Distribution Route Optimization: The case study of Nicolau & Rosa

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Abstract

The globalization of the economy and the great increase of competitive pressure on the markets, forced companies to improve the efficiency of their operations in order to keep their business going. Therefore, it has become essential to analyse the whole supply chain and investigate alternatives that could lead to cost reductions as well as to improve the quality of the service provided to the customers. Due to this growing relevance, the optimization of transports has been one of the areas that has aroused greater interest. It was in this context that this work appeared in Nicolau & Rosa, a wholesaler of technical materials for civil construction, which try to minimize the distance travelled by its vehicles using an algorithm that defines its optimized routes for the distribution operation.

In this paper was conceived a mathematical model based on the Multi-Compartment Vehicle Routing Problem (MCVRP), which is a variant of the simple Vehicle Routing Problem (VRP). The model was also implemented in the mathematical programming and optimization modelling system GAMS and was applied to the case study, considering three different scenarios for the distribution operation. The results of the best scenario suggest that the implementation of the model enables to define routes that not only minimize the total distances travelled, reducing 8,65 % per month, but also improve the use of the space available for loading in each compartment, increasing 22,6% of the total capacity used per vehicle, and still reduces the number of necessary routes, reducing 37,5 % per month.

Key words: Supply Chain, Multi-compartment Vehicle Routing (MCVRP), Transportation, Vehicle Routing Problem (VRP), Optimization.

1. Introduction

The economic crisis that Europe has been experiencing in recent years has alarmed the market and has encouraged companies to become more efficient to survive. Pressured to increase their productivity and reduce the waste inherent in their operations, many companies faced the situation not as a problem, but as a business opportunity. With no margins to invest in costly solutions to preserve their financial results, they were left only to intervene on the costs of their operations. Companies were forced to increase the productivity of their operations to improve their results, using the same or even fewer resources.

In most cases, transport represents the largest share of the final price presented to the customer, sometimes reaching about 50% of total logistics costs (Swenseth & Godfrey, 2002). As such, it is simple to understand that optimizing transport costs is one of the biggest concerns of companies. The problem proposed by the company Nicolau & Rosa (N&R) is precisely a matter related to transportation, where the main objective is to improve the distribution process, optimizing distribution routes to customers and making the operation more efficient for the company and its workers.

All distributors around the world are faced daily with this type of problems, better known in the literature as Vehicle Routing Problems. Due to its applicability in real cases, over the years several innovative academic studies have emerged in the area of Operational Research. In this case study, it is intended to implement a mathematical algorithm that defines the optimal routes and that minimizes the total distance travelled by the company's vehicles, and then the model is implemented in a mathematic programming and optimization modelling system GAMS and applied to different scenarios.

The structure of this paper is: section 2, contains a relevant bibliographical review about VRP, presents differents types of VRP and methods for their resolution; section 3, presents the case study and describing the problem characteristics; section 4, is presented the mathematical model; section 5, the model is implemented in three different scenarios, results are compared and is made a sensitivity analysis for the better scenario presented, to study the impact of the variation of some parameters; at last, in section 6 are presented the conclusions and proposed possible futures studies to improve the results.

2. Literature review

2.1 The context

The intensification of competition in the 1990s and the consequent globalization of markets triggered significant changes throughout the process of acquiring a product or service. One of the most significant paradigm changes of modern management is that companies no longer compete independently, but as one only Supply Chain (SC) (Lambert and Cooper, 2000). An efficient and effective management for the creation of competitive advantages in the market has become essential (Li et al., 2006).

Any product, however good and innovative, has very little value to the consumer unless it is available in a place where it can be consumed (Stock and Lambert, 2001). It is essentially for this reason that organizations invest much of their budget in transporting the products and in all activities associated with it. The application of computational methods to the planning of the distribution process causes, mainly, significant reductions in transport costs and the impact in the SC is in turn quite considerable. In the literature we can find the most varied implementations that have been successful in the automatic planning of distribution routes, thanks to the advances of algorithms in the area of vehicle routes and the evolution of new software and computer technologies (Laporte and Osman, 1995).

2.2. Vehicle Routing Problem

The VRP is a combinatorial optimization problem, which aims to determine optimal routes to be performed by a set of identical vehicles, starting from a Distribution Center (DC) , serving a set of customers with a specific demand and who are subject to certain restrictions (Cordeau et al., 2007).

As each company can have quite different organizational objectives, the objective function that is defined can have the most varied purposes: minimization of total distance, minimization of total costs, minimization of operating times, minimization of fleet vehicles, among others.

Laporte (1992) defines the mathematical model for Capacitated Vehicle Routing Problem (CVRP), the classic version of VRP, as follows:

Indices and Sets:

i- Place of departure, $i \in L=\{0,\dots,n\}$

j- Place of arrival, $j \in L=\{0,\dots,n\}$

v- Vehicle, $v \in V=\{1,\dots,m\}$

Parameters:

c_{ij} - Cost of travel between place *i* and place *j*

q_i – Demand of location *i*

Q_v – Maximum vehicle capacity *v*

D_v – Maximum duration of the route traveled by the vehicle *v*

t_{ijv} –Travel time between *i* and *j*, performed by vehicle *v*

d_i – Loading time in place *i*

S- Sub-set of customers

Binary Variables:

x_{ijv} - variable that assumes the value 1 if the vehicle *v* is responsible for making the route between location *i* and location *j*, otherwise it is 0.

Mathematic Formulation:

The mathematic model is formulated taking into account the indices, sets, parameters and variables

$$min \sum_{i=0}^{n}\sum_{j=0}^{n}\sum_{v=1}^{m} c_{ij}\, x_{ijv} \quad [1]$$

$$\sum_{i=0}^{n}\sum_{v=1}^{m} x_{ijv} = 1 \;, \quad \forall \; j \in L \quad [2]$$

$$\sum_{j=0}^{n}\sum_{v=1}^{m} x_{ijv} = 1 \;, \quad \forall \; i \in L \quad [3]$$

$$\sum_{j=0}^{n} x_{jiv} = \sum_{i=0}^{n} x_{ijv} \;, \quad \forall\, i,j \in L \quad [4]$$

$$\sum_{i=0}^{n} q_i \sum_{j=0}^{n} x_{ijv} \le Q_v \;, \quad \forall\, v \in V \quad [5]$$

$$\sum_{i=0}^{n} d_i \sum_{j=0}^{n} x_{ijv} + \sum_{i=0}^{n}\sum_{j=0}^{n} t_{ijv} x_{ijv} \le D_v \;, \quad \forall\, v \in V \quad [6]$$

$$\sum_{j=1}^{n} x_{ijv} \le 1 \;, \quad \forall\, v \in V \quad [7]$$

$$\sum_{i=}^{n} x_{jiv} \le 1 \;, \quad \forall\, v \in V \quad [8]$$

$$\sum_{j=0}^{n} x_{0jv} \leq 1 \ , \ \forall v \in V \qquad [9]$$

$$\sum_{\forall i \in S} \sum_{\forall j \in S} x_{ijv} \leq |S| - 1 \ , \forall S \subseteq V \setminus \{0\} \ ; S = \emptyset; \forall v \in V \qquad [10]$$

The objective function of the problem [1] minimizes the total cost of distribution. Meanwhile, equations [2] and [3] ensure that each customer is supplied only by a single vehicle. Equation [4] ensures that all vehicles that stop at a particular customer leave it, ensuring continuity of routes. The equation [5] is responsible for not being overweight in the vehicles. On the other hand, equation [6] controls whether the sum of service times in clients does not exceed the maximum time stipulated for each route. The equations [7] and [8] are created to understand if there is a vehicle available to effect the route. While equation [9] defines if a specific vehicle leaves DC. Finally, it remains only to add the equation [10] that eliminates the creation of sub-routes.

2.3 Resolution methods for the VRP

VRP is a problem that can present a very high set of solutions and becoming impracticable over a tolerable period of time, this is the reason why VRP is classified as a NP-Hard, non-deterministic polynomial-time hard problem. Over the years, several mathematicians have contributed to the development of methods that try to find the best possible solution. In the literature were found several techniques to achieve them, highlighting three types of approaches:

1.Exact methods- presents the proposal with the best possible solution satisfying all the constraints required, ensuring that the proposal is optimal. However, due to the complexity of these issues that have to take into account a large number of components and restrictions may not be able to solve them computationally. An example of an exact approach was presented in 1960 by Doig and Land, the Branch and Bound (B&B) method, it is the most used algorithm for solving large-scale optimization problems. The main problem, *P*, is divided into sub-problems, P_i, of smaller size, which become simpler to solve than the initial one and need to be solved in order to be able to find a solution to the main problem.

2.Heuristic methods- this methodology is less detailed and computationally rigorous than the previous one, although it presents good solutions in the end, these may not be optimal. In the literature, these methods are classified into three types (Assad et al., 1983): a) Constructive methods, make it possible to construct a solution to the problem, approximated to the optimal solution, based on a distance or time matrix between different points. The Savings algorithm, designed in 1964 by Clarke and Wright is one of the examples; b) Improvement methods, allow to randomly select a route from a set of several possible routes and then make changes in the places to visit until a better solution is found; c) Compound methods, can achieve very approximate results of the optimal solution, try to find a very good initial solution and then apply improvement methods to achieve values for even better solutions.

3.Meta-heuristic methods- these types of algorithms can solve more complex optimization problems when the classic heuristic and optimization methods are not effective and efficient enough to solve them. They solve optimization problems and examine the most promising regions of the solution. There are a lot of meta-heuristic used on the literature, such as: ant colony (Reimann, 2005), simulated annealing (Kikpatrick et al., 1983) and the Tabu Search algorithm (Fallahi et al., 2008).

2.4 Different types of VRP

There are several types of VRP that take into account the particular constraints of each problem, such as: time constraints on customers, homogeneous or heterogeneous vehicle fleet, type of customer demand, vehicle travel times, homogeneity and vehicles capacity, existence of more than one DC, and so on. However in this literary review only the type of VRP that have characteristics similar to the case study will be studied, the multi-compartment VRP.

2.4.1 Multi-compartment VRP (MCVRP)

In many industries, products are not considered homogeneous and can happen, they may not be transported together. In order to save money on transportation costs, companies use vehicles with compartments to be able to transport heterogeneous products in the same vehicle, but in different compartments (Derigs et al., 2010). The demand is all assured by a single DC, which supplies a set of customers with a homogeneous fleet. Each compartment has its own capacity, which may not be the same between compartments and each of these divisions brings together similar products. The arrangement of the space for loading in a vehicle may be configurable in some cases where the spacers between the compartments are adjustable and in other cases this compartments are static. The compartments may have very specific physical characteristics, such as temperature and pressure.

Some of the real cases where this model can be applied are: transport of dairy products, transport of different types of milk, such as cow's and goat's milk, or milks of different qualities or different dates of breastfeeding (Mendoza et al. , 2010); urban waste collection (Elbek et al., 2016); food distribution companies that require various levels of refrigeration (Chajakis et al., 2013); transport of live cattle to slaughterhouses, since animals of different species are transported separate (Oppen et al., 2008). However, the most studied real problem of a multi-compartment VRP is fuel delivery (Coelho et al., 2015).

Although this type of VRP variant had been defined and formulated mathematically in 2010 by Derigs et al., the studies on problems with similar variables and with load restrictions started in the 1980s by Brown and Graves, 1986. However, were Muyldermans and Pang (2010) and Derigs et al. (2010), who are continued the studies on this subject.

2.5 Conclusions of Chapter

The review of the literature allows concluding that the application of a VRP to real problems is not always a simple and linear situation. It is necessary to consider the characteristics of the problem and its constraints, to associate the problem with a specific type of VRP and to apply one or more methods of resolution. Based on these theoretical teachings, the following chapters were elaborated include the mathematical model for the particular case of the company.

3. Case-study

The present work will focus on the distribution operation of the Carnaxide DC. This DC is responsible for providing not only the other company DCs and which are dispersed throughout the country, but also supplies customers daily in the Lisbon and Tagus Valley. It is in this last type of distribution that the present dissertation will concentrate.

Every day, depart vehicles from the Carnaxide DC that deliver twice a day. At 9:00 am the first shipment, which was prepared the afternoon of the previous day, while the second one only leaves the CD after lunch, at 2:00 pm, these last orders were organized in the morning.

When a customer makes an order by phone or via email, it is registered with all the necessary data: customer address, bar code of the products, quantities, date of delivery, among others. The CD operators prepare each order individually, and then these are checked and packaged together with the invoice. Next, the logistic manager adds all the orders that are already finished and defines a route. The delivery routes are defined manually and daily, without the help of any software or any other tool, and later assigned to a specific driver.

The routes are defined according to an approach of the client closest, when the driver leaves the DC he must go to the client that is at a shorter distance, the second customer to be visited must be the one that is closer to the first one , and so on.

Since the final products to be placed on the vehicles are pallets or tubes, N&R has chosen to divide the cargo space in the vehicles into two compartments. Since a part of the vehicle can only carry pallets, a maximum of 12 pallets, and the other part can carry only a maximum of 100 tubes.

The model to be studied will have to consider some restrictions:

-Customer orders must always be made, and there are no minimum quantities to order and ideally delivery should be made up to a maximum of 24 hours;

-It is mandatory to comply with the law on maximum load capacity of vehicles;

-The distribution begins at 9:00 am and concludes at 6:00 pm, with a lunch break from 1:00 pm to 2:00 pm;

-Each route starts and ends on the DC;

-The working hours of drivers must be respected, from 9am to 6pm;

-Vehicles perform only distribution tasks;

-The fleet of vehicles must be maintained, or if possible reduced;

-The space available for loading in the vehicle must be optimized.

4. Mathematical model

4.1 Description of the mathematical model

The model that will be presented for solving the N&R problem will be modeled as a variant of the VRP, the Multi-Compartment VRP. This mathematical formulation was based on the works of Derigs et al. (2010) and Henke et al. (2017).

Consider a set of n clients that have associated each of them an order, o_{ip}. In this order, the index i represents the customer to be supplied and the index p, the type of product ordered, pallets or tubes. It was established that p=1 refers to pallets and p=2 to tubes.

The fleet contains m vehicles with equal capacity between them. However, each vehicle, index v, is divided in two compartments, index c. Pallets can only be placed on one side and tubes on only one side. It was also defined that for this index, *c*=1 is for pallets and *c*=2 is for tubes.

The maximum capacity of each type of compartment is the same in all vehicles, $cmax_c$. To ensure that the products are place in the correct compartment, it is necessary to define which products are incompatible with the compartments. The relationship $IncProdComp \subseteq P \times C$ defines incompatibilities between products and compartments, $(p, c) \in IncProdComp$ means that product *p* can not be transported in compartment *c.* In the case of N&R, the incompatibilities that will exist are $(1,2) \in IncProdComp$ and $(2,1) \in IncProdComp$.

Regarding the incompatibility between products, it can also be defined by the relation $IncProd \subseteq P \times P$, where $(p, q) \in IncProd$ means that products *p* and *q* can not be transported in the same compartment. In this case, since there are only two types of products to be placed in the vehicles, there is only incompatibility between the pallets and the tubes, so that $(1,2) \in IncProd$.

When a vehicle travel from a location $i=\{0,\ldots,n\}$ to another location $j=\{0,\ldots,n\}$ implies that it is associated a travel time, $tviagem_{ij}$, and a distance of travel, $dviagem_{ij}$. Each vehicle will thus satisfy a set of customers. The location with $i=0$ represents the distribution center.

The total duration of deliveries consists of a fixed fraction and a variable fraction. The fixed part, which corresponds to parameter *ta*, is the time spent with administrative stuffs, such as payments and completion of administrative documents. The variable part will be divided into two parts, the time of pallet unloads, tdp_i, and the time of tube unloads, tdt_i. These last two values will depend on the number of pallets and the number of tubes to be delivered in each customer, so it is associated with them the index *i*.

4.1.1. Indices and Sets

i - visited place, $i \in L = \{0, \ldots, n\}$
j - place to visit, $j \in L = \{0, \ldots, n\}$
v - vehicle, $v \in V = \{1, \ldots, m\}$
p - product type, $p \in P = \{1,2\}$
c - compartment, $c \in C = \{1,2\}$

4.1.2. Parameters

o_{ip} - Quantity requested by customer *i* of product *p*.
$dviagem_{ij}$ - Distance between the place *i* and *j*, in km.
$tviagem_{ij}$ - Travel time between location *i* and *j*, in minutes.
ta - Fixed client time to handle administrative stuff, in minutes.
tdp - Discharge time per pallet, in minutes.
tdt - Discharge time per tube, in minutes.
tt - Total time available for the distribution operation, in minutes.
$cmax_c$ - Maximum compartment capacity *c*, in units.
k - Average speed of the vehicle, in km per minute.

4.1.3. Variables

Positive variables:
$dtotal_v$ - Auxiliary variable that saves the value of the total distance traveled by each vehicle *v*.
$ttotal_v$ - Auxiliary variable that saves the total time value of each vehicle *v*.
u_i - Entire auxiliary variable that takes values according to the position of client *i* in the route.
Binary variables:
x_{ijvpc} - binary variable that assumes the value 1 if the vehicle *v* transports the order from location *i* to location *j* of product *p*, in compartment *c*. Otherwise it is set to 0.
vf_v - variable that assumes the value 1 if the vehicle *v* makes a route and 0 otherwise.

4.1.4. Mathematic Formulation

Taking into consideration the characteristics and using the above indices, sets, parameters and variables, the model is formulated.

$$Min\ z = \sum_{v}^{m}\sum_{i}^{n}\sum_{j}^{n} x_{ijv11} \times dviagem_{ij} \qquad [11]$$

$$\sum_{i\geq 1}^{n} x_{0iv11} = vf_v \ , \quad \forall\ v \in V \qquad [12]$$

$$\sum_{i\geq 1}^{n} x_{i0v11} = vf_v \ , \quad \forall\ v \in V \qquad [13]$$

$$\sum_{i\geq 1}^{n}\sum_{v\geq 1}^{m} x_{jiv11} = 1 \ , \quad \forall\ j \in L\backslash\{0\} \wedge j \neq i \qquad [14]$$

$$\sum_{i\geq 1}^{n}\sum_{v\geq 1}^{m} x_{ijv11} = 1 \ , \quad \forall\ j \in L\backslash\{0\} \wedge j \neq i \qquad [15]$$

$$\sum_{j\geq 1}^{n} x_{jiv11} = \sum_{j\geq 1}^{n} x_{ijv11} \ , \quad \forall\ i \in L,\ \forall\ v \in V \qquad [16]$$

$$\sum_{i\geq 0}^{n}\sum_{j\geq 0}^{n} o_{i1} \times x_{ijv11} \leq camx_1 \ , \forall\, v \in V, \forall\, i,j \in L \wedge i \neq j \qquad [17]$$

$$\sum_{i\geq 0}^{n}\sum_{j\geq 0}^{n} o_{i2} \times x_{ijv22} \leq cmax_2 \ , \forall\, v \in V, \forall\ i,j \in L \wedge i \neq j \qquad [18]$$

$$x_{ijv11} \leq vf_v \ , \quad \forall\ i,j \in L,\ \forall\ v \in V \qquad [19]$$

$$\sum_{i\geq 0}^{n}\sum_{j\geq 0}^{n} (tviagem_{ij} + tdp.o_{i1} + tdt.o_{i2} + ta).x_{ijv11} \leq tt\ , \quad \forall v \in V \qquad [20]$$

$$u_i - u_j + n.x_{ijv11} \leq n-1, \forall\, i,j \in L\backslash\{0\} \wedge i \neq j, \quad \forall v \in V \qquad [21]$$

$$dtotal_v = \sum_{i\geq 0}^{n}\sum_{j\geq 0}^{n} x_{ijv11} \times dviagem_{ij} \quad , \qquad \forall\, v \in V \quad [22]$$

$$ttotal_v = \sum_{i\geq 0}^{n}\sum_{j\geq 0}^{n} x_{ijv11}\left(tviagem_{ij} + tdp.o_{i1} + tdt.o_{i2} + ta\right),$$
$$\forall v \in V \qquad [23]$$

$$x_{ijv11} = x_{ijv22} \quad , \qquad \forall\; i,j \in L\,,\; \forall\, v \in V \qquad [24]$$

The objective function, equation [11], corresponds to the company request: minimize the total distance traveled, in kilometers.

The equation [12] ensures that each route starts on the DC and equation [13] ensures and that each route must necessarily end on the DC. The following two equations ensure that for all routes, each customer will only be visited once. Equation [14] requires that each customer arrive at only one vehicle and, on the other hand, equation [15] requires that each customer depart from only one vehicle.

Regarding the continuity of the routes, equation [16] ensures that when a vehicle reaches a customer it will also have to leave it and proceed to the next destination. The following equation [17], make sure that the capacity of the pallet compartment is not exceeded, while equation [18] ensures that the capacity of the tube compartment is not exceeded.

To ensure that each customer will only be visited by a vehicle to which a route has been allocated, the constraint [19] appears. Equation [20] ensures that the time limit per route is not exceeded. That is, the sum of the time spent in the distribution operation does not exceed the available time, per period for the distribution operation per conductor. The time of a route will include not only travel time between points, but also the time spent for unload and management administrative issues. Equation [21] eliminates the creation of subroutines. In this constraint *n* represents the dimension of the set of clients, while the variable *u* indicates the position that each client has in a distribution route.

The following two equations [22] and [23] were constructed to calculate the total distance traveled and the total time spent by each vehicle, respectively. One of the conditions required by N&R was that if a customer is going to be supplied by the vehicle *v*, it will have to carry both the ordering of the tubes and that of the pallets. Therefore, the following equation [24] guarantees that it is the same vehicle to take all the orders that a customer can request.

The model designed to solve the MCVRP is thus formed by the objective function [11] and by all constraints from [12] to [24]. It is intended to find the sequence of customer visits that minimizes the total distance traveled, respecting the capacities of the vehicle, time limit, compartments and incompatibility relations.

5. Results

5.1 Resolution of the case study

In order to be able to implement the model in GAMS language and simulate the N&R distribution operation, it was necessary to collect some data regarding the final product, fleet, customers, visiting times and operating hours. To collect all this information it was essential analyze one month of orders, which correspond 40 shifts, 20 shifts during the morning and 20 shifts during the afternoon. Knowing the orders of each client per shift, it was possible to construct the distance matrix and time matrix per shift, between each client and between each client and the DC. It was also possible to construct tables with the values of each client orders quantity. Through the observation of distribution operation in the company, was define the value of parameters who was applied on the model, the table 1 brings these values.

Table 1: Model parameters (Source: Author)

Parameter	Value
ta	5
tdp	4
tdt	0,5
tt	240
k	0,83
$cmax_1$	12
$cmax_2$	100

Using Google Maps, was created the distance matrix between customers and DC for each shift. From this matrix was created another matrix with travel times, knowing that the average speed of the vehicles is 0.83 km/min. Finally, a table with the orders of each client was created by type of final product, pallets or tubes.

Initially, when the model was implemented in the computer in GAMS language, it inevitably presented errors that needed to be corrected. For this reason, it was extremely important to test and refine the model, where it was tried to correct the greatest number of detectable gaps, and consequently to increase the validity of the results that will be obtained in the future.

Thus the model was tested with a smaller example, where the shift selected has a small number of customers that need to be supplied but who have orders for both pallets and tubes. The chosen shift has only six search points (*i*1 to *i*6) and the DC (*i*0).

With the computational application of the model it was possible to obtain the route, travel times and verify that all equations worked correctly. However, to make it more reliable and to finalize the validity tests of the model, it was necessary to change the value of some parameters, like the demand and the duration. In the case of demand, the number of ordered pallets and tubes was increased to see if the formation of two routes was verified correctly and if the orders of the same customer but of different types of products go in the same vehicle. For the duration, the established time limit was varied, decreasing it and increasing it. The tests made it possible to conclude that the model worked correctly and that all the equations had their functionality ensure.

5.2 Scenarios Results

The mathematical model was applied to the case study, but to evaluate the impacts of the different scenarios, was created three different options:

- Scenario 1 – applies the MCVRP model using exactly the data collected and that represent the current situation of the company;

- Scenario 2 – use only one vehicle, the maximum permissible duration for each shift is relaxed and is only possible if the total number of pallets is less than or equal to 12 pallets and the number of tubes is equal to or less than 100 tubes. Otherwise two vehicles will continue the operation;

- Scenario 3 – there is only one vehicle for the operation and in the shifts where it is not possible to serve all the customers, the last customers to demand the order are supplied in the next shift.

The following table 2 presents the results obtains for each scenario and the values of the N&R actual situation.

Table 2: The final results for each scenario and N&R actual situation (Source: Author)

	N&R	1	2	3
Total distance per month (km)	4718	4324	4307	4310
Number of routes per month	64	55	48	40
% of pallet compartment occupation per month	49	57	65	78
% of tubes compartment occupation per month	19	23	27	32
% of vehicle total occupation per month	38,5	45	52	61
Average shift time (min)		169	190	213
Total transportation costs per year (€)	57.808	56.032	55.974	37.837

Starting the scenarios comparison with the distances traveled, it is possible to verify that scenario 2 is the one who has the lowest value, but the difference of values between this scenario and scenario 3 is small, which presents a solution with more 2.98 km per month. Both scenarios show a reduction of 8.7% relative to the company's scenario.

Regarding the routes average duration, it is scenario 1 that presents a better proposal, but it was also this scenario that proposed a bigger number of routes per month. Scenario 3 was able to reduce significantly the number of routes, ensuring that it would not be necessary to use two vehicles for the distribution operation. This significantly reduction of the number of routes is about 37,5%.

It is clear that scenario 3 is the one that can achieve better results about the using of compartment space, since there is only one vehicle and it has to put the maximum load in it. This scenario, compared to the initial one, shows an increase of 22.5% of the total space occupied.

The analysis becomes more interesting and can be more conclusive if take into account all costs associated with transport, such as: vehicle depreciation costs, driver costs and fuel costs.

Fuel costs are directly proportional to the distance traveled. For vehicle depreciation, was needed to consider vehicle acquisition costs and service life, so that can apply the vehicle's amortization rates. Driver costs include monthly salaries, subsidies and overtime payment.

But once again, the last scenario guarantees that it has the best value proposition for the company, causing an annual reduction of 35% in transportation costs, compared to the current situation.

Although scenario 3 had very good results, were registered 20 customers who were not able to go immediately on the next shift to which they placed the order. Therefore, the probability that a customer would not be served immediately on the next shift when ordering and having to wait for the next day was 7.6%, which translates into a reduced probability of occurrence.

One of the problems that both scenario 2 and 3 present is the average duration of the routes. Although the route average per shift is less than the 240 minutes initially defined, there are some cases in which the route times per shift exceed this value. However, in scenario 1 as there is a restriction that prohibits the execution of routes with excessive time, there is no record of any such case. In scenario 2 there were 7 cases with delays. Consequently it can be concluded that the time limit established was only exceeded in 17.5% of the tests carried out and that the maximum time that a route checked was 263 minutes, that is, 23 minutes more than that established. However, not all routes that require the most time reach these 23 minutes.

In scenario 3 the values were slightly different. The established time limit was exceeded in 27.5% of the tests and the maximum time was 331 minutes, that is, 91 minutes more than established. The average time of those 11 cases, in which there was a delay, was 32 minutes.

All the shifts that have increased the duration of your routes are orders that arrived in the morning and will be distributed during the afternoon. To study a viable solution that could be presented to the company to circumvent this time that is exceeded, it was necessary to analyze the routes that preceded these delays. It was necessary to examine whether the routes that were conducted in the morning on the same day there were routes with less than 240 minutes.

Shifts precede overtime shifts always have values significantly lower than 240 minutes, except rare cases. As drivers start the morning routes at 9am, in cases where the afternoon shift requires more time, it is suggested that drivers when they finish the morning route, which is shorter than the 240 minutes, do their pause for one hour of lunch and then start the afternoon route that is longer. Thus, workers would continue to work 8 hours a day. Another option would be pay extra hours to work overtime.

Another question that could be raised here would be the temporary windows of the clients. Since most customers are stocked in their stores, and generally close at 8:00 p.m., two hours after 6:00 p.m., this factor does not present any constraints.

Another of the points that the company asked to be studied in this work was the possibility of an improvement in the operation of loads and unloads, so the drivers work could be more efficient. Currently the placement of the products in the compartments of the trucks does not follow any order, regardless of where the pallets or tubes are placed inside the compartment. In order to facilitate this operation of loading to workers during the routes, it is proposed the Last In First Out (LIFO) method of storage. Since the routes are already defined with the MCVRP model and it is already known which sequence of clients to visit it would be advisable to follow this method.

In this LIFO methodology, products that are last placed on the truck during the loading operation on the DC before they go to distribution will be the ones who are removed first as soon as deliveries to customers begin. In other words, the order of loading of the lorry must be the reverse of the sequence of deliveries. Thus, the first customer to be visited will have its request next to the unloading door of the truck, facilitating the operation for the worker. While the last customer to be served will have your order as far away from the door as possible.

The process described above concerns the loading of the pallets. With regard to the loading of the tubes, the method must be the same, however the tubes need to be stacked one on top of the other. The tubes below will be the last ones to leave and the first to be placed in the truck, while the first tubes to leave for customers will have to be at the top. This methodology makes the loading and unloading process more efficient, not only because it allows a reduction of the physical effort of the workers and as such they can work with more agility, but can also allow reductions the operating time.

5.3 Sensitivity Analysis

Although the three scenarios proposed fulfill the main objective of the study, to minimize the total distances travelled, scenario 3 is the one who can present a better value proposition for the company. As such, in this subchapter is performed a sensitivity analysis only for scenario 3, where some relevant parameters such as demand and time spent on clients are changed.

In first sub-scenario, sub-scenario 3.a, was made a 10% reduction in the quantities ordered by customers.

The second sub-scenario, sub-scenario 3.b, studies the inverse situation, the changes in the results if there is a 10% increase in the quantities ordered by the customers.

The last sub-scenario, sub-scenario 3.c, wants understand how the elimination of time spent with administrative tasks, 5 minutes per client, can influence the results regarding the duration of the routes.

The following table 3 presents the results obtains for each sub-scenario and the values of the simple scenario 3.

Table 3: Summary table with the results of scenario 3 and each sub-scenario (Source: Author)

	3	**3.a**	**3.b**	**3.c**
Total distance per month (km)	4310	3890	5016	4310
Increase/Reduction of total distance (%)		-9,7	+16,4	
Average distance per shift (km)	108	97	125	108
Average time per shift (km)	213	198	226	180
Increase/Reduction of average		-7	+6,1	-16

time per shift (%)				
% pallets	78	70	86	78
Increase/ Reduce % pallets		-8	+8	
% tubes	32	27	36	32
Increase/ Reduce % tubes		-4	+4	

Initializing the sensitivity analysis with the results concerning the total distance traveled, we can see that in the first sub-scenario the distance covered by the vehicles decreases by 9.7%, while in the reverse situation with the increase in demand there is a 16.4% increase. The last sub-scenario 3.c does not have any variation of the kilometers traveled, since the sequence of the routes in this case does not change, the only value that varies is the time spent in each client, therefore only changes related to the duration of each route. There aren't statistics relating to the number of routes because there was no change. Since there was only one driver to deliver, only a maximum of two routes per day could be made.

For the average duration per shift, the sub-scenario 3.c is the one that shows a more significant improvement, with a decrease of 16% of the average time per shift. As regards the occupation of cargo space in vehicles, sub-scenario 3.a shows a decrease of 8% of the space occupied with pallets, while sub-scenario 3.b increases by 8%, in this case a percentage of occupancy of the pallet compartment of 86%. On the other hand, in terms of occupancy of the space for the pipes, there was only a decrease of 4% for the first case and an increase of 4% for the second scenario. As would be expected in the last sub-scenario there is no change in the figures for the occupation of the compartments.

In order to demonstrate in detail the impact of the elimination of payment collection tasks on the final results, it was analyzed the number of shifts that exceeded the limit of 240 minutes.

There were only three shifts in the times were over 240 minutes. There being a decrease in the percentage of occurrence of this type of event, going from 27.5% to 7.5%. Since these shifts that require more time all take place during the afternoon, the three shifts of the morning of each of these days were analyzed.

All shifts that precede shifts with overtime always have values significantly lower than 240 minutes. It was verified for the three cases that in the morning shift there always remains time to complete the time that is lacking during the afternoon. As drivers start the morning routes at 9am, in cases where the afternoon shift requires more time, it is suggested that drivers when they finish the morning route, which is shorter than the 240 minutes, do their pause for one hour of lunch and then start the afternoon route that is longer. Thus, workers would continue to work 8 hours a day.

With this final sensitivity analysis of sub-scenario 3.c, we understand that when this strategy of eliminating administrative tasks is applied, the driver does not need to make extra minutes, nor does the company need to have another financial burden. In this way the worker's work period is respected.

6. Conclusions

The developed model allows not only to provide optimum routes to N&R, which minimizes the distance traveled by vehicles, but also to improve the use of the available space to store the load and reduce the number of routes required, always respecting the restrictions on the maximum capacities of load per compartment.

Although all scenarios show significant improvements, scenario 3 is clearly the proposal that the company should consider, since it allows to significantly improve all parameters studied and still allows the vehicle that is no longer used can be allocated to a new DC of the company, which will be opened in 2017, thus avoiding the purchase of a new vehicle and an expensive investment. However, the level of service in this case decreases by 7.6%, since customers can only receive their order on the shift after what they would expect, and there may be cases where it is necessary to pay overtime to drivers.

Through the sensitivity analysis to the time spent with administrative tasks during the deliveries, it was possible to conclude that the elimination of these tasks from the routes will cause significant improvements. If these activities were no longer practiced, the company would not have to pay overtime to the workers, since the time never exceeded 8 hours a day and it was still possible to reduce the total time of each route. Therefore the company is advised to reflect on this new option.

As future work, it is suggested that the hypothesis of a new configuration for the cargo compartments of the vehicles should be studied. It would be interesting to consider also as a future study the development of an MS Excel tool, supported by heuristics, for an autonomous use by the company in defining the routes in their daily lives, instead of being elaborated manually by the responsible logistic.

This work aims to develop well-founded proposals to the company that can help improve the distribution operation. However, the choice of which strategy to adopt will depend solely on the company's final decision.

Finally, it is expected that the work carried out in this dissertation will be an advantageous tool for the company to decide on the best alternative to improve its current distribution operation.

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