

MATLAB tool for loading of boxes in 3L-CVRP problem

Herramienta en MATLAB para acomodo de cajas en 3L-CVRP

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KEYWORDS:

3L-CVRP 3D-visualization,
3L-CVRP tool, logistics,
MATLAB program.

ABSTRACT

The Three-Dimensional Capacitated Vehicle Routing Problem, or 3L-CVRP, is one NP-Hard Problem in the logistics field. In the 3L-CVRP the length, width and height dimensions of items and vehicle are considered. Hence, each item must be sequentially loaded to avoid overlaps between items of different customers, fragile items must not support no fragile items. Items can be rotated in x-y axes. In this work, a MATLAB program for plotting the solutions obtained for 3L-CVRP is proposed as a technique to verify errors such as overlaps, intersections, not enough supporting area and the invalid combination of items.

PALABRAS CLAVE:

Visualización 3D en 3L-CVRP; herramienta 3L-CVRP; logística; programa en MATLAB.

RESUMEN

El problema de enrutamiento de vehículos con carga tridimensional, o 3L-CVRP, es un problema NP-Completo en el campo de la logística. En el 3L-CVRP se consideran las dimensiones de largo, ancho y alto de los artículos y el vehículo. Por lo tanto, cada artículo debe cargarse secuencialmente para evitar que artículos de diferentes clientes se apilen entrelazados, artículos frágiles no deben dar soporte a artículos no frágiles. Los artículos pueden rotarse en los ejes x-y. En este trabajo, se propone un programa MATLAB para trazar las soluciones obtenidas para 3L-CVRP como una técnica para verificar errores tales como superposiciones, intersecciones, área de soporte insuficiente y la combinación no válida de elementos.

Recibido: 11 de diciembre de 2019 • **Aceptado:** 7 de abril de 2020 • **Publicado en línea:** 30 de junio de 2020

1. MOTIVATION AND SIGNIFICANCE

The vehicle routing problem (VRP) is a combinatorial optimization problem that is widely used in logistics for the distribution of items to satisfy the demand of customers. This type of problem was initially addressed by Dantzig and Ramser in 1959 for the distribution of fuel. This problem has been discussed in the literature to seek its resolution with various methods, as shown in [1], [2]. Recently, the VRP was extended to address the container load [3]. Within these extensions, the multi-Pile VRP (MP-VRP) are the most significant advances, where the items are loaded in different batteries inside vehicles with two-dimensional load restrictions. The 2L-CVRP, where each item is considered to have only dimensions on the x and y-axes, and there are no items stacked on top of the others, a typical example are refrigerators. Finally, the Three-Dimensional Capacitated Vehicle Routing Problem (3L-CVRP) which considers the three-dimensional load on vehicles for distribution.

The first researchers to consider the 3L-CVRP were [4] who proposed to solve the routing problem with Tabu-Search (TS) metaheuristics, while the load of the vehicles was solved with nested Tabu-Search metaheuristics, applying this solution to the furniture distribution. Since then, different proposals have been made to solve various aspects of this problem. However, to solve this problem in a mathematical manner consume time that increases with the size of the instances and verifies manually that the boxes have not intersections is so hard and consume much more time.

After the initial proposal of [4], the work of [5]

is an algorithm that combines TS with Local search (LS) to maximize vehicle utilization and minimize total distance. [6] used the Ant Colony Optimization (ACO) algorithm to obtain high-quality solutions within reasonable computation time, their algorithm can work with large instances. [7] solved the problem using metaheuristics that combined TS strategies and Guided Local Search (GLS). [8] Worked with Heterogeneous Fleet Vehicle Routing Problem with Three-dimensional (3D) loading constraints (3L-HFVRP) and proposed Adaptive Variable Neighborhood Search (AVNS) using vehicles with different capacities in weight and volume to satisfy the demands of a set of customers; to accelerate the process they used two data structures, thus reducing the calls to the load verification. However, the first to propose an exact method to solve the 3L-CVRP were [9]. On the topic about the location of the load within the container, [10] proposed the use of extreme points of the items for the location on the axes x, y and z. Based on the extreme point algorithm, [11] proposed his VRLH1 based on TS algorithm for Vehicle Routing Problem and a TRSA algorithm for vehicle loading. On the other hand, [12] proposed an algorithm to accommodate the items of several customers in a container, without the use of fragility also they have a software to make a graphical representation of the items in a vehicle. The software that they have requires that in a document of text the dimensions of the vehicle, the number of items, the coordinates of the x, y and z-axis and the dimensions of each item is provided. The proposed software does not need that all the data are in a document of text, the

data can be provided for each box one at a time, this helps researchers to verify the results of their algorithm in two ways, manually or in automated form. In the automated form, the software can be added to programmed algorithms of the researchers.

1.1 The standard model of 3L-CVRP

In this section, the standard model of 3L-CVRP and the constraints that are considered in this type of problems is described.

Vehicles with the same dimension (homogeneous fleet), with length L , width W , and height H will be used. Where $V = \{1, \dots, n+1\}$ is the set of $n+1$ nodes, where node 1 is the depot, and the nodes 2 to n are the customers. Having a set of edges A from i to j , that connect all the pairs of nodes.

It also has a distance c_{ij} ($c_{ij} > 0$) that will be assigned to each edge (i, j) , where $(1 \leq i < j \leq n+1)$. Each customer i ($i = 2, \dots, n+1$) will be supplied with a total of b_i rectangular items, where the set of rectangular items per customer is represented by I_{ik} ($k=1, \dots, b_i$). Each item has width w_{ik} , height h_{ik} , and length l_{ik} dimensions.

The first quadrant of the Cartesian plane to accommodate the items will be used. The location of an item I_{ik} within the container is given by the coordinates x_{ik} , y_{ik} , z_{ik} , of the left rear corner of the item. The rotation of the items on the axes x and y is permitted. The fragility of the item is considered.

For an item to be placed on top of another, it must be supported by at least 90% of its lower area. The items will be ordered in the following

way:

- a. In the reverse order in which they will be delivered
- b. For each customer, the items will be ordered from the bigger to the smaller base area.

According to [13] the restrictions of the 3L-CVRP problem that exists in the literature are:

- a. Orientation: Items may have a fixed orientation, or (more frequently) can be rotated 90° in the horizontal plane.
- b. Fragility: Each item I_{ik} may have a fragile flag f_{ik} , which takes the value of 1 if I_{ik} is fragile, and the value of 0 in another case. Also, non-fragile items cannot be placed on top of fragile items.
- c. Support Area: When an item I_{ik} is placed on top of other items, having the area A from the bottom of I_{ik} that is in contact with the items below, in this case, the packaging is only feasible if $A \geq a \cdot w_{ik} \cdot l_{ik}$ where a is a threshold ($0 \leq a \leq 1$).
- d. Sequential Load: When a customer i is visited, there must be a sequence of movements parallel to longitudinal axis of the loading space (one per item I_{ik}), which allows unloading the items without having to move other items.

2. SOFTWARE DESCRIPTION

This tool was developed for Matlab R2015a and has a Graphical User Interface, it permits to the users sequentially write the necessary data. There are three cases to use this software. Case one, when a user needs to put a group of boxes in a vehicle. Case two, when a user would verify his algorithm, whichever that it could be.

Moreover, case three, when a user would verify the results of a paper.

The interface to provide the necessary data is shown in Figure 1. The first step is to provide the dimensions of the vehicle and push the button to send the vehicle dimensions after that only is necessary to provide the position, dimensions and the number of one box each time. For example, a group of boxes to place are shown in Table 1, where the boxes that are not fragile have 0 and the boxes fragile have 1.

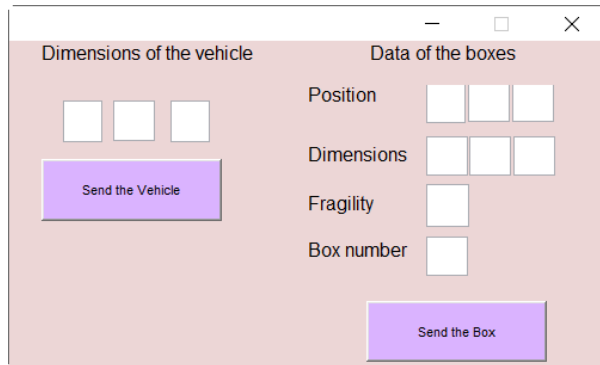


Figure 1. The interface of software.

Table 1. Data of boxes to place in the vehicle.

| Box | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
|-----------|----|----|----|----|----|----|----|----|----|----|
| Length | 33 | 36 | 12 | 27 | 20 | 23 | 21 | 15 | 27 | 31 |
| Width | 15 | 5 | 14 | 11 | 9 | 7 | 7 | 14 | 8 | 6 |
| Height | 16 | 6 | 12 | 6 | 16 | 10 | 10 | 12 | 7 | 9 |
| Fragility | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 0 | 0 | 1 |

The dimensions of the vehicle are 60,25,30 (large, width, height), this data is provided in the software to obtain the container visualization, is presented in Figure 2.

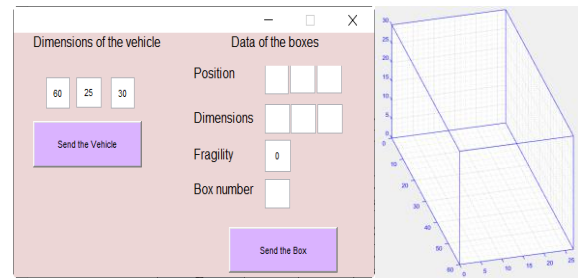


Figure 2. The dimensions of the vehicle to place the items.

From this point, there is necessary only to put the data for the boxes, and they will be placed where the user indicates with the position. The first box placed is shown in Figure 3.

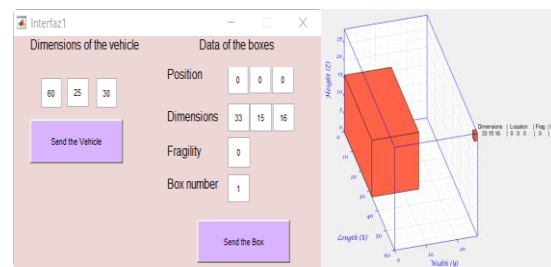


Figure 3. The placement of the first box.

The next boxes are placed in the vehicle, and the user can decide if want to rotate them in any of the axes because the user provides the dimensions.

One of the advantages of this software is that the user can observe where the boxes are placed, and with these data, he can decide where to put the next box. For example, to put the item 9, the user can observe in the Figure 4(a) that the next box can be placed in $x=0$, $y=15$ (where the box 1 finishes), and $z=0$; or to place the box 2, the user can use $x=0$, $y=0$, and $z=16$ (where the box 1 finishes).

Another advantage of the software is to visually verify where to put a box according to its

fragility, for example, the box number five is fragile, then it could be placed on top of other fragile or not fragile box, but it cannot be under a no fragile box, its correct location in the vehicle is shown in Figure 4(a). In Figure 4(b) is shown an example of an incorrect placement of a fragile box.

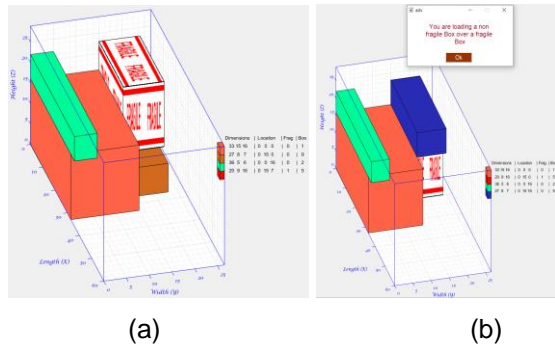


Figure 4. The placement of a fragile box.

If the user has a mistake when placing a box, he can take notes about where the previous items were placed and send the vehicle dimensions again to erase all the boxes placed and correct his error. A message is show in order to advertise the loading of a no fragile box over a fragile box. Also, the label of fragile is show in the box that is fragile, like is shown in Figure 4(b).

2.1 System Requirements and User Recommendations

The visualization depends on the user data; this program also has a document to indicate how it can be used. Only the basic package of MATLAB is needed, and the code can be run in a Personal Computer with Core i5 or higher, the MATLAB version needed is 2015a or higher, the

code was tested with Windows 8.1 of 64 bits, to has the data for the software is necessary to has an instance where the dimension of the vehicle and dimension of boxes are provided.

To run the software package, click on the main program how is shown in Figure 5.

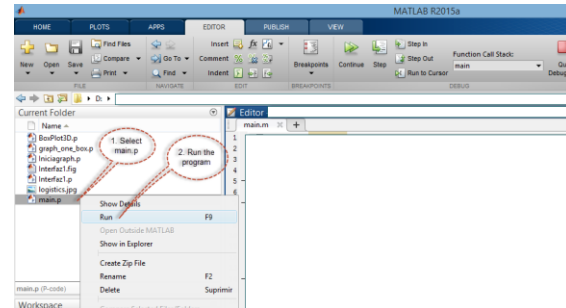


Figure 5. Run the software package.

3. THE PACKAGE SOFTWARE AS AN AUTOMATED TOOL

Another way of use this software is feed automatically from a program calling once time the program `Iniciagraph.p` and sending the dimensions of the vehicle (Large, Width, Hight) and in a cycle (according with the algorithm of the user) call the program `graph_one_box.p` with the parameters (position x, position y, position z, large, width, height, color, number of box, B, txtpos). Where color is a number between 1 and 37 and txtpos is a number that needs begin with the height of the vehicle less 2 and decreased each time in 2, and B is composed by the size of the vehicle (Large, width, height). The call to programs `Iniciagraph.p` and `graph_one_box.p` and their parameters are shown in Figure 6.

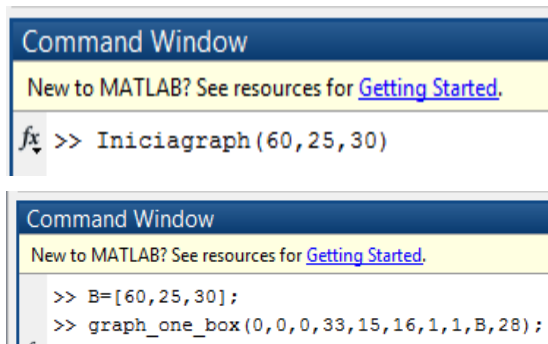


Figure 6. Running parts of the software package, to integrate into a user program

To obtain any instances, the website of Duhamel can be visited (<http://fc.isima.fr/~duhamel/3LCVRP/index.html>). To verify the results of some researchers for the 3L-CVRP problem can probe with the work “A matheuristic algorithm for the three-dimensional loading capacitated vehicle routing problem (3L-CVRP)” [14]. Another paper that can be verified is “A GRASP x ELS for the vehicle routing problem with three-dimensional loading constraint” [12]. Both of them are sufficiently detailed, and it permits to be verified with the program.

4. IMPACT AND CONCLUSIONS

A previous version of this software is register in INDAUTOR with the number 03-2018-111612242600-01 Spanish version, in that version the fragility was not consider.

This software permits the user not only verify the data provided in a paper, but also the user can verify the data of his algorithm or without the necessity of an algorithm. This tool places a group of boxes in a vehicle, visually verifying that

fragile items are not under no fragile items or that the support area of the items is appropriate.

This work differs from the work of (Lacomme et al., 2013) that the software that they provide requires all the data in a text document. It needs that the user previously knows where the items are placed. This software package can be feed with separate data, sending first the dimensions of the vehicle, and later the data of each one of the box to place in the vehicle, sending each time, the coordinates (x,y,z) and the dimensions (large, width, height) of the boxes. The use of this software package can be used manually or in automated form. In a manually form the user put the data each one at a time. In the automated form the algorithm programmed by the user sends the data, first send the dimensions of the vehicle, after in a while send the data to place the boxes (coordinates and dimensions) in a while that ends according to the conditions that the user establish.

The advantages that the visualization of the items in the vehicle presents is to allow the programmer to visualize when there is a mistake in the programming of the 3L-CVRP solve and apply the necessary corrections to the program. Verifying the results presented in papers, verify the results of his algorithm or merely put a group of boxes in a vehicle and visually verify that all the restrictions are fulfilled.

The data necessary to obtain the visualization are provided in the instances or/and in the papers that the user like verified the results.

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