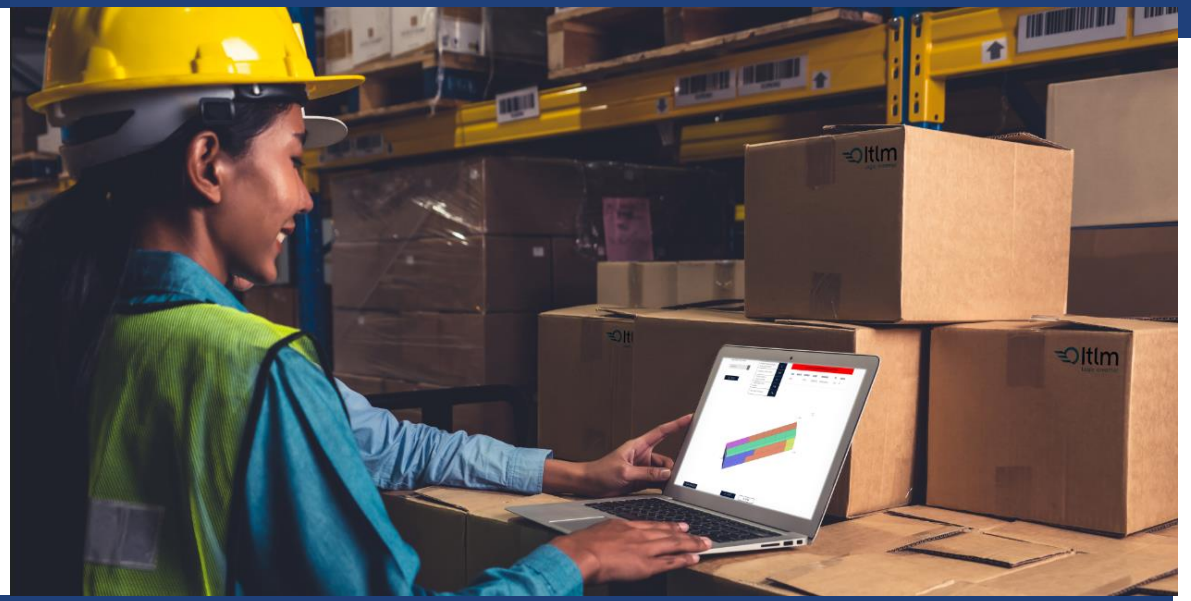
EURO ATHENS 2021 GREECE HYBRID



Sustainable and efficient logistics: How optimization transformed Italmondo's cargo loading operations

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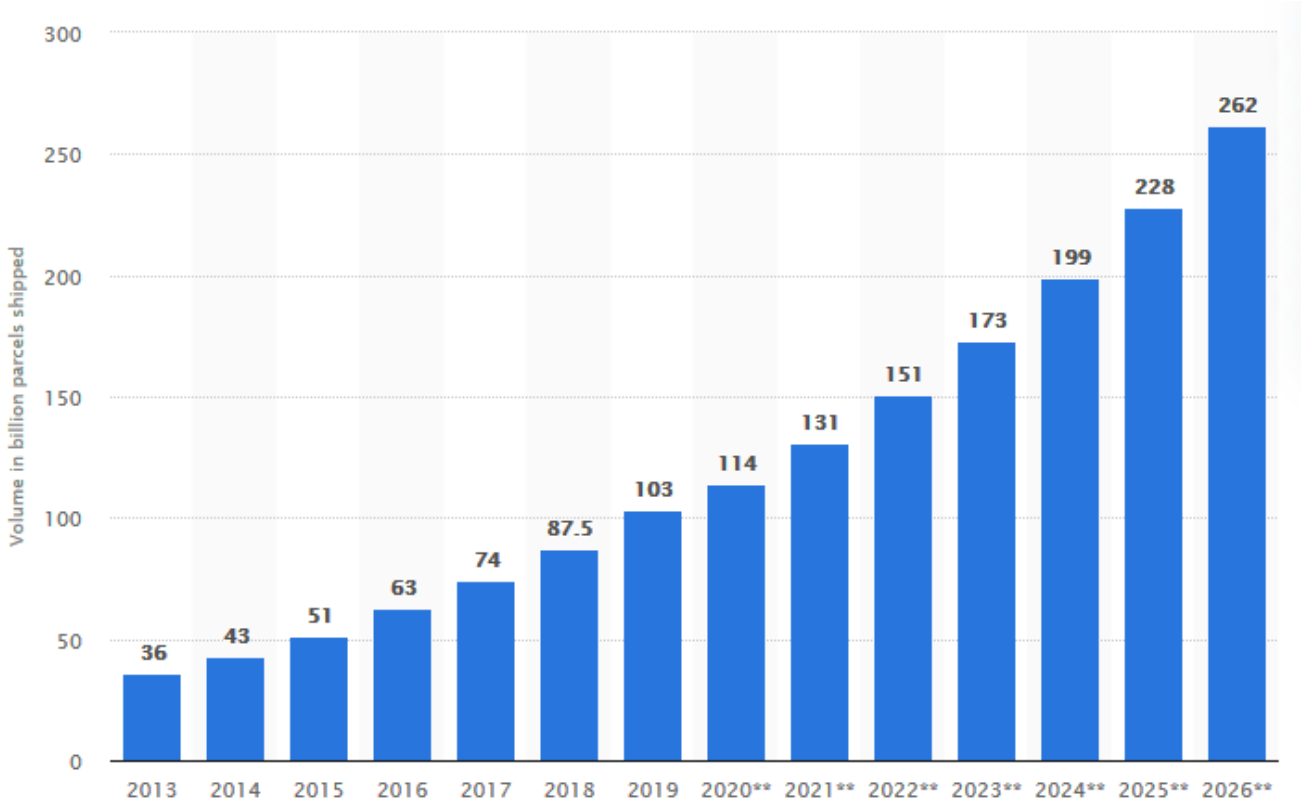
Background

- The logistics sector is growing
- The number of parcels shipped globally is expected to **double** from 2020 (>100 billion) to 2025 (>200 billion)
- **Covid-19** has exacerbated this trend



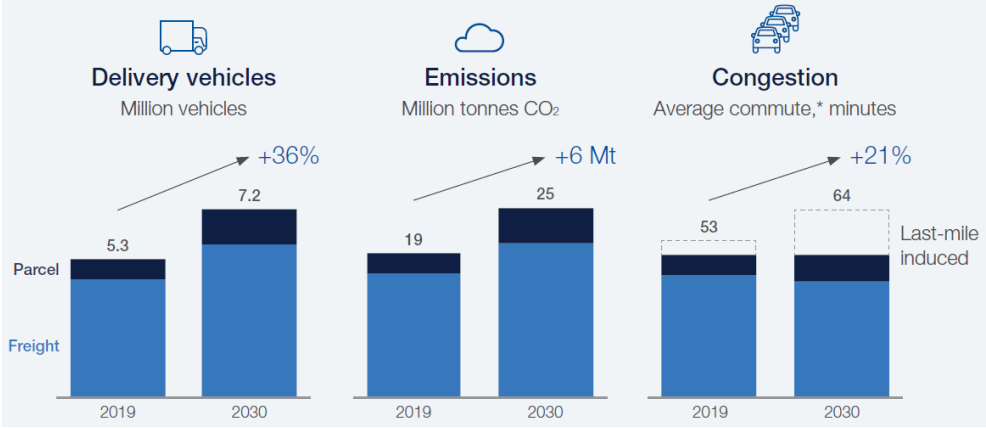
Global parcel shipping volume (billion parcels); statista.com (2020)

Opportunities & Challenges

- This growth is an **opportunity** for logistics operators…
  …but also a **challenge**, due to increasing:

Operational costs

Environmental concerns



Base scenario for urban freight 2030; World Economic Forum (2020)

- Turning this opportunity into higher profits/sustainability requires **efficient operations** (loading vehicles, managing inventories, routing strategies, etc.)

- How?

Technology

Digitalization

Modern analytics (AI, ML, OR)

Italmondo (ITLM Group)

- HQ in Italy, branches in Europe and Asia

65 Years of history

15 Millions of packages

25 Branches

500.000 sqm of property area

250.000 sqm of covered warehouse

1.000+ Collaborators

- Operations cover different modes

- Road transport one of the main businesses with **hundreds of trucks loaded** on a daily basis
  - Before: done manually
  - Goal: use optimization to improve it

International transport by road
Freight transport services in Europe, North Africa and Asia with an associated management of customs procedures.

Sea transport
Customized services for shipping containers by sea to and from the major ports in the world.

Air transport
Highly personalized air freight service safe and quality based on worldwide scale.

Integrated logistics
E-logistics solutions for every business need, from purchase to physical distribution until warehouse management.

National transport
Road freight transport service throughout the country with groupage, full truck and part-load modes.

E-commerce
Integrated logistics services and customized software solutions for the digitalisation of small and large business processes.

Digital consulting
A mix of highly qualified skills able to guarantee cutting-edge digital services for successful startups and e-commerce.

2MH
Transport, delivery, installation and replacement of furniture and appliances of all sizes.

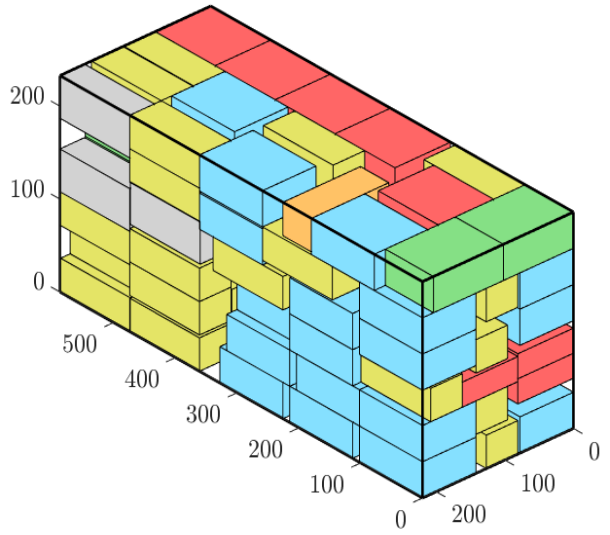
Parcel
Fast and secure online shipments able to deliver parcels in Italy and abroad with the best partner carriers.

Loading Operations

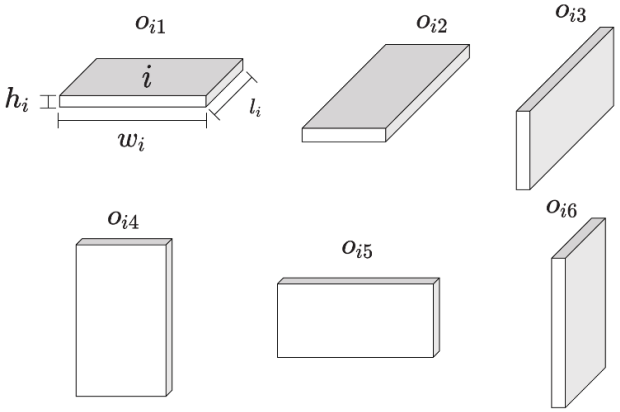
Loading Operations

Container Loading Problem (CLP)

- 3D packing problem with a single container
- Maximize value under “physical” constraints: Non-overlapping, boundaries, orthogonal packing
- Can be formulated as a mixed-integer program (MIP)



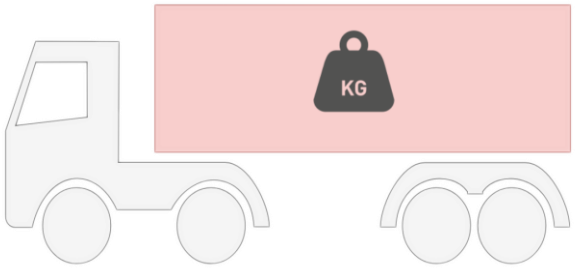
$$
\begin{aligned}
\max \quad & \sum_{i \in \mathcal{B}} \pi_i \, t_i \\
\text{s.t.}: \quad & f_{ij} + f_{ji} + b_{ij} + b_{ji} + u_{ij} + u_{ji} + (1 - t_i) + (1 - t_j) \geqslant 1 && \forall i, j \in \mathcal{B},\ i < j, \\
& x_i + w_i(o_{i2} + o_{i4}) + l_i(o_{i1} + o_{i6}) + h_i(o_{i3} + o_{i5}) - x_j \leqslant L(1 - b_{ij}) && \forall i, j \in \mathcal{B}, \\
& y_i + w_i(o_{i1} + o_{i3}) + l_i(o_{i2} + o_{i5}) + h_i(o_{i4} + o_{i6}) - y_j \leqslant W(1 - f_{ij}) && \forall i, j \in \mathcal{B}, \\
& z_i + w_i(o_{i5} + o_{i6}) + l_i(o_{i3} + o_{i4}) + h_i(o_{i1} + o_{i2}) - z_j \leqslant H(1 - u_{ij}) && \forall i, j \in \mathcal{B}, \\
& x_i + w_i(o_{i2} + o_{i4}) + l_i(o_{i1} + o_{i6}) + h_i(o_{i3} + o_{i5}) \leqslant L && \forall i \in \mathcal{B}, \\
& y_i + w_i(o_{i1} + o_{i3}) + l_i(o_{i2} + o_{i5}) + h_i(o_{i4} + o_{i6}) \leqslant W && \forall i \in \mathcal{B}, \\
& z_i + w_i(o_{i5} + o_{i6}) + l_i(o_{i3} + o_{i4}) + h_i(o_{i1} + o_{i2}) \leqslant H && \forall i \in \mathcal{B}, \\
& o_{i1} + o_{i2} + o_{i3} + o_{i4} + o_{i5} + o_{i6} = 1 && \forall i \in \mathcal{B}, \\
\text{var.}: \quad & f_{ij},\, b_{ij},\, u_{ij},\, t_i,\, o_{i1},\, o_{i2},\, o_{i3},\, o_{i4},\, o_{i5},\, o_{i6} \in \{0, 1\} && \forall i, j \in \mathcal{B}, \\
& x_i,\, y_i,\, z_i \geqslant 0 && \forall i \in \mathcal{B}.
\end{aligned}
$$



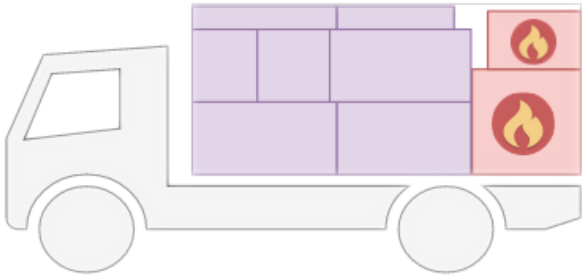
Practical Constraints

All constraints are defined jointly with Italmondo

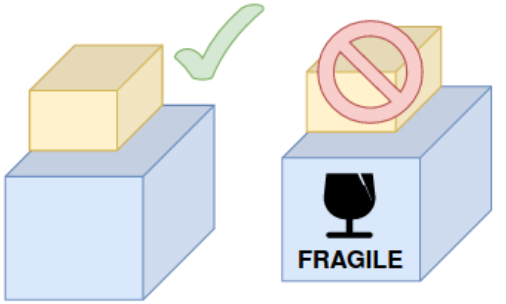
1 Weight limit



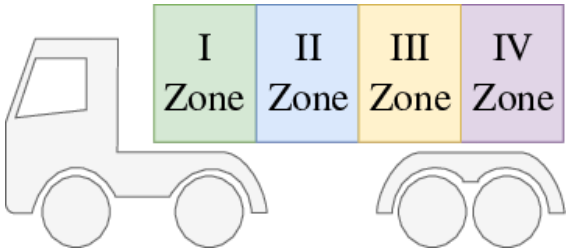
2 Dangerous cargo (ADR)



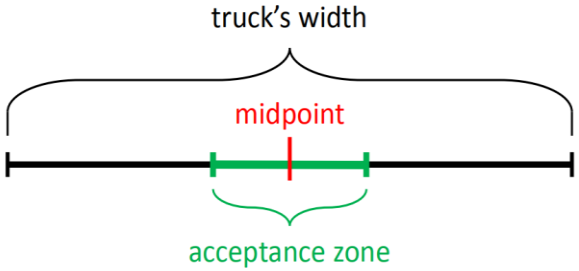
3 Stacking constraints



4 Longitudinal load distribution

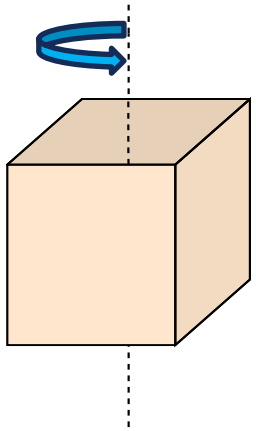


5 Horizontal load balancing

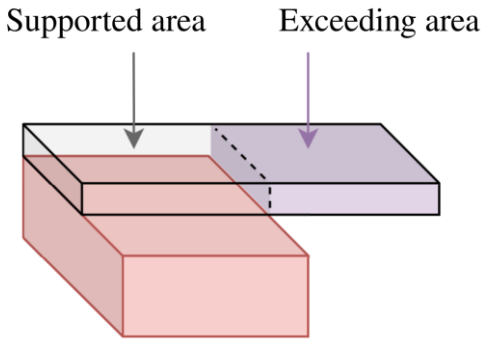


Practical Constraints

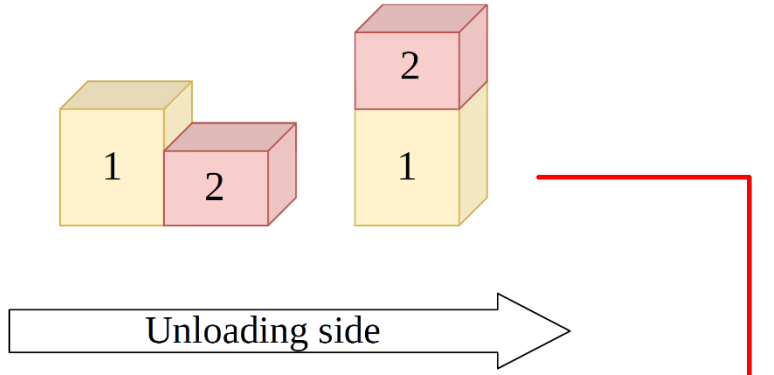
6 Orientations



7 Stability



8 Multi-drop shipments



Soft constraints

Loading priorities

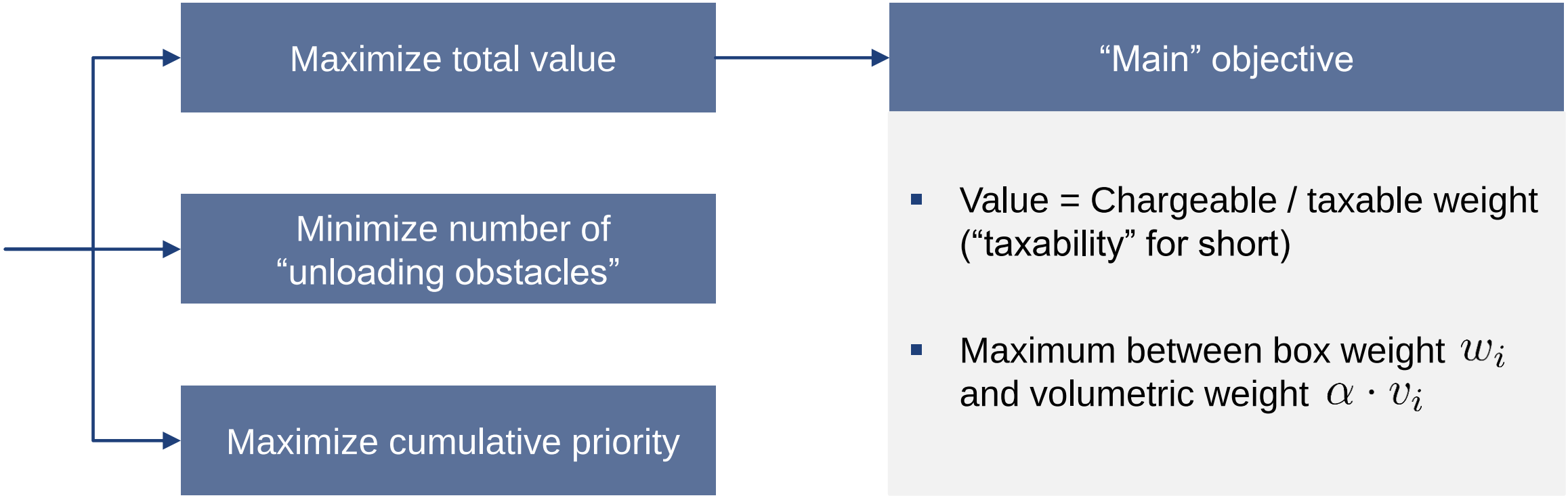
Priority	Description	Constraint type
10	Mandatory item	hard
9	Highest level of priority	soft
...	...	soft
1	Lowest level of priority	soft

9 Lower priorities

10 Mandatory items

Loading Objectives

The problem is inherently multi-objective



Computational Requirements

1. Handle **large-scale** instances with up to 500 items
2. Handle **strongly heterogeneous** instances in both size and weight
3. Provide feasible and optimized solutions within **5-10 seconds**

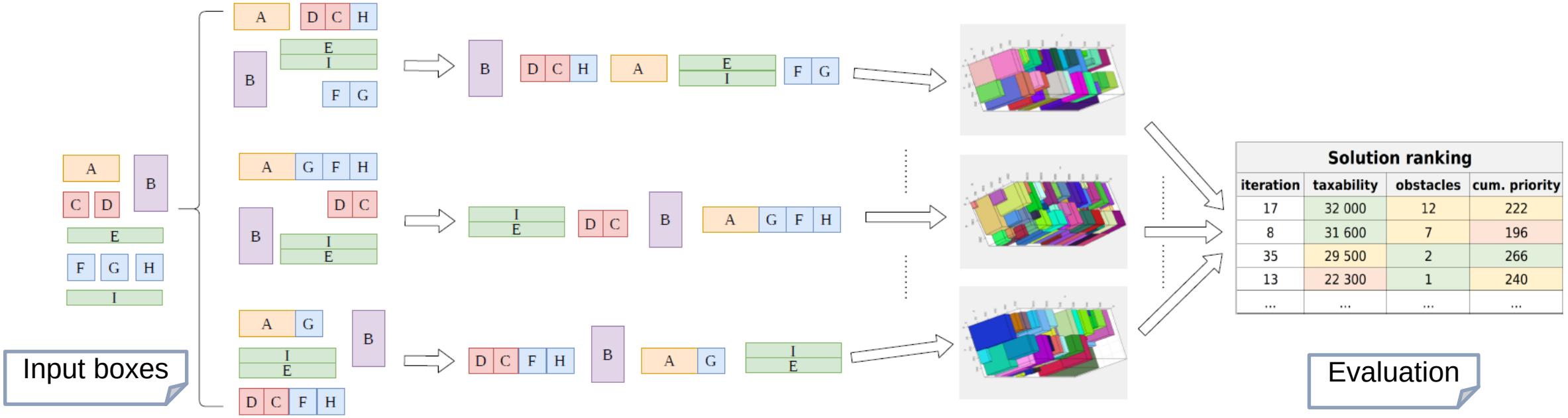
Accounting for all practical constraints under such strict requirements is challenging!

State of Research

- The CLP is well studied (Bischoff and Ratcliff 1995, Pisinger 2002, Bortfeldt and Wascher 2013, Zhao et al. 2016, Araya et al. 2017, Silva et al. 2019)
- Both exact and heuristic methods for the CLP (Zhao et al. 2016, Silva et al. 2019).
  Exact methods far from meeting industry standards: Not fast enough, not flexible enough (Junqueira et al. 2012, Alonso et al. 2019, Kurpel et al. 2020, Nascimento et al. 2021)
- Practical constraints have also been studied
  - Individually (Baldi et al. 2012, Ramos et al. 2018, Trivella and Pisinger 2016, Oliveira et al. 2020)
  - Or in small subsets (Junqueira et al. 2012, Alonso et al. 2019, Kurpel et al. 2020)
  - Da Silva et al. (2020) deal with weakly heterogeneous instances
  - Nascimento et al. (2021) consider many constraints but model and test one at a time
- Unloading constraints are always modeled as hard constraints (Pollaris et al. 2015)
- Multi-objective analysis of loading objectives not considered in the literature

Overview of Approach

- We developed a multi-run constructive approach based on multiple phases



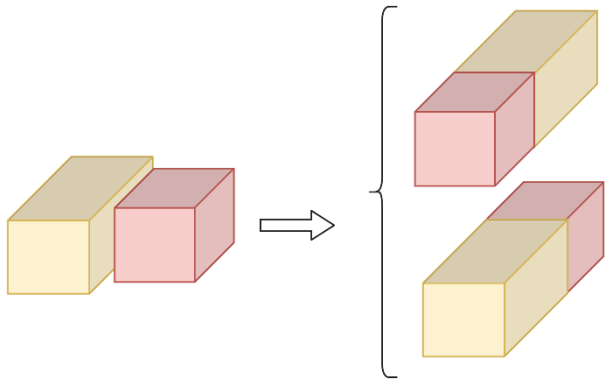
Solution ranking

iteration	taxability	obstacles	cum. priority
17	32 000	12	222
8	31 600	7	196
35	29 500	2	266
13	22 300	1	240
...	...	...	...

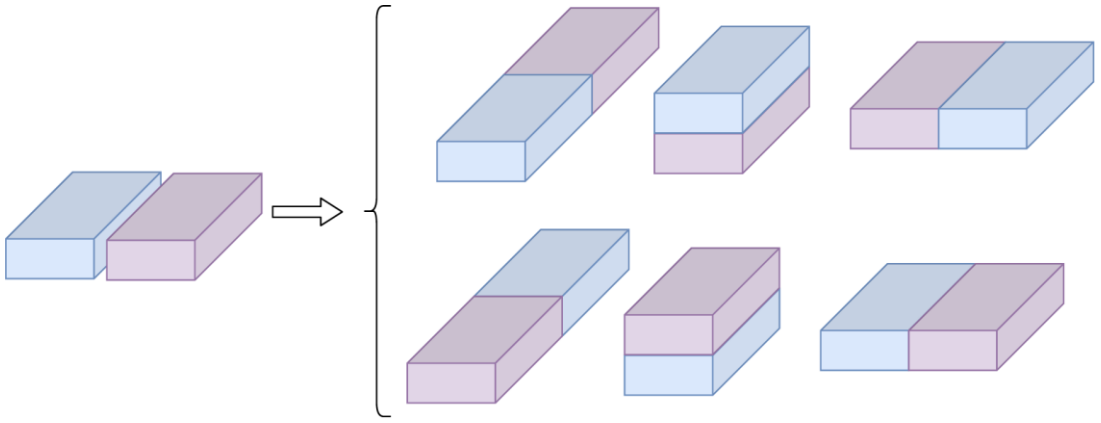
Block Generation

- Larger blocks are created from boxes sharing certain features

Boxes sharing two dimensions



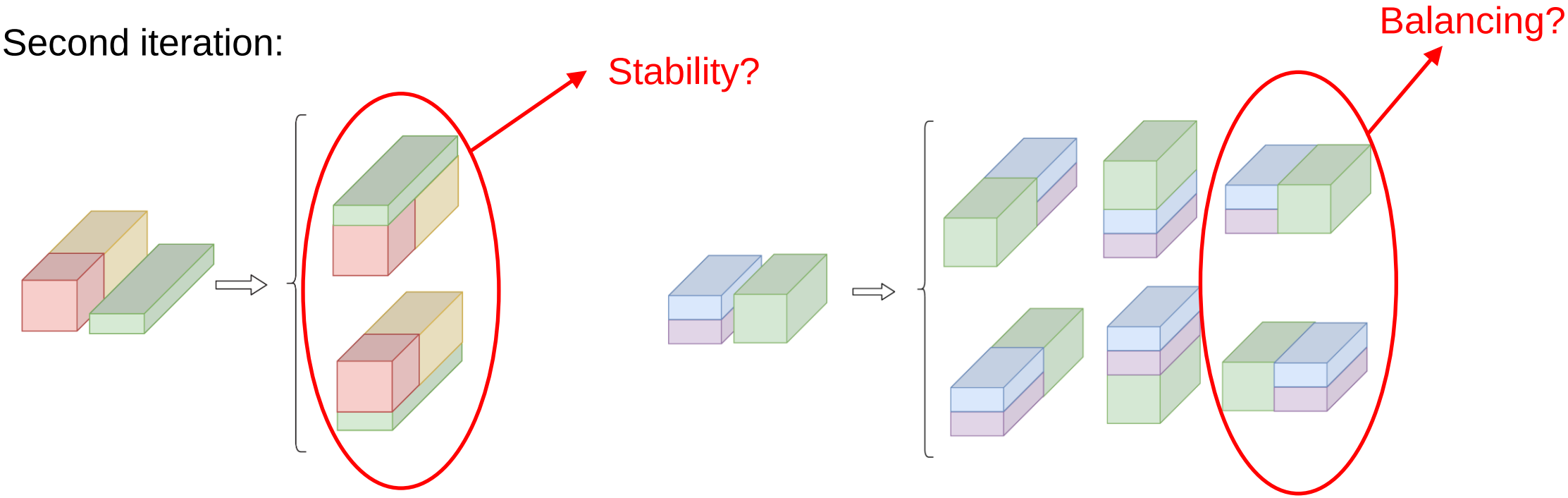
Boxes sharing all dimensions



- The procedure is repeated iteratively

Block Generation

- Second iteration:



- Blocks help to better utilize the volume (as done in the literature)
- Using blocks with practical constraints is non trivial
- Individual items within the blocks have to be tracked

Sorting and Randomization

Item sorting

Idea: The outcome from loading items sequentially depends on their sorting

- taxability
- priority level (then by taxability)
- customer number (then by taxability)

List perturbation

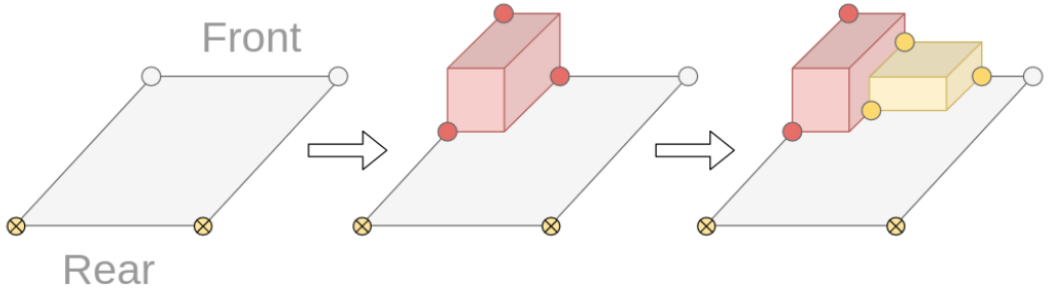
Idea: Perturbing the list allows diversifying the loading and explore a larger space of solutions

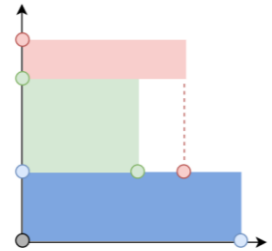
- Randomize **orientations**
  - Of each individual item
  - Of all items sharing all dimensions
- Perturb order by **similarity**
  - By volume
  - By weight

- In contrast to GRASP, randomization is decoupled from construction, hence faster: $\mathcal{O}(|\mathcal{B}|^2)$

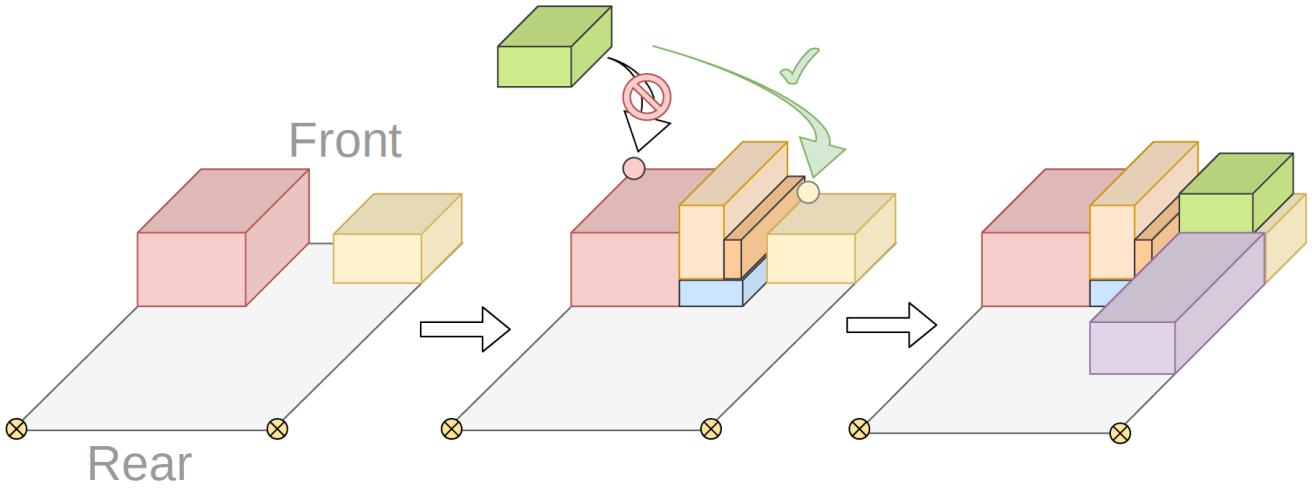
Constructive Packing

- Load items sequentially in candidate locations - Potential Points (PPs)
- Update PPs list after each insertion





- Choose PP to insert the item such that insertion is feasible w.r.t. load distribution (zones), stackability, stability, ADR cargo, blocks



- Ensuring a larger proportion of the contact surface with the underlying items

  (In tie-breaking cases, minimize the x-coordinate, i.e., load from the front of the truck)

Dual Bounds on Taxability

1 Continuous upper bound

1. Load all mandatory items
2. Load all others sorted by taxability/volume, until their joint volume fits
3. Load all others sorted by taxability/weight, until their joint weight fits
4. Take the minimum taxability achieved

2 3D Knapsack Packing

- Solve the MIP, adding weight limit, forcing mandatory items and allowed orientations
- Take the best upper bound available on the branch-and-cut tree

Numerical Results

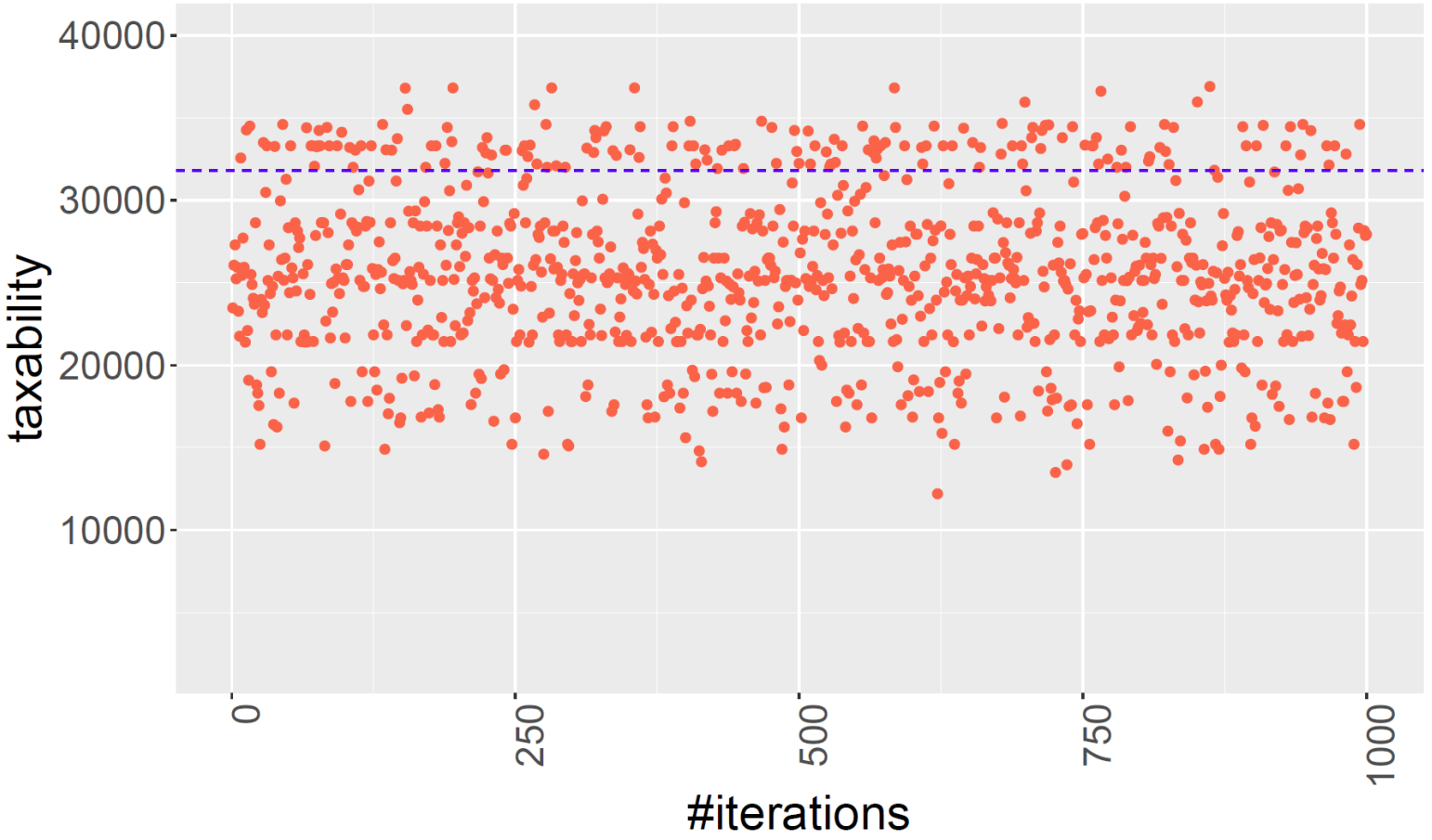
- 38 representative **real instances and solutions** provided by Italmondo, up to 450 items

	Bound	Company		Heuristic		
Average	tax	tax	gap (%)	tax	gap (%)	time (s)
All instances	31.3	24.8	16.7	26.7	9.9	4.8
Exclude infeasible	26.2	17.8	21.5	21.8	9.1	4.1

- 9 of the company's solutions are provably **infeasible** (e.g., violate weight limit)
- The average taxability improvement is **22.4%**, with **12.4%** lower optimality gap
- The average runtime for 500 iterations is less than **5 seconds**

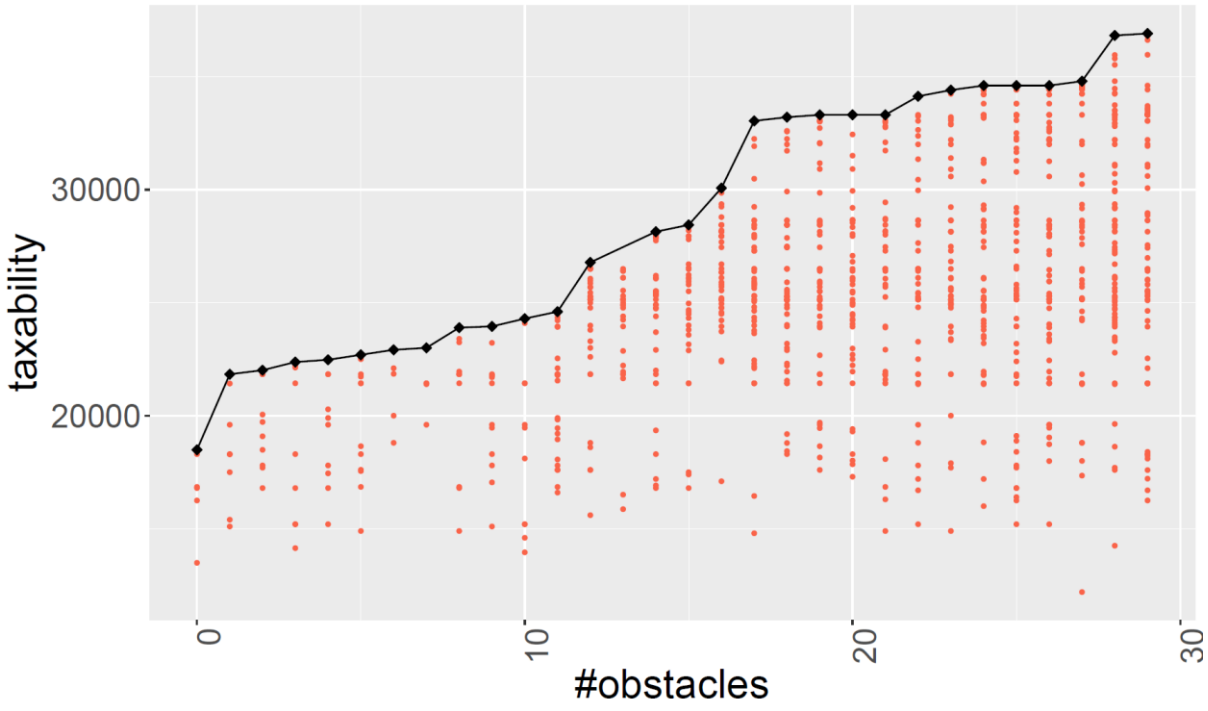
→ Significantly superior solutions in terms of value and constraint handling

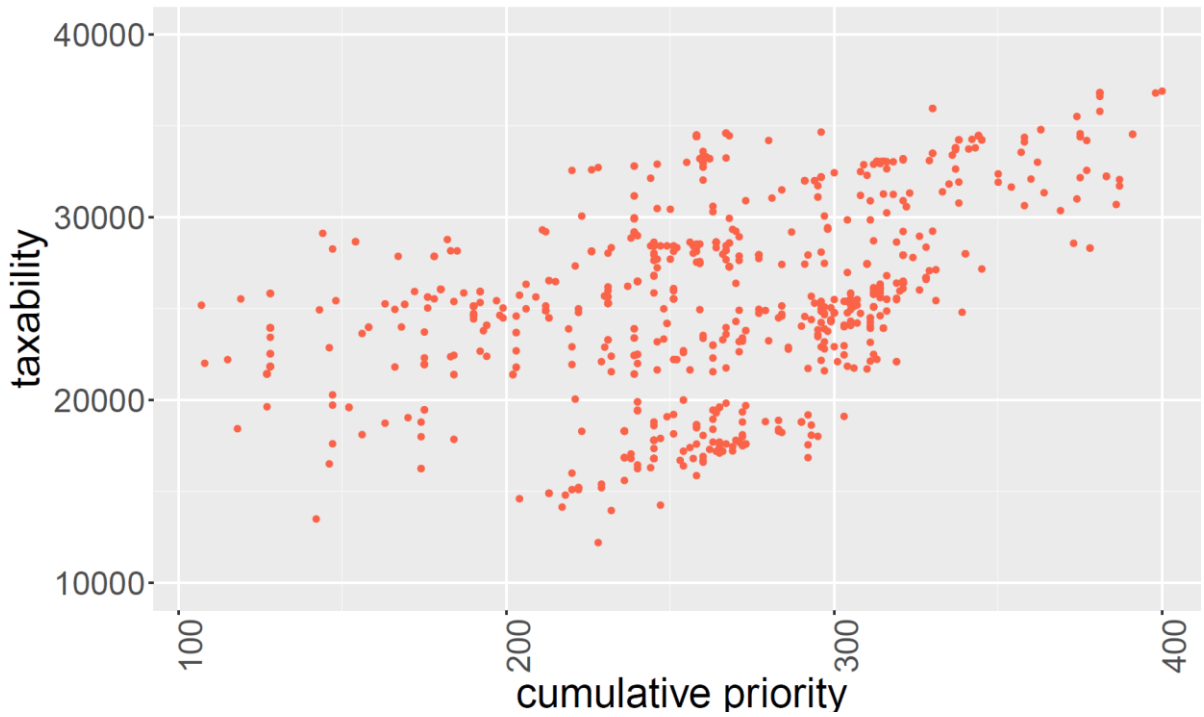
Usefulness of Randomization



- The initial sorting by taxability lead to a good solution on average (dashed blue line)
- Taxability in the best iteration is **16% higher**

Multi-objective Analysis of Soft Constraints

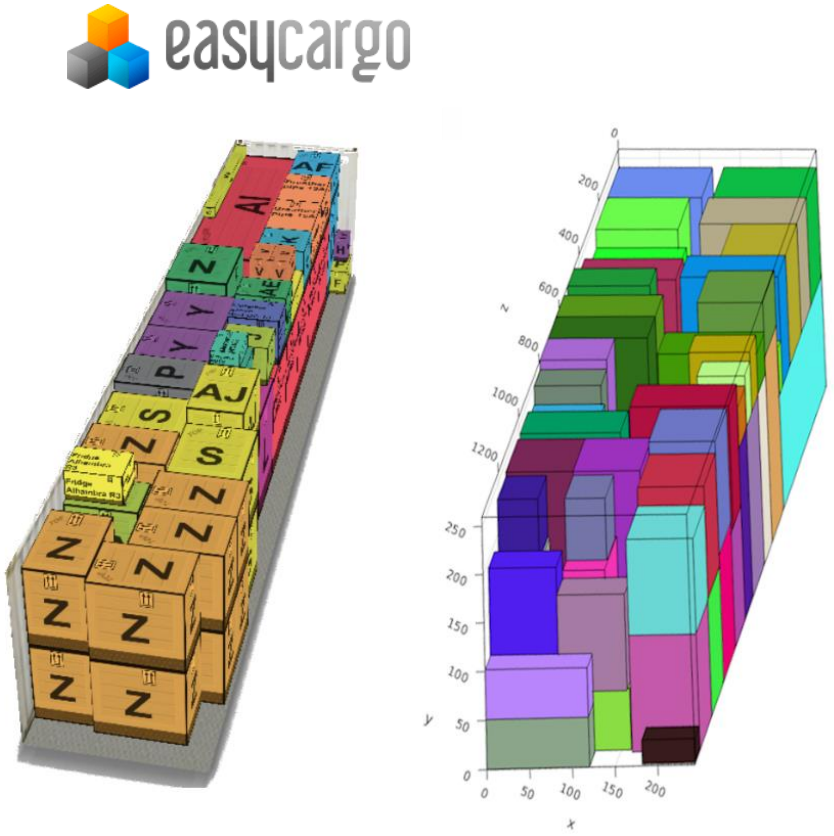




- Obstacles and taxability are **in conflict**: Limiting obstacles requires sacrificing taxability
- Cumulative priority and taxability are **less conflicting**: Managing priority less critical

Comparison with Existing Tools

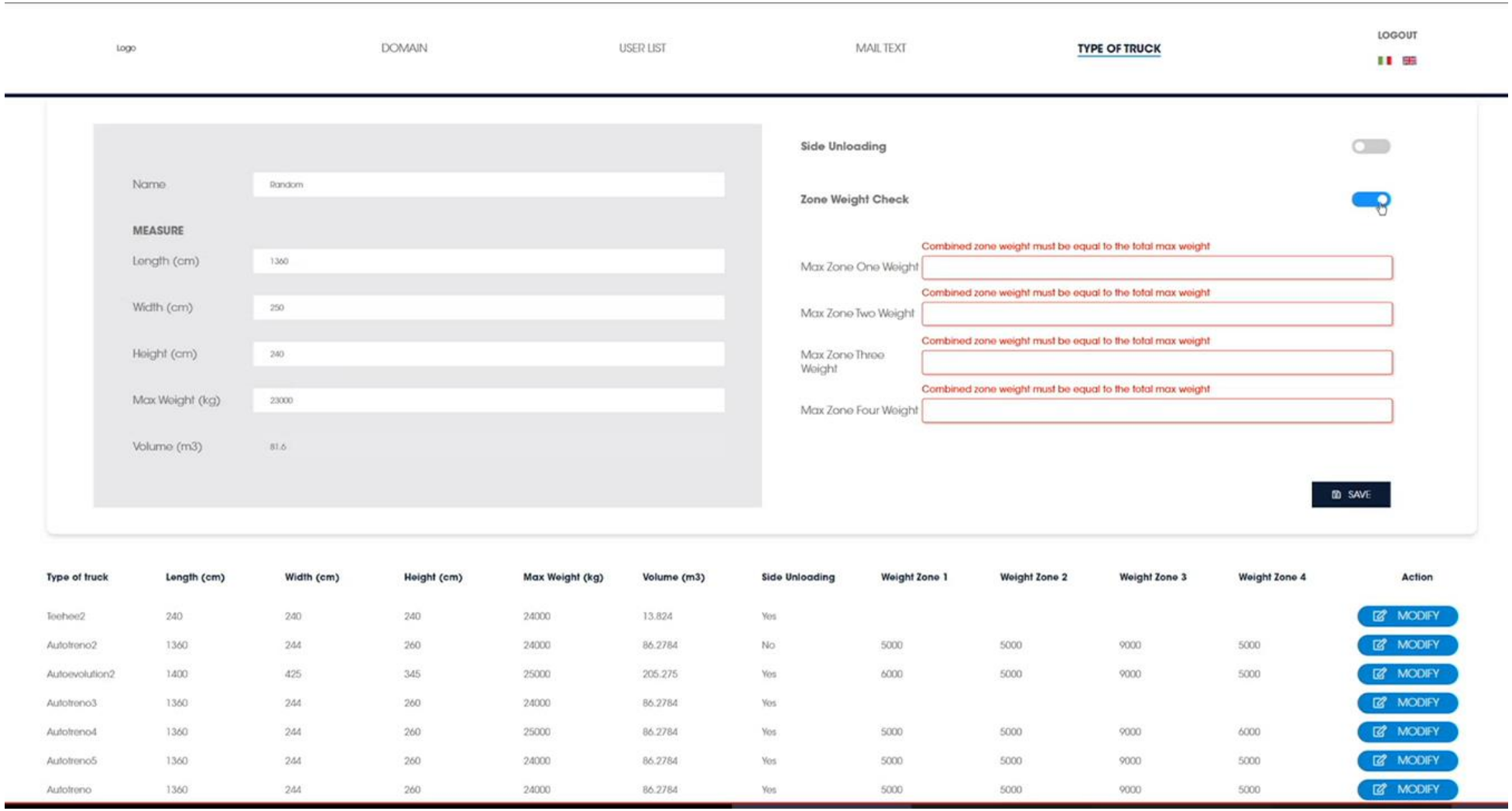
Commercial tools for the CLP exist, including the well-known EasyCargo, but



- **Less flexibility**: Only a few practical constraints can be enforced
- **Less value** is achieved, especially for strongly heterogeneous instances (up to 13% less)

The Optimization Software

- A tool has been developed and is being used



The Optimization Software

Logo

TRUCK LOADING SOFTWARE

LOGOUT

Year 2020

Branch 1

Truck Number 14723

Type of Truck

Autotreno

VIEW 3D

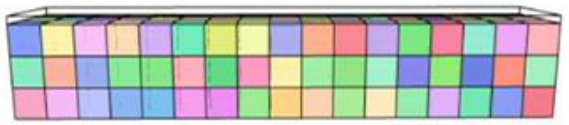
Max Container Weight	24000 kg
Occupied Weight	3060 kg
Total Container Volume	86.2784 cm3
Occupied Volume	78.34 cm3
Taxability	3060 kg
Items Packed	153 / 181

LIST OF LOADED SHIPMENTS BY ALGORITHM

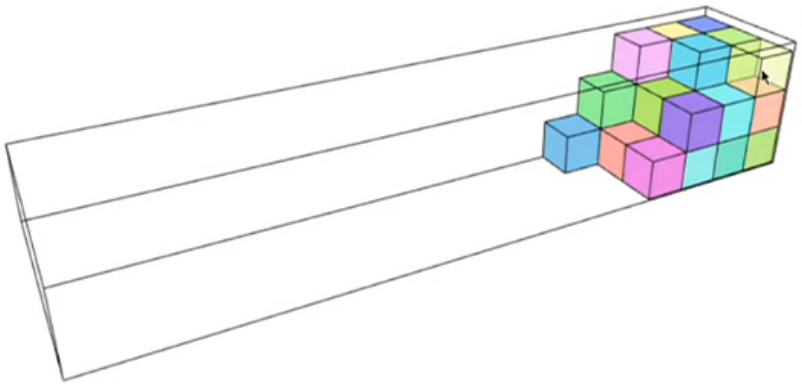
Year	Branch	Shipment	Sender	Consignee	ZIP	Nation
2020	1	1	[redacted]			BE
2020	1	116	[redacted]			BE
2020	1	117	[redacted]			BE

LIST OF NOT LOADED SHIPMENTS BY ALGORITHM

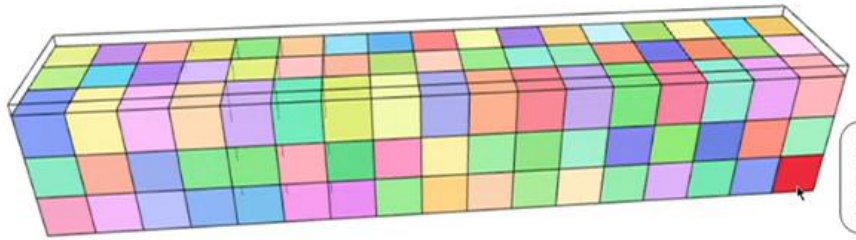
Year	Branch	Shipment	Sender	Consignee	ZIP	Nation
2020	1	6	[redacted]			BE
2020	1	47	[redacted]			BE
2020	1	48	[redacted]			BE



The Optimization Software



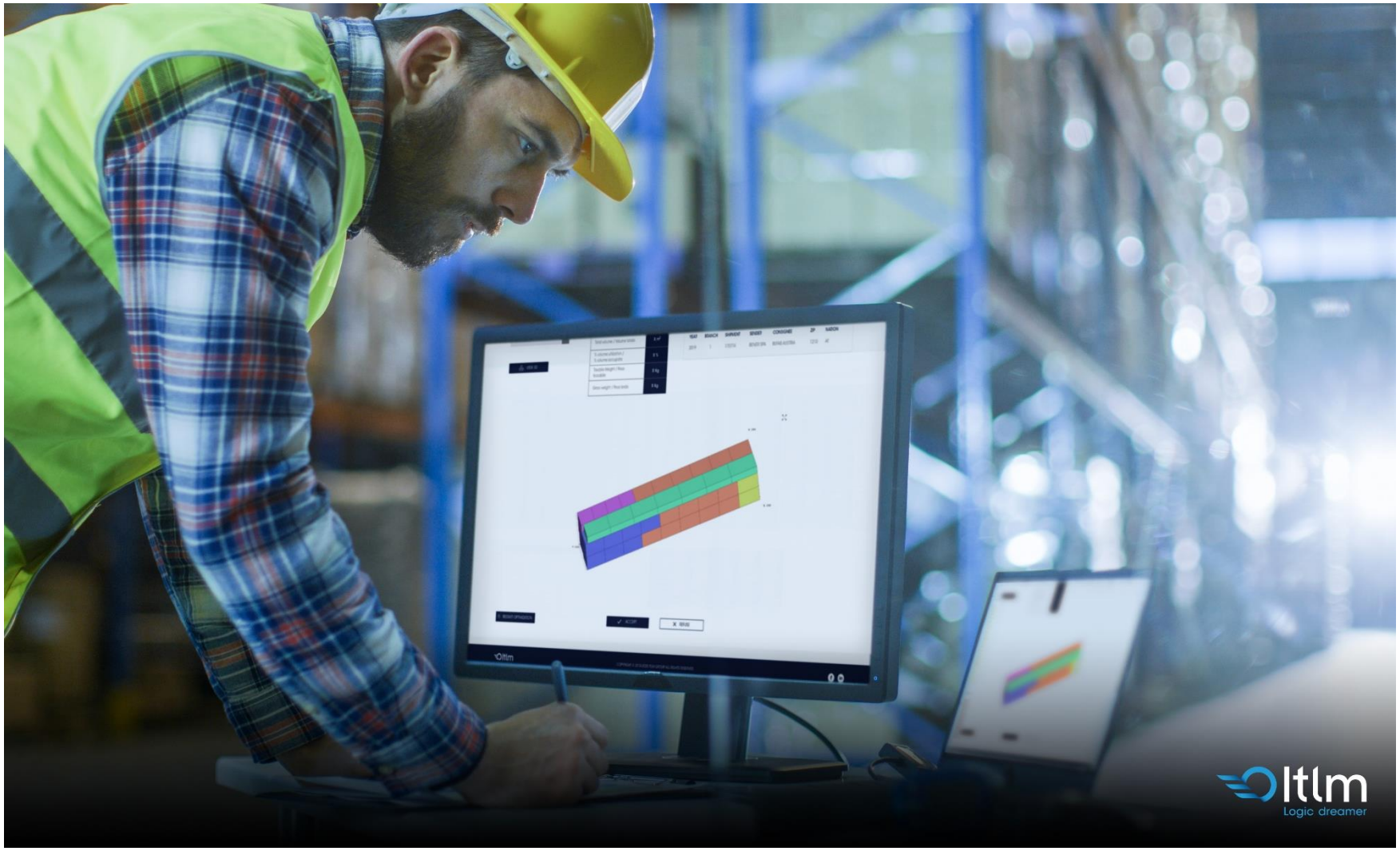
Id - e47fc7f7-ff4a-4e69-a74d-08d9309439ef
Shipment - 114
Number - 1
Sender - [redacted]
Consignee - [redacted]
Volume - 0.512



Id - ba76fb7c-dc38-490f-a7bd-08d9309439ef
Shipment - 44
Number - 1
Sender - [redacted]
Consignee - [redacted]
Volume - 0.512

N. Items	Type of Unit	Length	Width	Height	Weight	Volume	Stackable	Unloading Order	Priority	Taxability	Loaded	Loading Rules	Country Rules	Customer Partner Rules	Sender Rules	Consignee Rules	Goods	Traffic Line	Year	Branch	Shipment
1	PLT	80	80	80	20	0.512		0	0	20							Merce varia	B01	2020	1	1
1	PLT	80	80	80	20	0.512		0	0	20							Merce varia	B01	2020	1	2
1	PLT	80	80	80	20	0.512		0	0	20							Merce varia	B01	2020	1	3
1	PLT	80	80	80	20	0.512		0	0	20							ARTICOLI PER LA CASA	B01	2020	1	4
1	PLT	80	80	80	20	0.512		0	0	20							ARTICOLI PER LA	B01	2020	1	5

Acceptance by Warehouse Personnel



- Provide a few (non-dominated) solutions to choose from
- Combine human experience with the power of optimization

Impact on Practice

Revenue

- Higher average cargo value per shipment
- Reduced fleet size to transport the same amount of cargo (**10-15 trucks each day**)
- Yearly cost reduction estimated at **1 mln. EUR**

Safety

- Load is more evenly distributed across axles and more stable
- Reduce boxes' movements and damage
- Prevents fines due to irregular loadings

Efficiency

- Reduce repositioning of cargo, as opposed to manual approach
- Lower average loading time per unit volume
- Combine experience with optimization

Environment

- Reduce number of daily vehicles, hence fuel consumption
- Yearly CO_2 emission reduction estimated at **1 thousand metric tons**

Conclusion

- We developed OR techniques for optimizing cargo loading operations at Italmondo, increasing **revenues**, **efficiency**, **safety**, and reducing impact on **environment**

- Started an **“OR culture”** at the company, that understood:
  1. The potential of OR in modern logistics
  2. How to identify problems that can be tackled using OR

- New optimization-based projects being planned (loading, revenue management, inventory…)

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Thank you

Current version of the paper available at:
https://ssrn.com/abstract=3294724