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# Multi-Objective Approach: Multi-Compartment Vehicles For Pick-Up And Delivery Problem With Times Windows

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**Abstract – In this article, we address the pickup and delivery problem goods. In this problem, goods are collected from suppliers and delivered to different customers. Very often, single compartment vehicles are used to transport these goods. As a result, there are several damagesdue to some products being harmful to others stored in the same compartment: incompatibilitybetween products. It is therefore necessary to use multi-compartment vehicles to overcome theproblems of product incompatibility. It is necessary to produce a service that satisfies a set of customers according to their availability, respects the constraints linked to the capacity of eachvehicle compartment and each type of product, and ensures that each supplier is visited beforehis customer. This work is structured in two main blocks. The first block presents the modelling of the problem taking into account the minimisation of three main criteria, namely: the number of vehicles put into service, the total cost related to the vehicles and the delays on the nodes: min $f = (f_{1=}\ K\ ; f_2\ = \sum_{k\in K} \sum_{i\in F} \sum_{j\in F}$ max $(0, D_i - G_i) x_{ijk}\ ;\ f_3\ = \sum_{k\in K} \sum_{i\in F} \sum_{j\in F} C_k d_{ijk} x_{ijk}$ ). The second part will be devoted to the multi-criteria solution of the pick-up and deliveryproblem with time windows provided by multi-compartment vehicles by the NSGA-IIalgorithm.**

**Keywords – NSGA-II, Multi-Compartment Vehicles, PDPTW, Pareto criteria, multi-criteriaapproaches**

## I. Introduction

Nowadays, more and more companies are equipping themselves with a fleet of vehicles for the delivery of their goods after purchase. Technological advances have led to the creationof several companies for goods delivery services, which are generally collected from suppliers before being delivered to the various customers. It is clear that the cost of transporting goods between suppliers and customers, the number of vehicles used, the distance travelled (mileage)by these vehicles, and the various delays and expectations of suppliers and customers are factorsof capital importance in the logistics chain.

During this process, the company tries to minimise these expenses and be efficient while respecting the time frame defined by the clients. In fact, it generally operates in a very competitive environment. This transport service is confronted with various problems, inparticular:

- Environmental problems ($CO_2$ emissions from several vehicles),
- Vehicle management problems (numbers put into service for greater profitability)

- problems related to vehicle capacity and problems related to respecting the time intervalgiven by each client in order to produce a quality service.

It should also be noted that delivery personnel encounter several difficulties when unloading with single-compartment vehicles. During these unloading operations, they lose enough time unloading the goods at height, sorting the different products of this client due to the fact that some products are not generally compatible. In this article we will discuss the problem of delivery with the use of vehicles with several compartments. The problem we present is the multi-criteria approach of the MCV-PDPTW (multi-compartment vehicles for Pickup and Delivery Problem with Time Windows). This MCV-PDPTW problem is a variant of the VRPTW, which consists of gluing goods to suppliers and delivering them to geographically distributed customers. We also have a fleet of $V_k$ vehicles with a $Q_k$ capacity that must transport the goods intended for compartments of these vehicles to the customers.

Several works have been carried out on vehicles with several compartments. (Imen Harbaoui Dridi, Essia Ben Alaia,2017) have A multi objective optimization approach for the m-MDPDPTW (El Fallahi and al,2008) combined a memetic algorithm with a post- optimization phase based on path relinking, and a tabu search method. These algorithms are evaluated by adding compartments to classical VRP instances. (Yossi Bukchin and Subhash C. Sarin ,2006) have made two approaches, namely dynamic and static, are studied and their performances are compared with each other. In the thesis Optimization of flows: application to distribution problems in animal nutrition, (Cadet David JOSEPH,2013) proposes the algorithms" Greedy Randomized Adaptive Search Procedure" (GRASP) and" Iterated Local Search procedure" (ILS) to solve the MC-VRP with a fixed size compartment dedicated to each product. A new metaheuristic based on a tabu algorithm integrated in a simulated annealing, was developed by (Li, H and al,2001) to solve the mPDPTW, this by researching, from the current best solution if there is improvement over multiple iterations. (Timothy Curtois and al,2018) have also proposed a metaheuristic which combines" local search, large neighborhoodsearch and guided ejection search" for the resolution of the PDPTW. (Li, H and al,2002) have developed a method called" Squeaky wheel" to solve m-PDPTW with local search. (AlChami and al, 2018) worked on the Mu-PDPTWPD, a variant of the PDPTW and they combined the Greedy Randomized Adaptive Search Procedure (GRASP) with the Hybrid Genetic Algorithm(HGA) to solve this problem by minimizing the total distance traveled. (Alexis Godart,2019) made a new variant of the PDPTW which authorizes a multiple visit with a storage transfer byproposing a hybrid metaheuristic based 1 on an evolutionary algorithm. (Zhihao Peng and al

,2018) Worked on the Selective Pickup and Delivery Problem with Time Windows and PairedDemands (SPDPTWPD)". they found the optimal solution using '' particle swarm optimization(PSO) and compared it with a 'genetic algorithm. Regarding the m-PDPTW, (Sol, M and al,1994) have proposed a branch and price algorithm to solve the m-PDPTW and this by minimizing the number of vehicles necessary to satisfy all the transport demands and the total distance traveled.

This article is divided into three main parts namely: the first part presents the mathematical modelling which aims to serve all customers by minimising the total cost of transport, the number of vehicles in service, the delay on the nodes and respecting the time, vehicle capacity and compartment constraints, in the second part we explain our approach to solving the PDPTW problem by the NSGA-II algorithm and in the last part we present our different results from the simulations.

## II. PRESENTATION AND MODELLING OF THE PROBLEM BY A GRAPH

Our problem can be translated by the following graph.

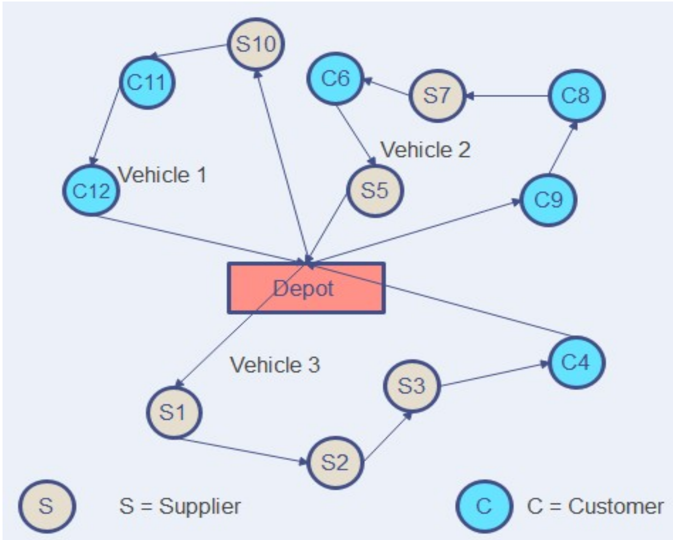


Figure 1: Modelisation of the MCV-PDPTW problem by a graph

## III. Multi-objective approach to the MCV-PDPTW problem

The improvement of a problem leads us to consider several criteria. Generally, for vehiclerouting problems the criteria or objectives can be grouped into different categories, namely: objective on the tours, nodes or arcs and resources. The following figure shows the different objectives found in the literature.

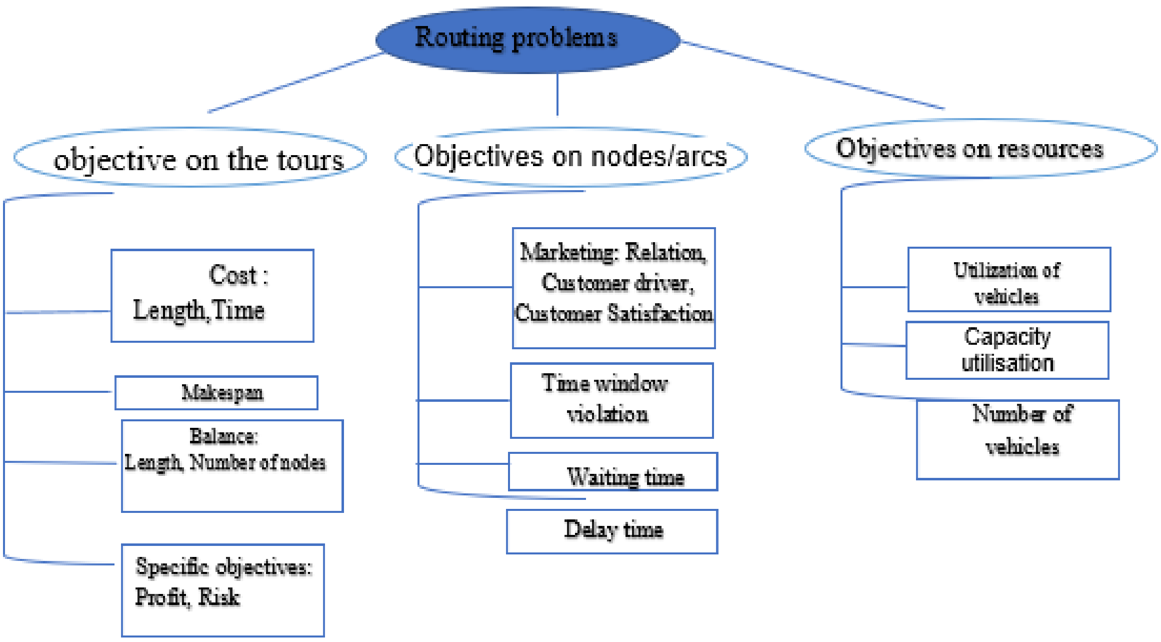


Figure 2: Different objectives for the PDPTW

The multi-criteria approach to a given problem can be done in two ways:

Either the decision-maker intervenes from the very beginning of the problem definition, by expressing his preferences, in order to transform a multi-objective problem into a single-objective problem (Behaviour 1). Two commonly used models are the additive andmultiplicative models

**Additive model**

$$U = \sum_{i=1}^{k} U_i(f_i)$$

This method consists of adding up all the objectives by assigning a weight coefficient to each of them. This coefficient represents the relative importance that the decision-maker attributes to the objective. This changes a multi-objective problem into a single objective problem of the form :

$$min \sum_{i=1}^{k} w_i f_i(x) \ \ avec\ w_i \geq 0$$

$w_i$ is the weight assigned to the criterion $i$ and :

$$\sum_{i=1}^{k} w_i = 1$$

**Multiplicative model**

$$\prod_{i=1}^{k} U_i(f_i)$$

$U_i$ is a scaling function of criterion $i^{ieme}$

Or the decision-maker makes his choice from the set of solutions proposed by the multi-objective solver (Behaviour 2).

**Dominance in the Pareto sense**

Consider a minimization problem. Let: $u$ and $v$ be two decision vectors. We say that thedecision vector $u$ dominates the vector $v$ (denoted $u \leq v$), if and only if:

$$\forall\ i \in \ \{1,2,\dots,k\}; f_i(u) \leq f_i(v) \wedge \exists\ i \ \in \ \{1,2,\dots,k\}, f_i(u) < f_i(v)$$

The main quality of a multi-objective solver is therefore to make decisions easier by proposing a representative subset of F (the set of achievable objectives). We opt for the second behaviour for the resolution of our problem To solve our problem. We use this meta-heuristic (NSGA-II) because of the complexity of the problem which is NP-difficult and allows the Pareto front to be available in a reasonable time for the decision maker to make a choice.These two behaviours are represented by the following figure.

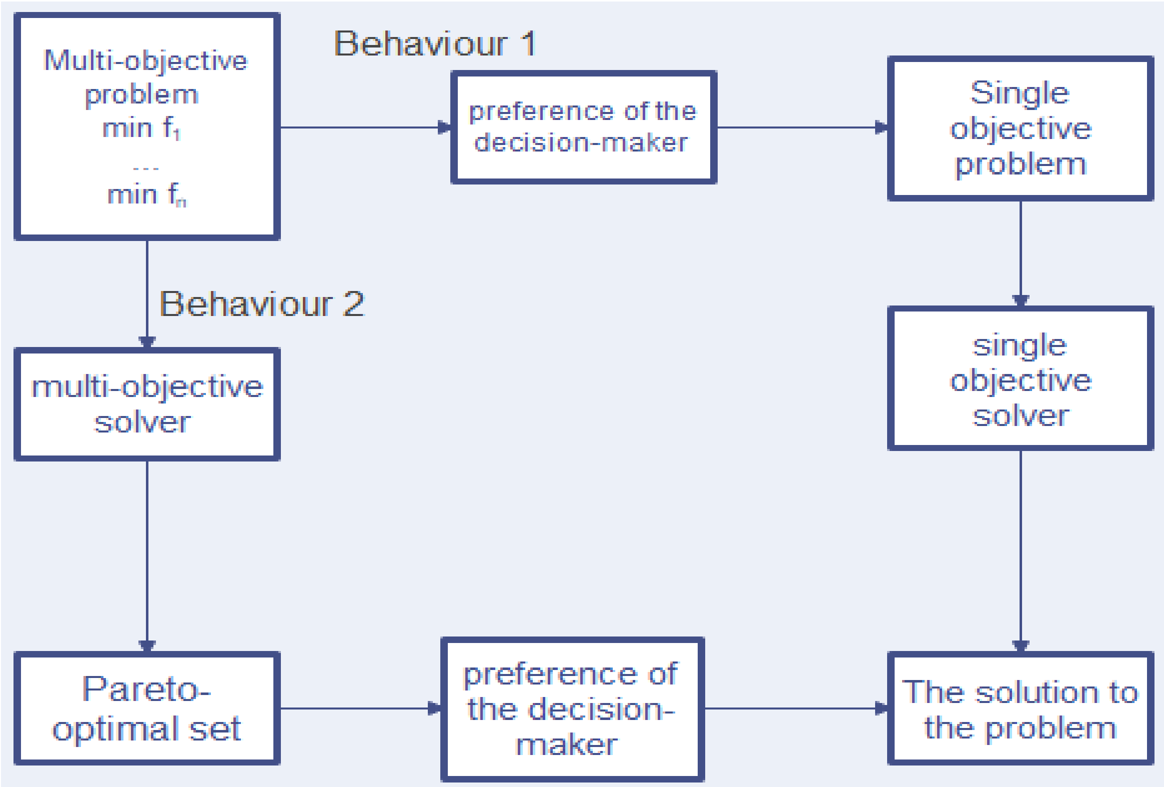


Figure 3: Modes for solving a multi-objective

## IV. Mathematical model

In companies, the major challenge is to produce a qualitative service. To do this, the objective is to serve all customer requests, while minimizing the total cost of transport. This cost is relative to the number of vehicles used and the distance traveled by each vehicle. The problem we are trying to solve has three objectives that we are going to minimise: to minimise the number of vehicles, to minimise the delay time at each node and to minimise the total costrelated to the total distance travelled by all the vehicles used.

Our problem is characterized by the following parameters:

- $F$ : Set of customer, supplier and depot nodes,
- $F'$ : Set of customer and supplier nodes,
- $F^{+}$ : Set of supplier nodes,
- $F^{-}$ : Set of client nodes,
- $K$: Number of vehicles,
- $d_{ij}$ : Euclidean distance between node $i$ and node $j$ if $d_{ij} = \infty$ then the path between $i$ and $j$ does not exist
- $t_{ijk}$ : time taken by the vehicle $k$ to go from node $i$ to node $j$ ,
- $[E_i; G_i]$: time window of node $i$,
- $s_i$ : time of stop at node $i$,

- $q_{ip}$ : quantity of product $p$ to process at node $i$. If $q_i > 0$, the node is supplier; If $q_i$ <0, the node is a client and if $q_i = 0$ then the node has been served.
- $Q_k$ : vehicle $k$ capacity,
- $P$ : all the products delivered to customers
- $W_p$ : the capacity of a compartment carrying the product $p$
- $i = 0, \ldots, F$ : index of predecessor nodes,
- $j = 0, \ldots, F$: index of successor nodes,
- $k = 1, \ldots, K$: vehicle index,

1 $if\ the\ vehicle\ k\ traveled\ from\ the\ node\ i\ towards\ the\ node\ j$

- $X_{ijk} = \{$
- $A_i$: time of arrival at node $i$,
- $D_i$ : departure time of the node $i$,

0 $else$

- $y_{ik}$ : quantity present in the vehicle $k$ visiting the node $i$,
- $C_k$ : transport cost associated with the vehicle $k$,
- A node (supplier or customer) is only served by one vehicle and at one time,
- There is only one depot,
- The capacity constraints must be respected,
- The time constraints are rigid regarding the time of arrival,
- Each vehicle begins the journey from the depot and returns there at the end,
- A vehicle remains stationary at a node for the time necessary to process the request.
- If a vehicle arrives at the node $i$ before its window start date$e_i$ , it waits. (ImenHARBAOUI ,2011),
- The function to be minimized is given as follows:

$$\min f = \left(f_1 = K\ ;\ f_2 = \sum_{i\in F}\sum_{j\in F} \max(0, D_i - G_i) X_{ijk}\ ;\ f_3 = \sum_{k\in K}\sum_{i\in F}\sum_{j\in F} C_k d_{ij} X_{ijk}\right) \quad (1)$$

S.C

$$\sum_{i=1}^{F}\sum_{k=1}^{K} X_{ijk} = 1 \qquad j = 2, \dots, F \qquad (2)$$

$$\sum_{j=1}^{F}\sum_{k=1}^{K} X_{ijk} = 1 \qquad i = 2, \dots, F \qquad (3)$$

$$\sum_{i \in F} X_{i0k} = 1 \qquad \forall k \in K \qquad (4)$$

$$\sum_{j \in F} X_{0jk} = 1 \qquad \forall k \in K \qquad (5)$$

$$\sum_{i \in F} X_{iuk} - \sum_{j \in F} X_{ujk} = 0 \qquad \forall k \in K, \forall u \in F \qquad (6)$$

$$X_{ijk} = 1 \implies y_{jk} = y_{ik} + q_i \qquad \forall\, i, j \in F;\ \forall k \in K \qquad (7)$$

$$y_{0k} = 0 \qquad \forall k \in K \qquad (8)$$

$$Q_k \geq y_{ik} \geq 0 \qquad \forall i \in F, \forall k \in K \qquad (9)$$

$$\sum_{i g F} q_{ip} \left(\sum_{i \in F} X_{iuk}\right) \leq W_p \qquad \forall k \in K, \forall u \in F \qquad (10)$$

$$D_w \leq D_v \qquad \forall i \in F, \forall w \in F_i^{+}, \forall\, v \in F_i^{-} \qquad (11)$$

$$D_0 = 0 \qquad (12)$$

$$X_{ijk} = 1 \implies E_i \leq A_i \leq G_i \qquad \forall\, i, j \in F;\ \forall k \in K \qquad (13)$$

$$X_{ijk} = 1 \implies E_i \leq A_i + s_i \leq G_i \qquad \forall\, i, j \in F;\ \forall k \in K\ s_i \neq 0 \qquad (14)$$

$$X_{ijk} = 1 \implies D_i + t_{ijk} \leq (G_j - s_j) \qquad \forall\, i, j \in F;\ \forall k \in K \qquad (15)$$

Contraints (2) and (3) ensure that each node is served only once by one and only one vehicle. Contraints (4) and (5) ensure that a vehicle leaves and returns to the depot only once. Contraint (6) ensures the continuity of a tour by one vehicle: the node visited must be left. Contraints (7), (8) and (9) ensure that the transport capacity of a vehicle is not exceeded. Contraints (10) requires that the capacity of the compartment allocated to product p must be atleast equal to the sum of the demands for product. Contraints (11) and (12) ensure that the precedents are respected. Contraints (13), (14) and (15) ensure that the time windows.

## V. Multi-criteria resolution of the MCV-PDPTW

In our problem we will use vehicles with several compartments to produce a quality service. These compartments will be used to store our different products by type. These products can be classified according to the order of loading from suppliers and unloading from

customers, while respecting their geographical positions. The quantity of the product type dedicated to a compartment must be less than or equal to the capacity of this compartment. Also, the sum of the quantities of the products must be less than or equal to the total capacity of the vehicle ( Berte Ousmane et al,2021).

Several works have been carried out on the Multi Compartment Vehicle associated with the VRP. These authors have presented these vehicles with their compartments which resolve the problems linked to the transport of incompatible goods. Also they came up with methods for solving their problems. We present some that are: (Manuel Ostermeier ,2018) Worked on the MCs associated with the VRP. they developed the branch a branch-and-cut (B&C) algorithm as an exact approach and extend a large neighborhood search (LNS) as a heuristic approach' for its resolution. (lMahdi Alinaghian and al, 2018) have proposed a hybrid algorithmcomposed of adaptive large neighborhood search and variable neighborhood search to solve the MCVRP with several repositories in which they seek to minimize the number of vehicles as well as the routes. (Hadhami Kaabi and Khaled Jabeur,2015) presented multiple compartment vehicles in which they will assign a type of product in a compartment with each client havinga time window in which he will be served. they developed a hybrid algorithm including geneticalgorithm (GA) and the iterated local search (ILS) is used.

We will solve our problem with the NSGA-II algorithm as follows:

**Algorithm 1** Pseudocode for NSGAII

**procedure** NSGAII($N$,$N_A$)
  $t \leftarrow 0$
  $P_t \leftarrow$ **new_population**($N$)
  $Q_t \leftarrow \emptyset$
  $A \leftarrow$ **non_dominated**($P_t$)
  **while** not stop criterion **do**
    $R_t \leftarrow P_t \cup Q_t$
    $\mathcal{F} \leftarrow$ **fast_non_dominated_sorting**($R_t$)
    $P_{t+1} \leftarrow \emptyset$
    $i \leftarrow 1$
    **while** $|P_{t+1}| + |\mathcal{F}_i| \leq N$ **do**
      $\mathcal{C}_i \leftarrow$ **crowding_distance_assigment**($\mathcal{F}_i$)
      $P_{t+1} \leftarrow P_t \cup \mathcal{F}_i$
      $i \leftarrow i + 1$
    **end while**
    $\mathcal{F}_i \leftarrow$ **sort**($\mathcal{F}_i, \mathcal{C}_i$, 'descending')
    $P_{t+1} \leftarrow P_{t+1} \cup \mathcal{F}_i[1 : (N - |P_{t+1}|)]$ ▷ fill $P_{t+1}$ with the $N - |P_{t+1}|$ less crowded individuals of $\mathcal{F}_i$
    $Q_{t+1} \leftarrow$ **selection**($P_{t+1}, N$)
    $Q_{t+1} \leftarrow$ **crossover**($Q_{t+1}$)
    $Q_{t+1} \leftarrow$ **mutation**($Q_{t+1}$)
    $t \leftarrow t + 1$
    $A \leftarrow$ **non_dominated**($A \cup Q_t$)
  **end while**
**end procedure**

Figure 4: Pseudo code for the general operation of the NSGA-II

## VI. EXPERIMENTATION

To solve our problem, we will use the NSGA-II algorithm which is based on the genetic algorithm. We use this meta-heuristic because of the complexity of the problem which is NP-hard and its multi-criteria character. It allows us to have a set of Pareto-optimal solutions in which the decision-maker will make his choice in a reasonable time.

we will list the different parameters that we will use for our different simulations.for our different simulations.
In our simulations, we find :

- a single depot,
- 160 nodes including the depot,
- a fleet of (23) heterogeneous vehicles with different compartments,
- all vehicles are at the same depot.

The algorithm we use minimises the three objectives, namely

- $f_1$= the number of vehicles,
- $f_2$= the sum of the delay times on the nodes,
- $f_3$= the total transport cost.

## VII. Presentation of the Pareto optimal solution set

- A solution will be represented by a vector ( $f_1, f_2, f_3$).
- A solution $v = (f_{12}\,; f_{22}\,; f_{32})$ is said to be dominated by $u = (f_{11}\,; f_{21}\,; f_{31})$ if $f_{11} < f_{12}$ ; $f_{21} < f_{22}$ and $f_{31} < f_{32}$ .
- The set of non-dominated solutions will be the Pareto optimal set.
- The solutions of the Pareto optimal set will be the optimal solutions of the problem

## VIII. Results

The following table contains some non-dominated solutions.

Table: Pareto optimal solutions

| | Number of nodes | $f1$= the number of vehicles, | $f_2$= the sum of the delay times on the nodes, | $f_3$= the total transport cost. | paths |
|---|---|---|---|---|---|
| | | 9 | 486,3701944 | 8894012.99 | V8 : D1-F49-C47-F58-C59-F59-C60-F60-C61-F63-C64-F101-C108-F118-<br>C125-D1<br>V9 : D1-F47-C44-F57-C58-F62-C63-F75-C76-F100-C107-F104-C111-<br>F115-C122-F117-C124-F123-C130-F125-C132-F130-C137-D1<br>V10 : D1-F35-C48-C102-F56-C57-C95-C101-F61-C62-F66-C67-F72-C73-<br>F73-C74-F79-C80-F81-C82-F92-C92-F116-C123-F120-C127-F121-C128-<br>F127-C134-F129-C136-F34-C40-C45-D1 |
| | | | | | V11 : D1-F36-C42-C96-F50-C49-C51-C50-C98-F51-C52-C53-F69-C70-<br>F74-C75-D1<br>V21 : D1-F44-C41-C97-D1 |

| | | | | | |
|---|---|---|---|---|---|
| | | | | | V22 : D1-F131-C138-F54-C46-C54-C99-F55-C56-C100-F64-C65-F65-<br>C66-F67-C68-F68-C69-F70-C71-F71-C72-F76-C77-C78-F78-C79-F80-<br>C81-F95-C103-F97-C104-F102-C109-F106-C113-F111-C118-F113-C120-<br>F114-C121-F119-C126-F128-C135-D1<br>V25 : D1-F91-C91-F93-C93-F98-C105-C106-F103-C110-F107-C114-F110-<br>C117-F112-C119-F126-C133-D1<br>V28 : D1-F105-C112-F108-C115-F109-C116-D1<br>V30 : D1-F122-C129-D1 |
| Instance | 160 | 9 | 484,9260378 | 8929048.60 | V8 : D1-F49-C47-F58-C59-F59-C60-F60-C61-F63-C64-F101-C108-F118-<br>C125-D1<br>V9 : D1-F47-C44-F57-C58-F62-C63-F75-C76-F100-C107-F104-C111-F115-<br>C122-F117-C124-F123-C130-F125-C132-F130-C137-D1<br>V10 : D1-F35-C48-C102-F34-C40-C45-F56-C57-C95-C101-F61-C62-F66-<br>C67-F72-C73-F73-C74-F79-C80-F81-C82-F92-C92-F116-C123-F120-C127-<br>F121-C128-F127-C134-F129-C136-D1<br>V11 : D1-F50-C49-C51-C50-C98-F36-C42-C96-F51-C52-C53-F69-C70-F74-<br>C75-D1<br>V21 : D1-F44-C41-C97-D1<br>V22 : D1-F55-C56-C100-F64-C65-F65-C66-F67-C68-F68-C69-F70-C71-F71-<br>C72-F76-C77-C78-F78-C79-F80-C81-F95-C103-F97-C104-F102-C109-F106-<br>C113-F111-C118-F113-C120-F114-C121-F119-C126-F128-C135-F131-C138-<br>D1<br>V25 : D1-F91-C91-F93-C93-F98-C105-C106-F103-C110-F107-C114-F110-<br>C117-F112-C119-F126-C133-D1<br>V28 : D1-F105-C112-F108-C115-F109-C116-D1<br>V30 : D1-F122-C129-D1 |
| | | 9 | 482,6168919 | 8929622.56 | V8 : D1-F49-C47-F58-C59-F59-C60-F60-C61-F63-C64-F101-C108-F118- |

| | | | | | | |
|---|---|---|---|---|---|---|
| | | | | | | C125-D1<br>V9 : D1-F47-C44-F57-C58-F62-C63-F75-C76-F100-C107-F104-C111-F115-<br>C122-F117-C124-F123-C130-F125-C132-F130-C137-D1<br>V10 : D1-F35-C48-C102-F34-C40-C45-F56-C57-C95-C101-F61-C62-F66-<br>C67-F72-C73-F73-C74-F79-C80-F81-C82-F92-C92-F116-C123-F120-C127-<br>F121-C128-F127-C134-F129-C136-D1<br>V11 : D1-F51-C52-C53-F36-C42-C96-F50-C49-C51-C50-C98-F69-C70-F74-<br>C75-D1<br>V21 : D1-F44-C41-C97-D1<br>V22 : D1-F55-C56-C100-F64-C65-F65-C66-F67-C68-F68-C69-F70-C71-F71-<br>C72-F76-C77-C78-F78-C79-F80-C81-F95-C103-F97-C104-F102-C109-F106-<br>C113-F111-C118-F113-C120-F114-C121-F119-C126-F128-C135-F131-C138-<br>D1<br>V25 : D1-F91-C91-F93-C93-F98-C105-C106-F103-C110-F107-C114-F110-<br>C117-F112-C119-F126-C133-D1<br>V28 : D1-F105-C112-F108-C115-F109-C116-D1<br>V30 : D1-F122-C129-D1 |
| | | | 9 | 481,693749<br>7 | 8929863.51 | V8 : D1-F49-C47-F58-C59-F59-C60-F60-C61-F63-C64-F101-C108-F118-<br>C125-D1<br>V9 : D1-F47-C44-F57-C58-F62-C63-F75-C76-F100-C107-F104-C111-F115-<br>C122-F117-C124-F123-C130-F125-C132-F130-C137-D1<br>V10 : D1-F35-C48-C102-F34-C40-C45-F56-C57-C95-C101-F61-C62-F66-<br>C67-F72-C73-F73-C74-F79-C80-F81-C82-F92-C92-F116-C123-F120-C127-<br>F121-C128-F127-C134-F129-C136-D1<br>V11 : D1-F36-C42-C96-F50-C49-C51-C50-C98-F51-C52-C53-F69-C70-F74-<br>C75-D1<br>V21 : D1-F44-C41-C97-D1<br>V22 : D1-F55-C56-C100-F64-C65-F65-C66-F67-C68-F68- |

| | | | | | |
|---|---|---|---|---|---|
| | | | | | C69-F70-C71-F71-<br>C72-F76-C77-C78-F78-C79-F80-C81-F95-C103-F97-C104-F102-C109-F106-<br>C113-F111-C118-F113-C120-F114-C121-F119-C126-F128-C135-F131-C138-<br>D1<br>V25 : D1-F91-C91-F93-C93-F98-C105-C106-F103-C110-F107-C114-F110-<br>C117-F112-C119-F126-C133-D1<br>V28 : D1-F105-C112-F108-C115-F109-C116-D1<br>V30 : D1-F122-C129-D1 |
| | | 9 | 479,5756332 | 8930503.18 | V8 : D1-F58-C59-F49-C47-F59-C60-F60-C61-F63-C64-F101-C108-F118-<br>C125-D1<br>V9 : D1-F47-C44-F57-C58-F62-C63-F75-C76-F100-C107-F104-C111-F115-<br>C122-F117-C124-F123-C130-F125-C132-F130-C137-D1<br>V10 : D1-F35-C48-C102-F56-C57-C95-C101-F34-C40-C45-F61-C62-F66-<br>C67-F72-C73-F73-C74-F79-C80-F81-C82-F92-C92-F116-C123-F120-C127-<br>F121-C128-F127-C134-F129-C136-D1<br>V11 : D1-F36-C42-C96-F50-C49-C51-C50-C98-F51-C52-C53-F69-C70-F74-<br>C75-D1<br>V21 : D1-F44-C41-C97-D1<br>V22 : D1-F55-C56-C100-F64-C65-F65-C66-F67-C68-F68-C69-F70-C71-F71-<br>C72-F76-C77-C78-F78-C79-F80-C81-F95-C103-F97-C104-F102-C109-F106-<br>C113-F111-C118-F113-C120-F114-C121-F119-C126-F128-C135-F131-C138-<br>D1<br>V25 : D1-F91-C91-F93-C93-F98-C105-C106-F103-C110-F107-C114-F110-<br>C117-F112-C119-F126-C133-D1<br>V28 : D1-F105-C112-F108-C115-F109-C116-D1<br>V30 : D1-F122-C129-D1 |

| | | | | | |
|---|---|---|---|---|---|
| | | 9 | 477,0643407 | 8933176.60 | V8 : D1-F60-C61-F49-C47-F58-C59-F59-C60-F63-C64-F101-C108-F118-C125-D1<br>V9 : D1-F47-C44-F57-C58-F62-C63-F75-C76-F100-C107-F104-C111-F115-C122-F117-C124-F123-C130-F125-C132-F130-C137-D1<br>V10 : D1-F35-C48-C102-F56-C57-C95-C101-F34-C40-C45-F61-C62-F66- C67-F72-C73-F73-C74-F79-C80-F81-C82-F92-C92-F116-C123-F120-C127- F121-C128-F127-C134-F129-C136-D1<br>V11 : D1-F36-C42-C96-F50-C49-C51-C50-C98-F51-C52-C53-F69-C70-F74-C75-D1<br>V21 : D1-F44-C41-C97-D1<br>V22 : D1-F55-C56-C100-F64-C65-F65-C66-F67-C68-F68-C69-F70-C71-F71- C72-F76-C77-C78-F78-C79-F80-C81-F95-C103-F97-C104-F102-C109-F106- C113-F111-C118-F113-C120-F114-C121-F119-C126-F128-C135-F131-C138-D1<br>V25 : D1-F91-C91-F93-C93-F98-C105-C106-F103-C110-F107-C114-F110-C117-F112-C119-F126-C133-D1<br>V28 : D1-F105-C112-F108-C115-F109-C116-D1<br>V30 : D1-F122-C129-D1 |
| | | 9 | 474,7720302 | 8933369.45 | V8 : D1-F59-C60-F49-C47-F58-C59-F60-C61-F63-C64-F101-C108-F118-C125-D1<br>V9 : D1-F47-C44-F57-C58-F62-C63-F75-C76-F100-C107-F104-C111-F115-C122-F117-C124-F123-C130-F125-C132-F130-C137-D1<br>V10 : D1-F35-C48-C102-F56-C57-C95-C101-F34-C40-C45-F61-C62-F66- C67-F72-C73-F73-C74-F79-C80-F81-C82-F92-C92-F116-C123-F120-C127- F121-C128-F127-C134-F129-C136-D1<br>V11 : D1-F36-C42-C96-F50-C49-C51-C50-C98-F51-C52-C53-F69-C70-F74-C75-D1<br>V21 : D1-F44-C41-C97-D1<br>V22 : D1-F55-C56-C100-F64-C65-F65-C66-F67-C68-F68-C69-F70-C71-F71- C72-F76-C77-C78-F78-C79-F80-C81-F95-C103-F97-C104-F102-C109-F106- C113-F111-C118-F113-C120-F114-C121-F119-C126-F128-C135-F131-C138-D1<br>V25 : D1-F91-C91-F93-C93-F98-C105-C106-F103-C110-F107-C114-F110-C117-F112-C119-F126-C133-D1<br>V28 : D1-F105-C112-F108-C115-F109-C116-D1<br>V30 : D1-F122-C129-D1 |

The compromise surface (Pareto front) taking into account the efficient solutions groupedin the previous table.

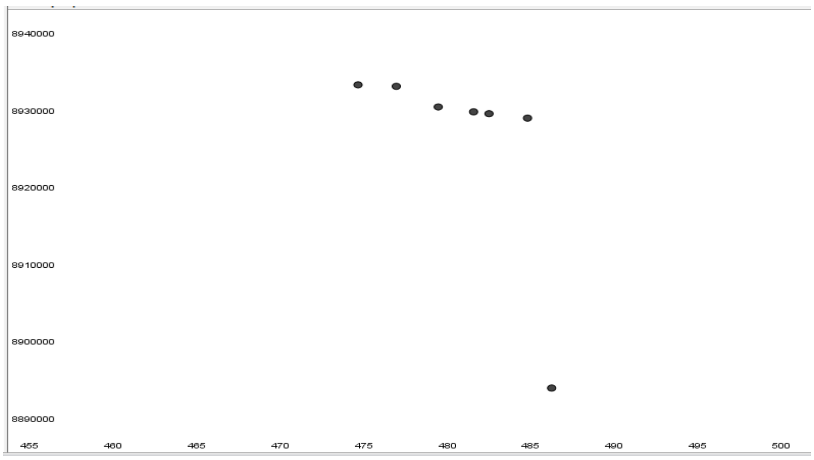


Figure 6: The compromise surface representing the solutions in the table

## IX. Conclusion

In this paper, we have solved by the NSGA-II algorithm the multi-objective approach to the problem with a time window provided by multi-compartment vehicles multi-compartment vehicles. This algorithm generated the Pareto front. We have presented in different tables some optimal solutions called Pareto optimal solutions. These solutions are a compromise because one is not necessarily better than the other better than the other. We can study this problem by making a flexible opening on the visit of the nodes, i.e. allowing several visits of a node in the same tour.

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