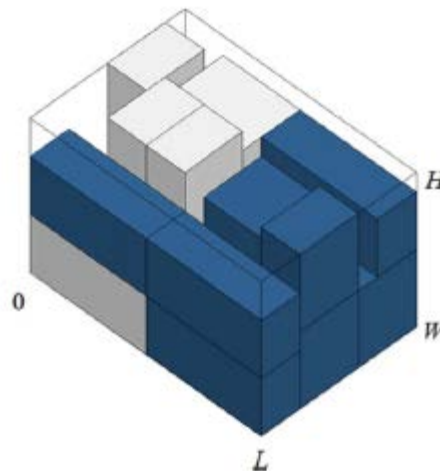


Intl. Trans. in Op. Res. 20 (2013) 645–666
DOI: 10.1111/j.1475-3995.2012.00872.x

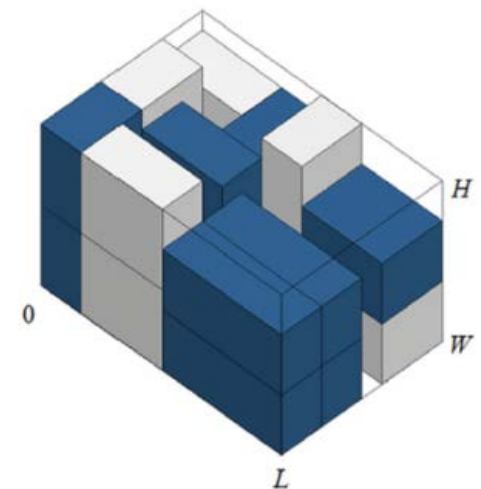
An optimization model for the vehicle routing problem with practical three-dimensional loading constraints

Leonardo Junqueira^a, José F. Oliveira^b, Maria Antónia Carravilla^b and Reinaldo Morabito^a

Multi-drop
Load bearing
Orientation
Static stability



With packing
constraints



Without packing
constraints

Routing meets Packing

- In most models, loading is handled as a subproblem of the routing model.
- First, solutions to the routing problem are computed
Then, loading constraints are checked for feasibility
- Some exceptions:
 - Moura and Oliveira (2009)
 - Bortfeldt and Homberger (2013)

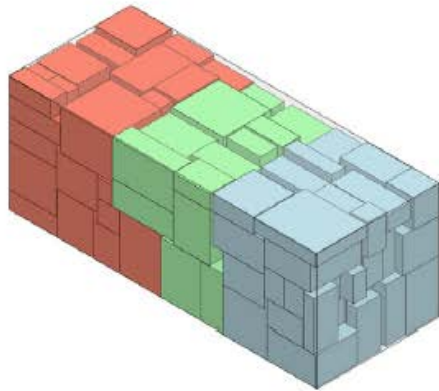
New challenges

- How to combine multi-drop with stability or with weight distribution?
- Should stability be maintained after each delivery?
- How to deal with half-empty trucks?
- How to include packing constraints into more complex routing problems?

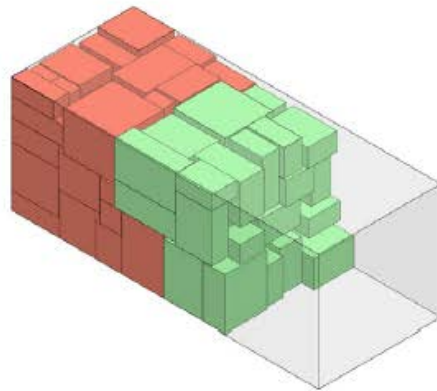
New challenges

- **How to combine multi-drop with stability or with weight distribution?**
- **Should stability be maintained after each delivery?**
- How to deal with half-empty trucks?
- How to include packing constraints into more complex routing problems?

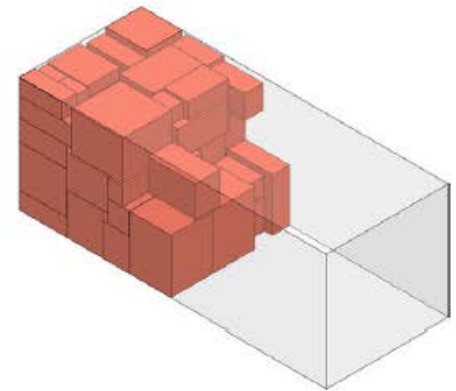
Recovering balance after unloading



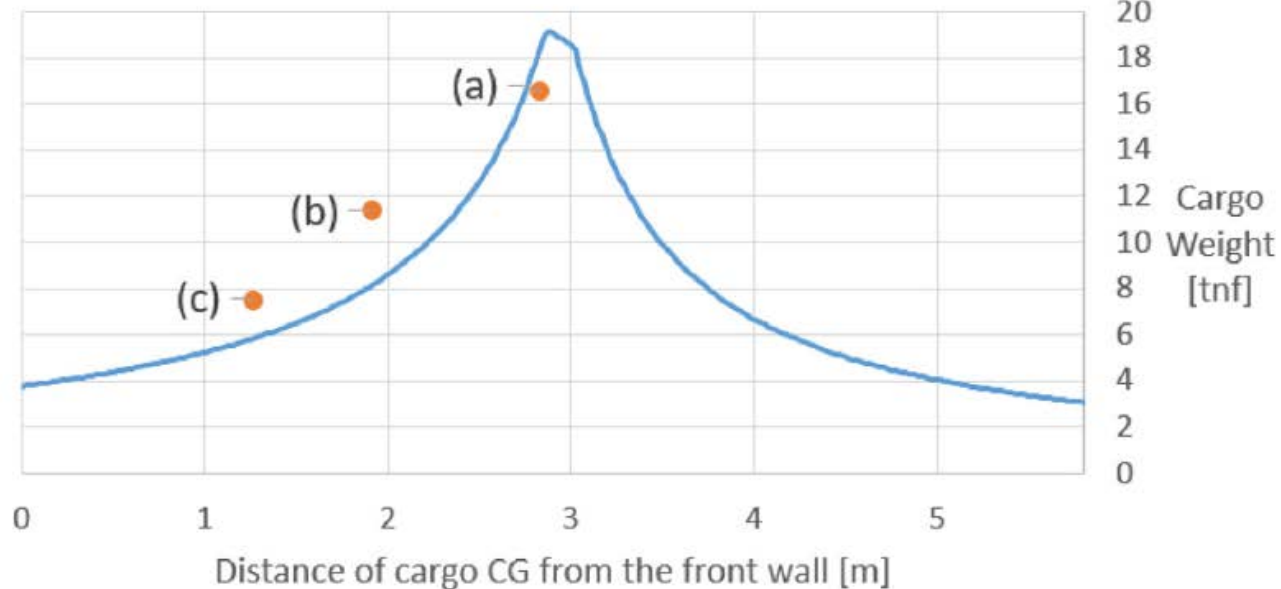
(a) Customers 1, 2 and 3



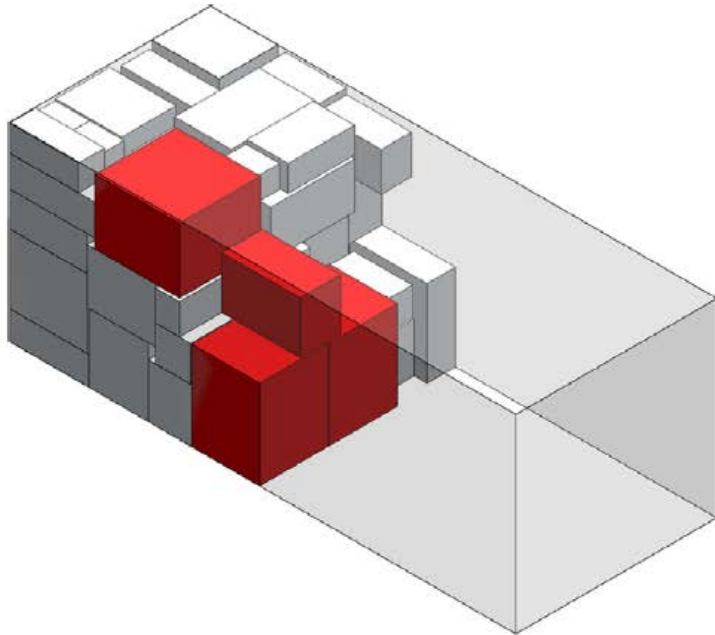
(b) Customers 2 and 3



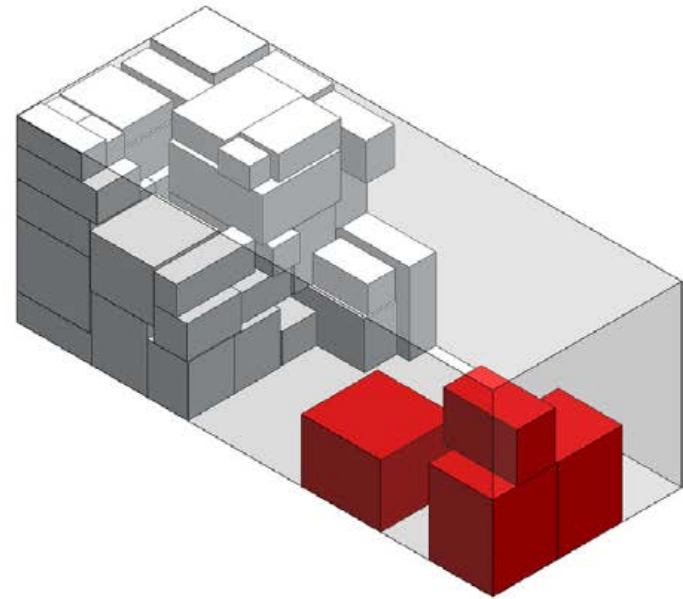
(c) Customer 3



Recovering balance after unloading



(a) Unbalanced Solution



(b) Balanced Solution

New challenges

- How to combine multi-drop with stability or with weight distribution?
- Should stability be maintained after each delivery?
- **How to deal with half-empty trucks?**
- How to include packing constraints into more complex routing problems?

New challenges

- How to combine multi-drop with stability or with weight distribution?
- Should stability be maintained after each delivery?
- How to deal with half-empty trucks?
- **How to include packing constraints into more complex routing problems?**

New challenges: Multi-compartment vehicles

OR Spectrum (2018) 40:997–1027

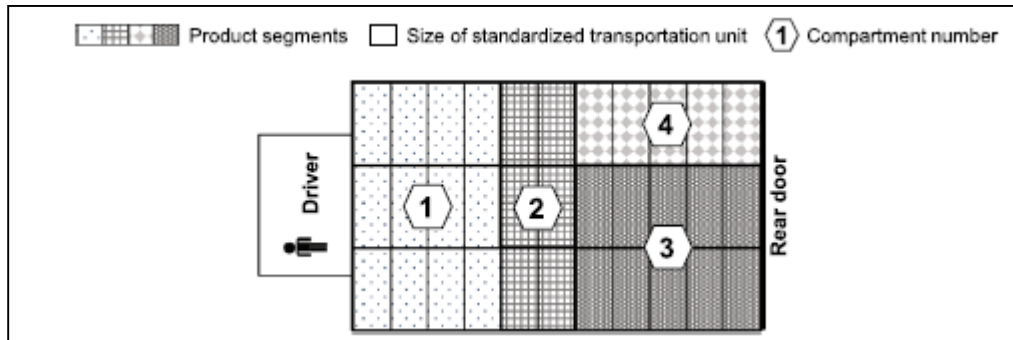
<https://doi.org/10.1007/s00291-018-0524-4>

REGULAR ARTICLE

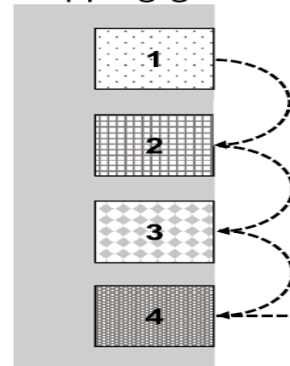
Loading constraints for a multi-compartment vehicle routing problem



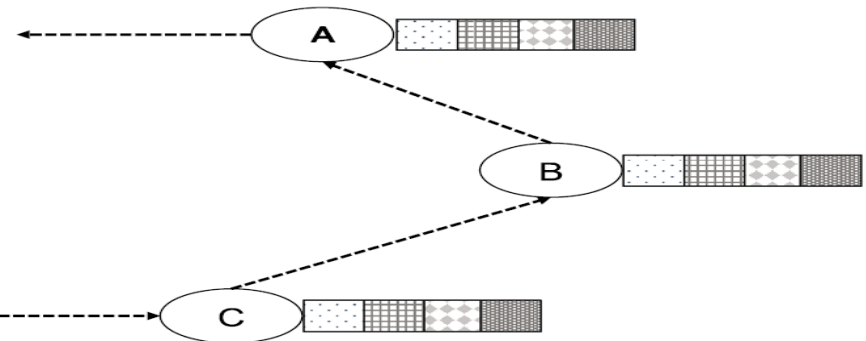
Manuel Ostermeier² · Sara Martins¹ · Pedro Amorim¹ · Alexander Hübner²



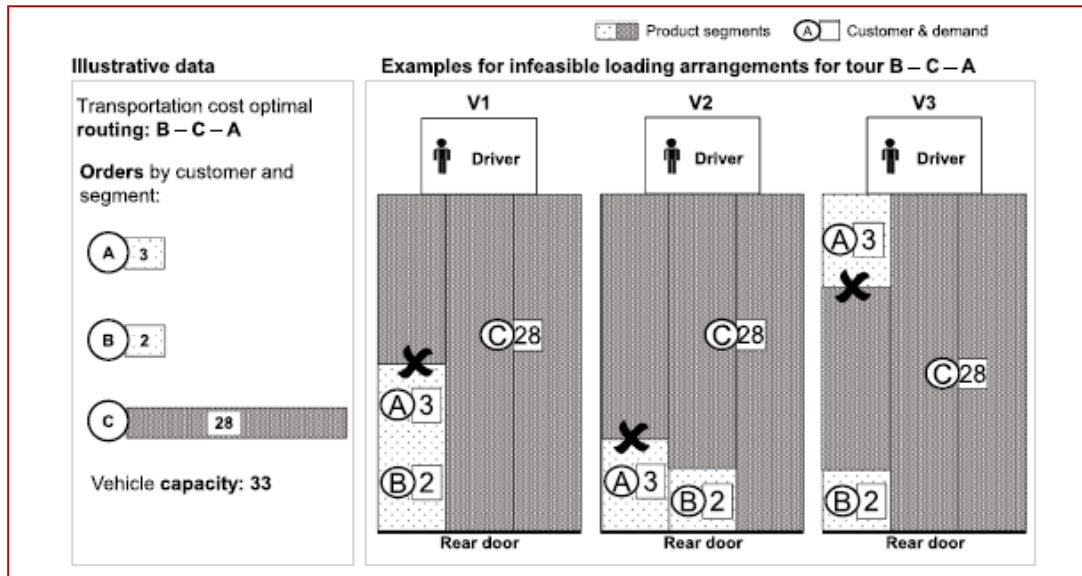
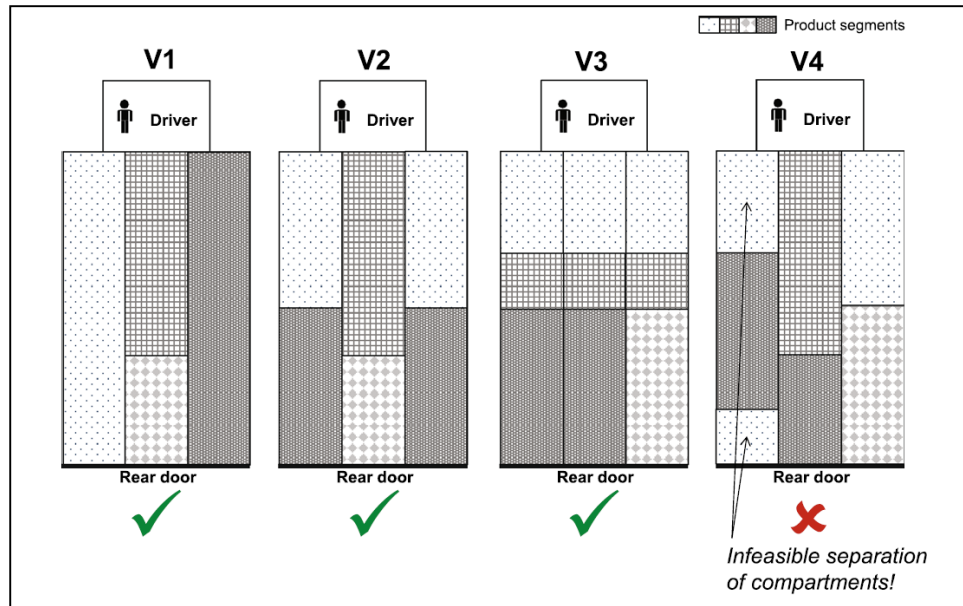
Loading process
Segment-specific shipping gates at DC



Routing and unloading process
Joint delivery of segments to customers



New challenges: Multi-compartment vehicles



New challenges: Pickup and delivery with loading constraints

OR Spectrum (2018) 40:1029–1075
<https://doi.org/10.1007/s00291-018-0506-6>



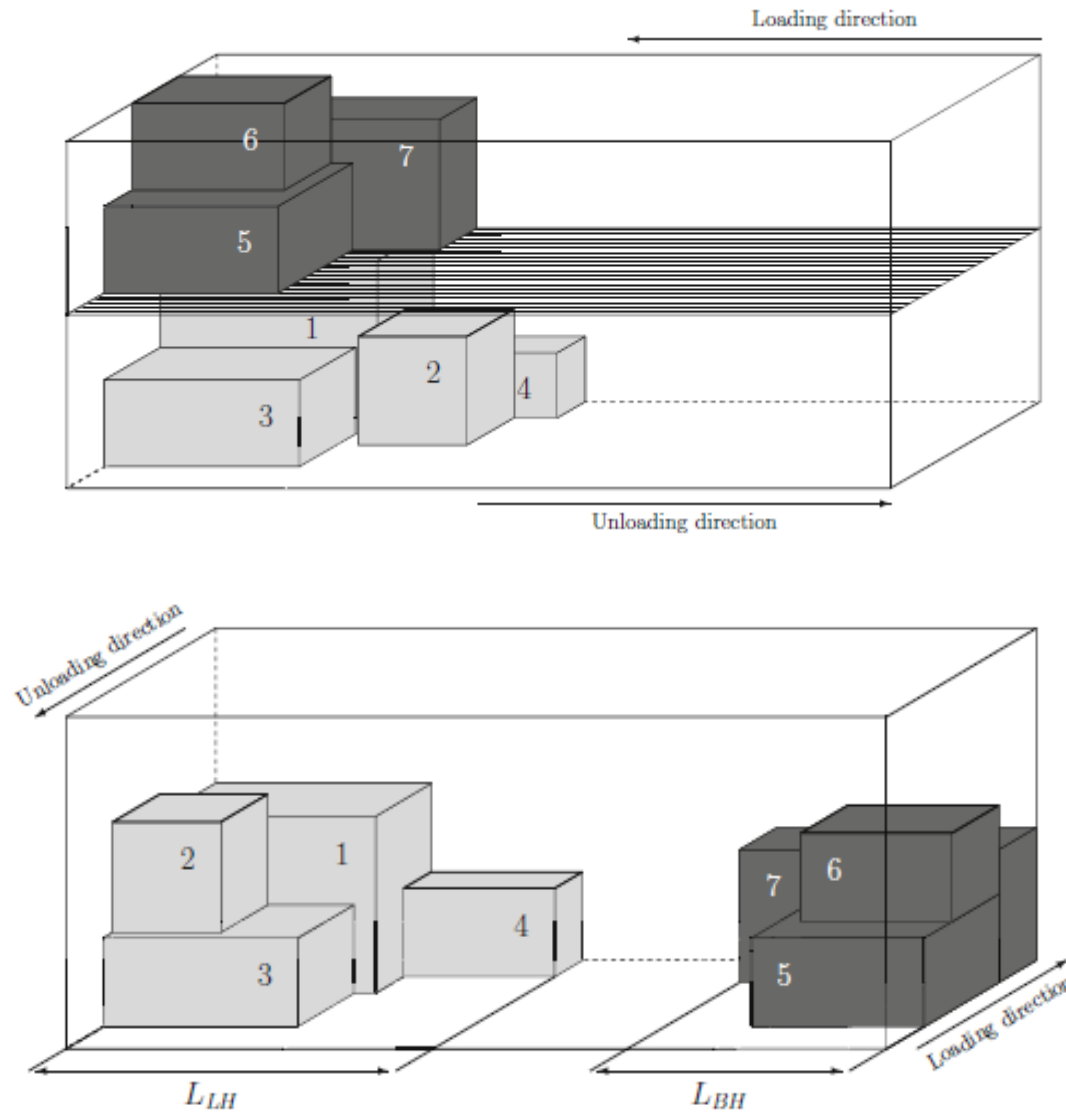
REGULAR ARTICLE

A hybrid algorithm for the vehicle routing problem with backhauls, time windows and three-dimensional loading constraints

Henriette Koch¹  · Andreas Bortfeldt¹ Gerhard Wäscher¹

- (P4) *Fixed vertical orientation* Each item has a fixed vertical orientation, i.e. the height dimension is fixed. The items can be turned by 90° on the horizontal plane, though.
- (P5) *Vertical stability* Each item must be supported by a given percentage α by the top face of other items or the container floor.
- (P6) *Fragility* The items are divided into fragile and non-fragile items. Whereas fragile items can be placed on top of any other item, non-fragile items can only be placed on top of other non-fragile items.
- (P7) *LIFO* In order to load and unload the items solely by straight movements towards the door, the items must be arranged in a way that the loading and unloading operations at a certain station are not obstructed by items that are to be delivered later or have already been picked up. That is, linehaul and backhaul items must not be placed in front or on top of each other. Moreover, a linehaul item that is delivered later must not be placed in front or on top of a linehaul item that is delivered earlier, and analogously for backhaul items.

New challenges: Pickup and delivery with loading constraints



Solving routing problems with realistic packing constraints

Thank you for your attention!

Any questions?

Ramón Alvarez-Valdés

Universitat de València, España

(with many collaborations: Francisco Parreño, Maite Alonso, José Fernando Oliveira, António Ramos, Manuel Iori,.....)

