DEI DOCTORAL RESEARCH SEMINARS

Decision and control problems in logistics 4.0

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Collaborations

This PhD scholarship is carried out under the supervision of the

- Decision and Control laboratory of the Polytechnic of Bari (http://dclab.poliba.it/)

in collaboration with

- Elettric80 an Italian company specialized in the development of automated and integrated intralogistics solutions (https://www.elettric80.com/it/)

OUTLINE

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- Nomenclature
- Automated Bin Packing
- Delivery planning
- Real time delivery update
- Conclusions and future development

Introduction

The field in which the scholarship is developed is **Industry 4.0** and in particular **Logistics 4.0** i.e. the overall process of managing how resources are acquired, stored (internal logistics), and transported to their final destination (external logistics).

The application of the theory of automatic controls combined with methods and techniques of operational research within Logistics 4.0 can easily allow to:

- Improve the efficiency of the packing and the saturation of space in the means of transport
- Enhance working conditions
- Increase the productivity and quality of the plants
- Reduce planning time and transport costs
- Automatically monitor and control fleet and deliveries in real time

Introduction

Traditionally in logistics most of the operation are conducted without the use of the automation such as:

- *the creation of the bins*: performed by hand by specialized operator and it quality only depends by the experience of the operator
- *the planning of distribution routes and of vehicle loads*: often conduced separately, although being correlated activities in delivery planning. This often requires re-designs to make the routes and the load plans compatible with each other and applicable in practice.
- the planned routes, which are static by definition, cannot always cope with *unexpected events* that can occur during the delivery. This results in lower service levels, undesired delays, and higher costs for logistics companies.

Research objectives

Automated Bin Packing

Optimization of the composition of the bins with particular attention to:

- the minimization of unused space
- the respecting of a wide set of geometric constraints and security of goods.

INNOVATION: Definition of a complete model of constraints useful to the application of the problem in real cases

Delivery planning

Optimization of

- the loading plan of the means of transport with particular attention to the balance and stability of the cargo.
- the route of delivery of goods by means of transport.

INNOVATION: Definition of a complete model of constraints useful to the application of the problem in real cases

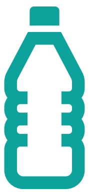
Real time dynamic vehicle routing

Management of unforeseen events, such as: congestion in road traffic, delays in unloading operations, delays in receiving operations at customers.

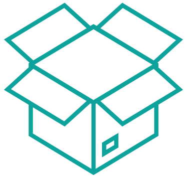
INNOVATION: Implementation of a dynamic routing that, provides for the possibility of performing real-time re-routing of means of transport through a feedback control system

Nomenclature

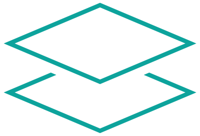
ITEM



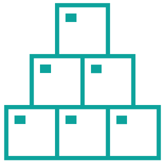
CASE



LOAD AID

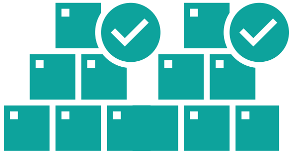


PALLET/BIN



TRAILER

SHIPMENT



DELIVERY

Automated Bin Packing

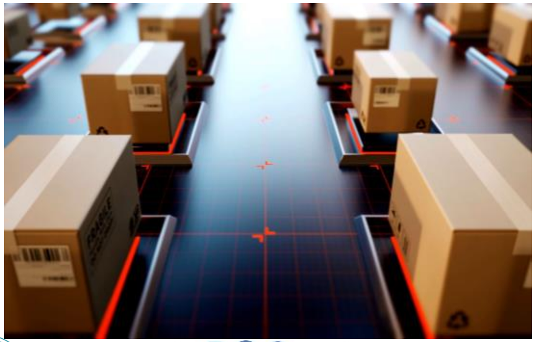
Objectives

- *Bin packing* belongs to the class of NP-hard problems and in particular the *cutting and packing problems*.

- It aims at optimizing the volume occupied by a set of objects within a bin while satisfying a series of logistics and physical constraints.

- In order to achieve good solution in fast computational time the developed algorithm is composed by 3 different phases:
  1. Prepocessing phase
  2. Layer building phase
  3. Bin building phase

  (2–3: **Wall building**)



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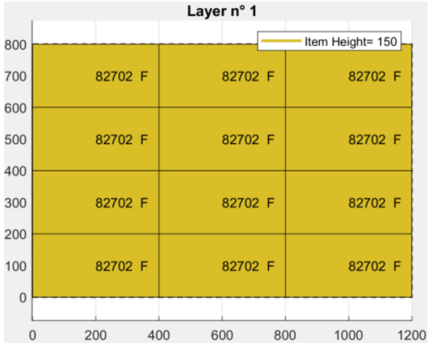
Grouping of items by delivery and monoitem layers creation

The main goals of this phase are:

- Process the input data from the dataset and organize them into classes.
- Group items by delivery.
- Verify if the quantity and the dimensions of a type of item allows the creation of monoitem layers without using the solver.

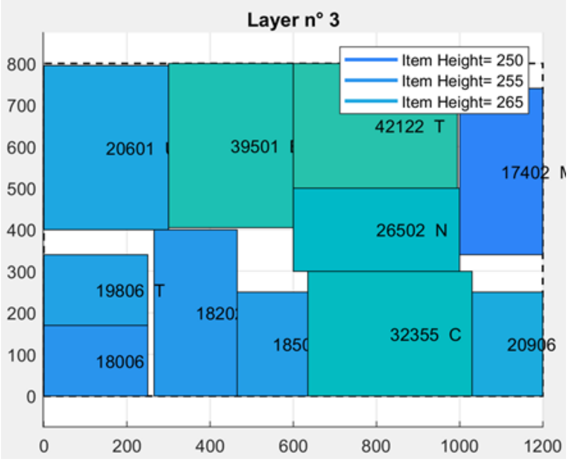


Layer building mathematical model – Objective function

Objective function: minimization of the empty space within a layer - i.e., the maximization of the layer fill ratio

$$\min\ ((W_k L_k) - \sum_k p_{ik} w_i\, l_i)$$

FILL RATIO:
Percentage of occupied space of a box. It is calculate as the difference of the total available space – the sum of the space occupied by the items.



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Layer building mathematical model – *Constraints*

Physical constraints

- An item can *rotate on the x/y axis*
- The items cannot exceed the *maximum layer size*
- An item must be *contained in at most one layer*
- Two items can have just one *relative position*
- The items must not *overlap*

Business Constraints

- *The placement of each item must not overhang* with respect to the dimensions of the layer taking into account a given tolerance.
- The *maximum gap between the items height* inside one layer must be lower than a threshold
- The *maximum gap between the items stackability* inside one layer must be lower than a threshold

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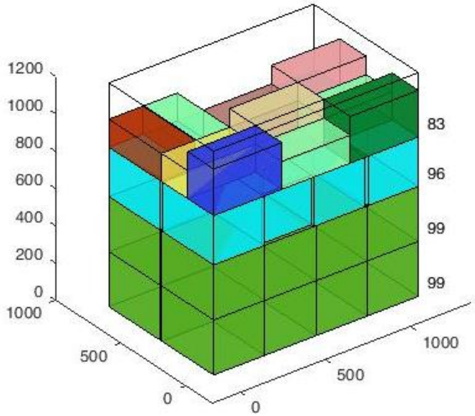
Bin building mathematical model – *Objective function*

- **Objective Function:** minimization of the number of bins to be filled

$$min \sum_{k} N_k$$



Bin building mathematical model – *Constraints*

Physical constraints

- There is a *maximum number of layers that can be occupied*
- The layers cannot exceed the *size of bin k*
- A layer can be contained *in at most one bin*
- Two layers can have at most one *relative position* in a bin
- The layer cannot *overlap*

Business Constraints

- The weight over a layer must be lower than the *maximum tolerable weight of that layer*
- The total weight over a load aid and a trailer must be lower than the *maximum weight supported by the trailer and the load aid*
- The *height of the final configuration* cannot exceed the maximum height
- The *weight and height of layer picking must be respected*
- The layers must be placed according their *stackability and stability* score

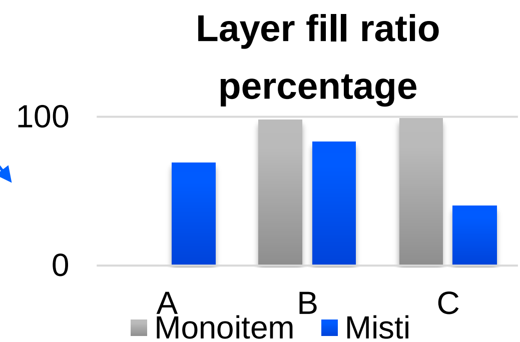
Testing and debugging

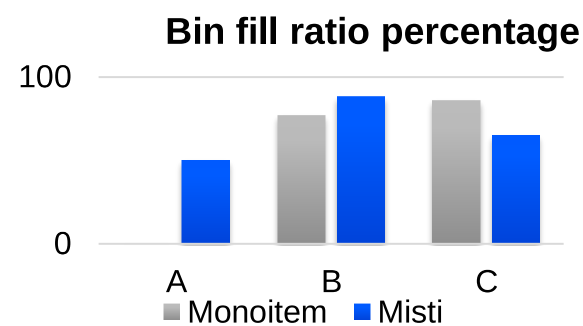
In order to test and validate the implemented algorithm, both *realistic and real datasets* have been used.

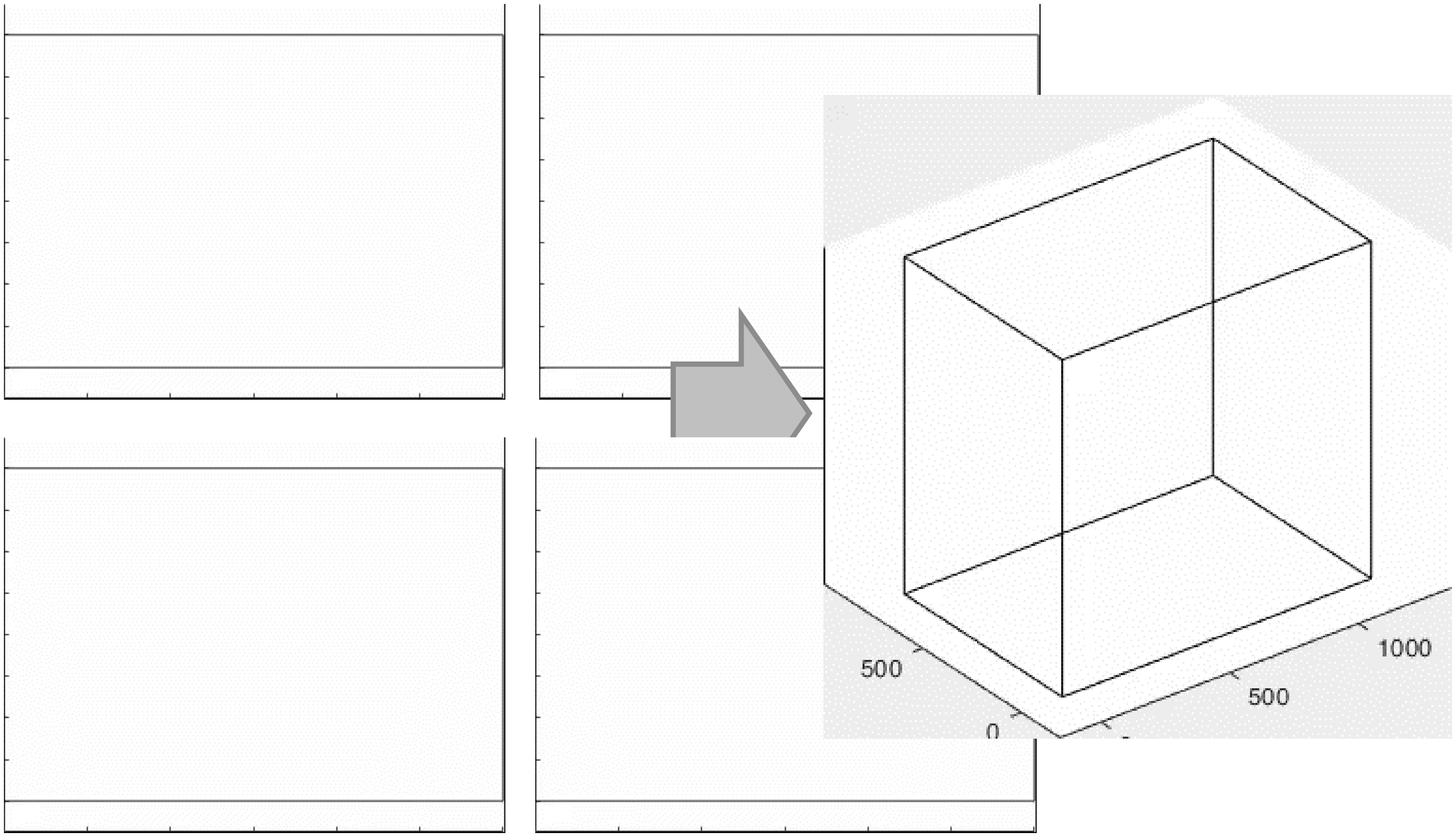
- The real datasets (*3 real shipments*), extracted from the company databases, allowed for the validation of the final version of the algorithm.

EXECUTION TIME [S]	SECONDS PER BIN
2.234	320
777	8.57
644	4

Real shipment	N° of items	N° of IDs
A	84	80
B	522	30
C	486	11






500
0
1000
500

Delivery planning

Objectives

We propose an algorithm that, automatically generates feasible routing and loading plans for a set of Transport Units (TUs) takes as input:

- a set of different clients,
- the list of products packed into bins (i.e., standard packing units) to be delivered to each client
- a set of transport units available for the deliveries

And provides as output

- the number and type of transport units to be used,
- the composition of the bins in each transport unit,
- the corresponding route while optimising the space occupation in each TU and the travel costs

The ***vehicle routing problem (VRP)*** deals with the creation of routes and the association of the corresponding vehicles in order to serve a set of customers.

The ***container loading problem (CLP)*** deals with the loading of bins inside a transport unit.

Vehicle Routing

Mathematical model – *Objective function*

Objective function: minimization of the sum of three different terms

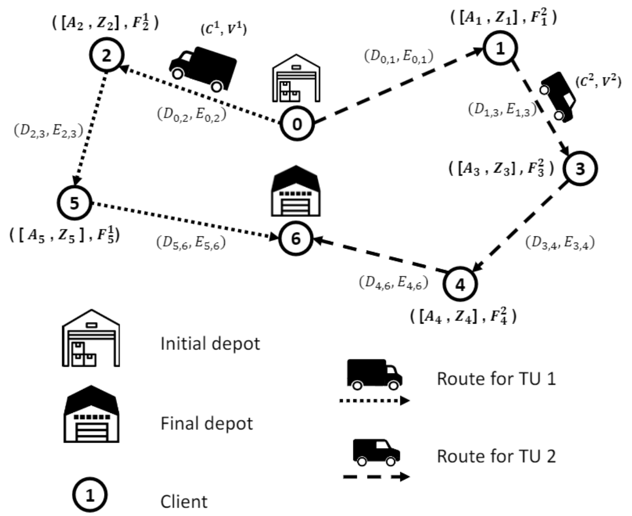
1. Base costs
2. Variable costs
3. Delay in the arrival time at each client

$$min\ [\ \underbrace{f_1 \sum_{k\in M}\sum_{j\in N} C^k\, {t_{(0j)}}^k}_{1} + \underbrace{f_2 \sum_{k\in M}\sum_{j\in N} V^k \mathrm{d}_{(\mathrm{ij})}\, {t_{(ij)k}}^k}_{2} + \underbrace{f_3 \sum_{k\in M}\sum_{j\in N} \Delta {A_i}^k {t_{(ij)}}^k}_{3}\ ]$$

Vehicle Routing

Mathematical model - *Constraints*

- Each node must be visited *at most once*
- Each customer can be served by only *one transport unit*
- Each route starts from the *initial deposit* and ends at the *final deposit*
- There are *no departures from the arrival* deposit and there are *no arrivals in the departure deposit*
- There are *no routes that start and arrive at the same node* (feasibility of the route)
- Routes *must not contain cycles* within them
- The bins associated with each transport unit *respects its capacity in terms of volume and weight*
- There is a *maximum number of trucks that can be used*/ limit on the *number of routes that can be created*
- Shipping must respect customers' *times windows*



Container Loading

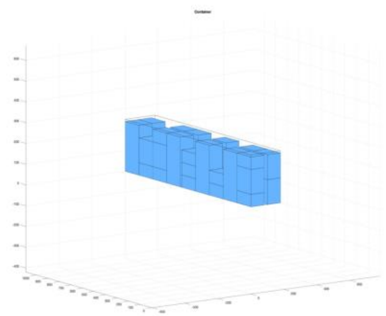
Mathematical model – *Objective function*

Objective function: minimization of the empty space within the container - e.g. the maximization of the layer fill ratio

$$\min \ ((W_k L_k) - \sum_k p_{ik} w_i l_i)$$

FILL RATIO:

Percentage of empty space, calculated as the difference between the total available space and the sum of the space occupied by the items



Container Loading

Mathematical model - *Constraints*

Physical constraints

- The total weight of all items must not exceed the *maximum permissible weight*
- There is *only one relative position among two* bins in a container
- *The coordinates* of the bins within the same transport unit *must not overlap*
- A bin can *rotate over the x/y axes*
- *A bin must be contained in only a transport unit*
- The total volume of all items must not exceed the *maximum permissible volume*

Business Constraints

- The bins must be stacked according to their *stability index*
- The bins must be placed according the *LIFO order of customers*
- The composition of the bins in the transport unit must produce a *stable configuration* and ensure that objects do not break both when *moving or still*
- *The weight of the load must be distributed* as evenly as possible on the floor of the transport unit, respecting the maximum weight supported by each axes

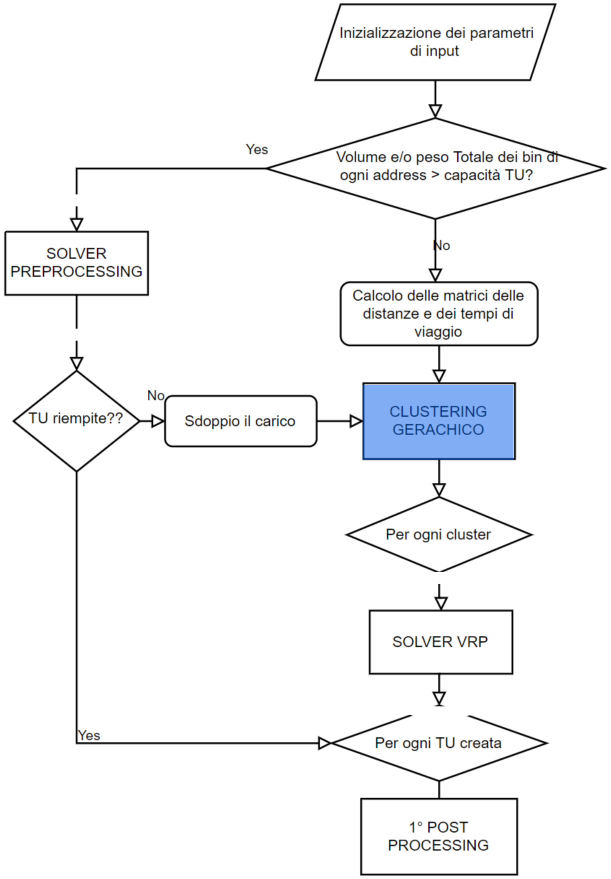
The combined algorithm for the CLP and VRP

The designed algorithm is composed by the following steps:

1. Parameters inizialization
2. Preprocessing
3. Creation of the delivery routes (VRP's output)
4. Creation of the loading plan (CLP's output)
5. Refinement of the solution and post processing

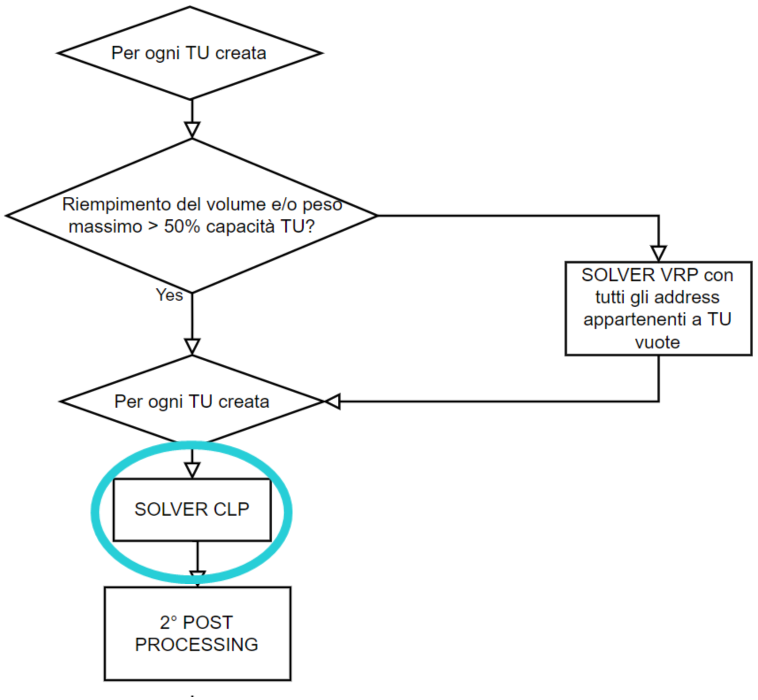
The combined algorithm for the CLP and VRP

The designed algorithm– Preprocessing and delivery routes planning



The combined algorithm for the CLP and VRP

The designed algorithm– Loading Plan



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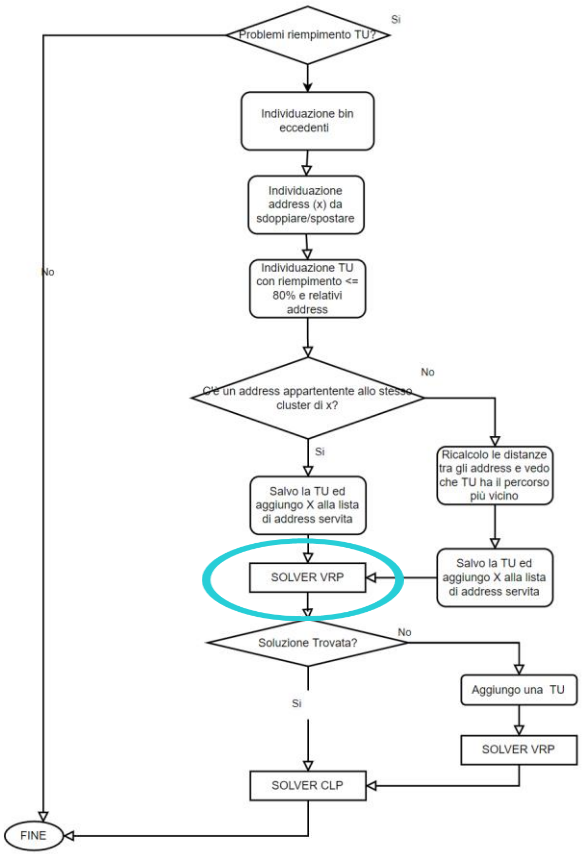
The combined algorithm for the CLP and VRP

Refinement of the solution and post processing



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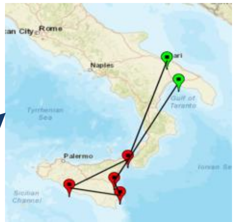
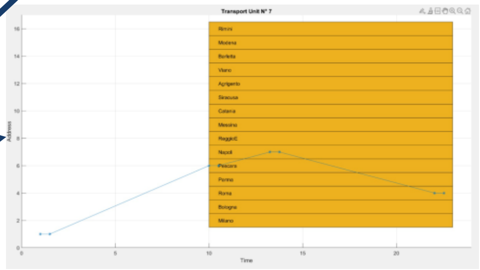
The combined algorithm for the CLP and VRP

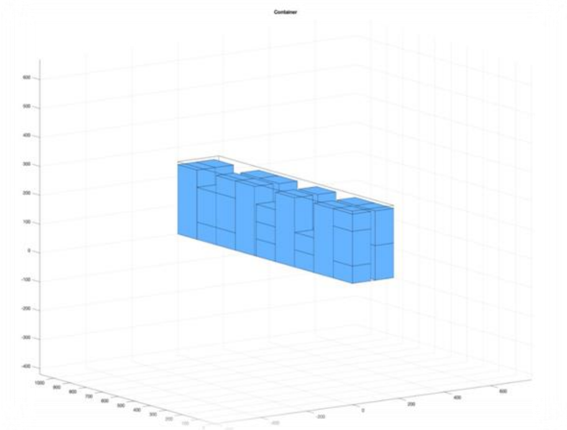
Outputs

Routing plan





Loading plan



Clustering

Real case simulations

We tested a **real dataset** provided by Elettric 80 that is composed by:

- ➢ 52 addresses spread all over Italy
- ➢ 299 bins with:
  - different heights
  - different weights
  - bins with EU standard pallet dimension 120x80
- ➢ 3 different types of TUs available with *an infinite fleet*

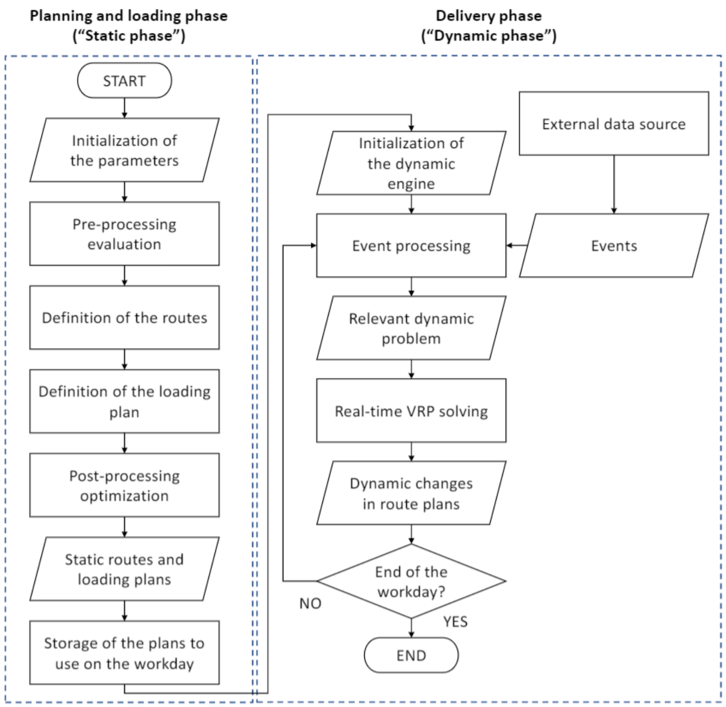
Real case simulations

- ❖ **EXECUTION TIME:**
  - 3896.1 seconds
- ❖ **NUMBER OF FILLED TUs**
  - 16
- ❖ **TOTAL DISTANCE TRAVELLED**
  - 8.012,263 meters
- ❖ **AVERAGE FILL RATIO**
  - supported weight of the 78.71%
  - volume filled of the 47.65%

Real time delivery update

An important variant of the VRP this problem is the ***dynamic vehicle routing*** which takes into account variations in the travel times during the shipments caused by various factors, such as accidents, traffic conditions, and weather conditions.

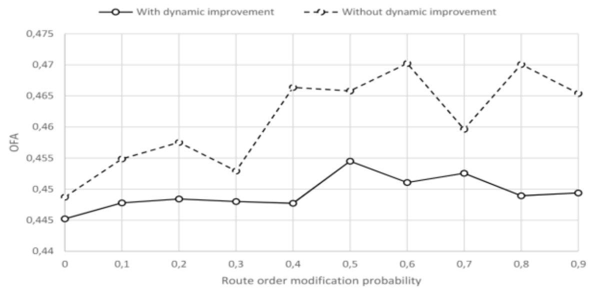
In particular, it:
- continuously monitors the travel speed and the timetable
- recalculates the VRP solution using a ***genetic algorithm*** in case of some delays respect to the planned times
- if needed changes the route and/or the sequence of the client.

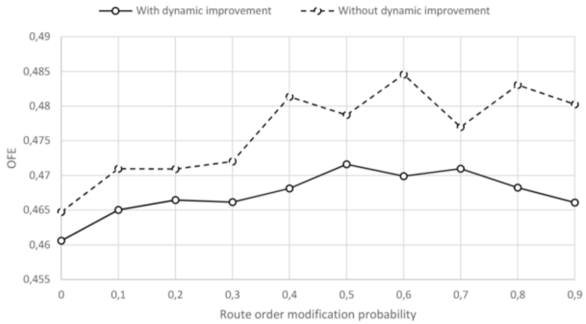


Real case simulations

Influence of unexpected human behaviour:
We conduct a series of tests to study the dynamic system's reaction to ***unexpected decisions*** (or mistakes) of the drivers - that is when an address is visited earlier than what is planned by the system. To that end, we run 10 simulation instances, where the only parameter that varies is the probability for a driver to deviate from their route, named *Route Order Change Probability*.

The solution quality is improved by the dynamic system: over all tests there is on average a 1.89% improvement on the overall objective function, 2.54% on recalculations and 6.08% on the distance traveled.





Conclusions and future development

The results achieved show how the implementation of decision and control techniques for logistics can significantly improve its operations inside and outside the warehouses by reducing time, costs and producing optimal solutions.

Future developments can include:

- a new bin packing algorithm which optimizes the bins' configurations by considering simultaneously the three dimensions;
- the formulation of new logistics constraints;
- the implementation of a new real time dynamic vehicle routing algorithm based on some feedback control techniques (for example, MPC)

Thanks for your attention!

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