Coordinating inbound and outbound deliveries in a distribution centre

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Supervisor: Prof. ir. Birger Raa

Master's dissertation submitted in order to obtain the academic degree of
Inkomende Gast- en Exchangestudenten

Department of Industrial Systems Engineering and Product Design
Chair: Prof. dr. El-Houssaine Aghezzaf
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Abstract

This Master dissertation report contemplates the development of a mathematical model for a supply chain optimization. The main objective is to schedule inbound and outbound deliveries in two-echelon distribution system and quantify the vehicle fleet size at the minimum overall cost. The problem studies the periodic replenishment of a given set of routes from a distribution centre, which acts as a cross-dock warehouse. The model is defined linear and deterministic and the costs considered are the fixed fleet vehicle cost, the fixed cost of incoming shipments, the cost of making the routes and the inventory holding costs.

First, a model for periodic replenishment is presented. The frequency of outgoing deliveries is set at the optimal cycle time of each individual route. Also, a second model is defined for non-periodic replenishments. In this case, outgoing deliveries are scheduled in order to minimize the total cost of the multi-echelon distribution system. Then, both models are tested in a set of experiments in which some factors vary in order to see how do the models work. An analysis of the results of this datasets prove that some costs affect more than others to the solution of the model.

Keywords

Supply chain

Inventory routing

Multi-echelon

Cross-dock

Replenish scheduling

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Coordinating inbound and outbound deliveries in a distribution centre

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***Abstract*: This paper explains the development and analysis of a mathematical model for a two-echelon inventory distribution system. The main objective is to schedule inbound and outbound deliveries in a distribution centre and quantify the vehicle fleet size at the minimum overall cost.**

Two linear and deterministic models are presented to solve the problem. The difference between them is that the first one considers periodic outgoing shipments while the second one this are scheduled in order to minimize the total cost. Both periodic and non-periodic models are tested in a design of experiments and then analysed the solutions for obtaining important factor effects.

***Keywords*: Supply chain, inventory routing, Multi-echelon, cross-dock, replenish scheduling**

I. PRESENTATION OF THE PROBLEM

The problem states a two-echelon distribution inventory system. First a distribution centre receives incoming shipments and then the products are distributed periodically to several retailers already clustered into routes. Demand rates are defined constant and known so the best solution is to plan cyclically the same schedule in an infinite planning horizon.

This inventory routing problem not only schedules inbound and outbound deliveries, but also sizes the vehicle fleet needed according to the best trade-off between involved costs. The solution also quantifies the product units to be shipped and to be stored.

II. LITERATURE REVIEW

This Master dissertation is an improvement of 'Fleet optimization for cyclic inventory routing problems', an inventory routing problem presented in 2014 by *B. Raa* [5]. The idea of considering the fleet size in the cost formula is extracted from as well as the cost of making the route. This previous abstract considers that the central depot has enough stock available to load all shipments. Hence, no coordination between inbound and outbound deliveries is studied.

The paper of S. Axsälter, 2002 [7] and also in the one of M. Seifbarghy and M. R. A. Jokar 2005 [6] is considered a two-echelon supply chain distribution. In both problems demand rates are set variable, so a stochastic is performed. The objective of them is to find the optimal reorder point for all retailers, which are defined identical, with predetermined batch order sizes.

III. MATHEMATICAL MODEL

As explained, the paper presents a two-echelon distribution inventory system with a distribution centre as one party and many retailers as the other one. The model has to coordinate the reception and distribution of inbound and outbound deliveries to each one of the retailers with the minimum total cost possible (see Figure 1).

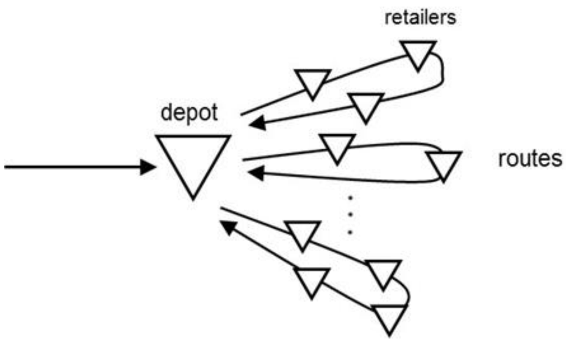

Figure 1. Two-echelon distribution inventory system

The mathematical model both parties, depot and retailers, so an integrated supplier-retailer optimum will be achieved. The model is aimed to adjust incoming and outgoing shipments in order to cross-dock or store the products (or a combination of both solutions) and so minimize the overall cost rate.

The considered costs, the sum of which must be minimized in the objective function (1) are the fixed vehicle cost, the fixed cost of incoming shipments, the cost of making the routes and the inventory holding costs (at the depot and at the retailers). Also some constraints are set such as unit products flow, capacity constraints and driving regulations. The entire model is defined below.

$$Minimize \sum_{v \in V} F \cdot nT \cdot Z_v + \sum_{r \in R} \sum_{v \in V} \sum_{d \in nT} C_r \cdot X_{r\,v\,d} + \sum_{d \in nT} H \cdot ID_d + \sum_{d \in nT} S \cdot Y_d + \sum_{d \in nT} H \cdot IR_{r\,d} \qquad (1)$$

$$Z_{V+1} = 0 \qquad (2)$$

$$Z_v \geq Z_{v+1} \quad \forall\, v \in V \qquad (3)$$

$$ID_0 = 0 \qquad (4)$$

$$IR_{r\,0} = IR_{r\,nT} \quad \forall\, r \in R \qquad (5)$$

$$ID_d = ID_{d-1} - \sum_{r \in R} QO_{r\,d} + QI_d \quad \forall\, d \in nT \qquad (6)$$

$$IR_{r\,d} = IR_{r\,d-1} - Dem_r + QO_{r\,d} \quad \begin{cases} \forall\, r \in R \\ \forall\, d \in nT \end{cases} \qquad (7)$$

$$\sum_{v \in V} \sum_{d \in T_r} X_{r\,v\,d} = 1 \quad \forall\, r \in R \qquad (8)$$

$$\sum_{v \in V} X_{r\,v\,d} = \sum_{v \in V} X_{r\,v\,d+T_r} \quad \begin{cases} \forall\, r \in R \\ \forall\, d \in \{1, \dots, nT - T_r\} \end{cases} \qquad (9)$$

$$QI \leq K \cdot Y_d \quad \forall\, d \in nT \qquad (10)$$

$$QO_{r\,d} \leq \sum_{v \in V} K \cdot X_{r\,v\,d} \quad \begin{cases} \forall\, r \in R \\ \forall\, d \in nT \end{cases} \qquad (11)$$

$$\sum_{r \in R} D_r \cdot X_{r\,v\,d} \leq M \cdot Z_v \quad \begin{cases} \forall\, v \in V \\ \forall\, d \in nT \end{cases} \qquad (12)$$

$$X_{r\,v\,d}, Z_v \in \{0,1\} \quad \begin{cases} \forall\, r \in R \\ \forall\, v \in V \\ \forall\, d \in nT \end{cases} \qquad (13)$$

$$Y_d, QI_d, QO_{r\,d}, ID_d, IR_{r\,d} \geq 0 \quad \begin{cases} \forall\, r \in R \\ \forall\, d \in nT \end{cases} \qquad (14)$$

The first version of the model takes into account the optimal cycle time for replenishment of each route. This means that each route *r ϵ R* will be performed periodically every T_r days respectively (defined with equations (8) and (9)).

On the other hand, the second version of the model is the model itself that places the outgoing shipments with frequency not fixed to be periodic. To perform that, constraints (8) and (9) are replaced for the (15) one.

$$\sum_{v \in V} \sum_{d \in nT} X_{r\,v\,d} \leq nT \quad \forall\, r \in R \qquad (15)$$

The possible solutions in the second model increase considerably respect the first one, as the cycle time is not fixed in advanced and lots of combinations can be done. Among all possible solutions, the optimal one of the first model is included. Hence the solution can be the same as in the first mathematical model or better.

IV. NUMERICAL RESULTS

For the resolution of the model, the same set of experiments as in *B. Raa, 2014* is used. From the initial factorial design used in the fleet optimization model, one of the four factors has been removed. On the other hand, two versions of the model are taken into account and both solutions will be analysed so the final group of experiments is formed by a 2 x 10 x 2^3 factorial design.

Apart from the periodicity of outgoing shipments, the other factors analysed are: the duration of the routes, the fixed cost for vehicles and the holding cost rate. From each factor, two levels are stated.

V. CONCLUSIONS

After analysing the results, some conclusions of the model can be determined. In advance, some factors are noticed to influence more than others in the schedule resolution.

The first studied factor is the duration of the routes. Comparing both small and large factor levels can be seen that all costs increase their values, especially the fixed vehicle cost. Logically, the overall cost also increases its value.

The daily fixed cost per vehicle hardly influences the distribution cost. It effects particularly to the fixed vehicle cost, the higher the price per vehicle the higher cost is. Therefore, the total cost for a schedule is also higher with the large level factor of the fixed vehicle cost.

The third factor analysed is the holding cost rate. The large level of the factor influences not only increasing the routes holding cost, but also decreasing all other allocations. Moreover, the resulting total cost for the large level is lower than for the small one.

Finally, the last considered factor is the routes replenishment frequency. It has been seen that non-periodic solutions get cheaper schedules indistinctly the other factors. Because much more solutions have to be checked in the same time, GAP values are higher in the non-periodic model.

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1. Purpose

The project involves developing and testing a linear mathematical model with CPLEX for minimizing the total cost in a two-echelon supply chain. The objective is to schedule all income and outgoing deliveries with the most suitable cost trade-off. The presented inventory routing problem coordinates a vehicle fleet and unit products, hence the concerning costs are fixed vehicle costs, fixed and variable shipment costs and inventory holding costs. For the purpose of providing better solutions, a variation of the model is developed. In both cases the software looks for the optimum solution (the best schedule possible), and it is analysed the behaviour of each factor in order to better understand the model.

2. Scope

In this section is described what is in the scope of the present project.

- Develop a first linear mathematical model easy to be solved. This one has been improved into a second mathematical model (also linear) in order to achieve better solutions.

- Ready all datasets in appropriate excel sheets and run both models with them with CPLEX software.

- Analyse the results obtained looking for behaviour patterns of each model. Datasets include variations in some key factors which must be studied in deep and detect if they are repeated through models.

3. Justification

3.1. Technical

In the present, most of mature companies look for cost reduction not only in their core business, but also in the rest of realized activities. Transportation of products and inventory management are used not to be optimized and usually are oversized. Large cost savings can be done with a minimum care in that points. Even from a studied schedule, a better solution can be defined. Hence, companies desire a good solution for their material flow policies so costs can be minimized and get higher margin for products. Regarding this project, the mathematical model is able to improve its first solution with the same amount of time and nearly reach to the optimum level

3.2. Personal

On the basis of my knowledge in quantitative methods and developer skills, harder issues could be treated. Personally, industrial organization and logistics are areas which strikes me and it is probable I will work in it in a future. This project has given me the opportunity to grow in both worlds and know deeper new strategies followed by current companies.

4. Presentation of the problem

This chapter provides context information about current supply chain solutions. The proposed solution is focused on this current situation. Also, a brief description of the framework and specifications of the problem are presented.

4.1. Background overview

Every company looks for the best inventory policy possible, as a good management of them has a very positive impact to the company's profitability. Since the vehicle routing problem was used for optimizing transportation of goods with one or multiple vehicles, the first variants of them appeared. Among them, the inventory routing problem has been struck for many companies in order to maximize its benefits. This problem is used specially in multi-echelon distribution inventory systems, where both inbound and outbound deliveries must be taken into account. In multiple-echelon problems, the inventory level is not only analysed in the central depot, but also in the lower levels.

Cross-docking is a popular practice for distribution centres. In this echelon, coordination between incoming and outgoing shipments must be extremely scheduled, as the aim of cross-dock operations is to have minimal or no inventory level at the central depot. As mentioned in the previous paragraph, in multi-echelon problems the inventory level is examined all across the supply chain. Cross-docking then, reduces it in the distribution centres.

4.2. Problem framework

The problem solved in this project is an improvement of a previous IRP (explained in the fifth point of this paper *Literature review*). Because that, the same framework has been established with some modifications. The project states a two-echelon distribution inventory system: first, a distribution centre receives the products when needed and next, they are shipped periodically at the retailers. Retailers have already been clustered in routes depending on proximity and demand orders. Demand rates are set to be constant and known and backorder is not allowed, so the achieved solution could be repeated cyclically and so, have an infinite planning horizon.

The model must optimize not only the fleet vehicle size, but also the replenishment frequency at the retailer clusters. Is essential that the schedule daily assigns which vehicles are used and the quantity of products to be delivered to each retailer. The optimum solution will consider the best trade-off among all costs according to the values of them.

5. Literature review

The most influent papers for the model presented in this project are summarized in this chapter. As the high popularity of the inventory routing problem, lots of variants of the problem can be found in the literature.

The paper 'Fleet optimization for cyclic inventory routing problems' (B. Raa, 2014) [5] is basis of the project. Actually, the project was born as a further application of the abstract of *B. Raa* 2014. This IRP holds an infinite planning horizon and constant demand rates at the customers. Depend on the selected frequency of them, some costs may vary so the optimum trade-off will be affected. The objective of the paper is to minimize the overall cost rate of the defined costs. Firstly, are stated the route-specific costs and the holding costs at the customers (which depends on the replenishment frequency) and secondly, fixed costs of the fleet are also taken into account.

In *B. Raa*'s 2014 abstract, the solution determines the vehicle fleet size that is needed to perform the routes. However, is considered that the distribution centre has enough stock available to load the vehicles. Therefore, is not treated as a multi-echelon supply chain. More literature is needed to understand how to align incoming shipments with the outgoing ones in order to cross-dock goods.

The abstract 'Cost evaluation of a two-echelon inventory system with lost sales and approximately Poisson demand' (M. Seifbarghy and M. R. A. Jokar, 2005) [6] considers a two-echelon inventory system; one of them is defined as a central warehouse and the second level are several identical retailers. The item demand at the retailers follows the Poisson law and backorders are allowed. The objective is to find the optimal reorder points with predetermined values of batch sizes.

Similarly, 'Approximate optimization of a two-level distribution inventory system' (S. Axsäter, 2002) [7] presents also stochastic demand for the same two-echelon inventory system. Unlike the last abstract, retailer lead times are stochastic as well.

In addition, more general ideas were extracted from a mix of abstracts and articles which talk about algorithms for serial systems (Clark-Scarf, 1960) and a wide range of multi-echelon inventory system with deterministic demand (Roundy, 1985), (Atkins et al., 1992).

6. Mathematical model and notation

This chapter presents the notation used for data and variables of the mathematical model and two versions of a linear mathematical model that describes the problem. All features of them and in what they differ is explained in deep in the concerned points.

6.1. Problem formulation

Because the mathematical model is an improvement of 'Fleet optimization for cyclic inventory routing problems' (B. Raa, 2014), the same framework is established. In a two-echelon supply chain distribution inventory system, a set of routes are given. Those routes are a cluster of retailers located nearby which have to be visited at the same time.

The planning horizon is considered infinite and the retailers demand rates are constant so the obtained schedule should be repeated periodically. The cycle time will be established on the basis of the optimal cycle time for replenishment of all routes.

The problem presented is a two level supply chain with a distribution centre as one party and many retailers as the other one. The depot has to coordinate the reception of inbound deliveries (whenever all over the cycle time) and it has to establish the transport of the outgoing deliveries to each one of the retailers with the minimum total cost possible (see Figure 2). As the two parties are involved in the same model, an integrated supplier-retailer optimum will be achieved, which is more profitable rather than two separate optimums. In addition, not only the total cost of scheduling is minimized but also the needed fleet is optimized according to it cost.

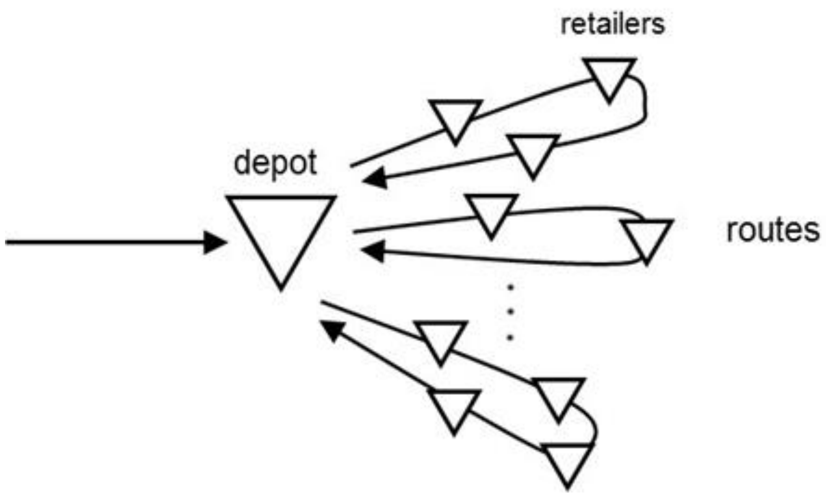

Figure 2. Two-echelon distribution inventory system

One enhancement over the fleet optimization problem is the consideration of the central depot with variable stock over days, therefore its inventory management must be included in the total cost formula. The mathematical model is aimed to adjust incoming and outgoing shipments in order to cross-dock or store the products (or a combination of both solutions) and so minimize the overall cost rate. In the same way as the first version of the problem, the retailers are also allowed to store the product and backlog orders are not permitted.

Regarding the vehicles, those are needed not only for outgoing product deliveries (as in 'Fleet optimization for cyclic inventory routing problems' (B. Raa, 2014)) but also for incoming product shipments. A maximum capacity of products per vehicle and a maximum number of driving hours (only for outgoing deliveries) are established. In this way, the mathematical model should fit the solution to fulfil those new constraints.

The notation of the used data is presented down below, as well as a little explanation and its corresponding units.

R number of routes required from a single depot (each route could be a single retailer or a set of retailers located nearby with a common cycle time)

V maximum number of outgoing delivery vehicles in a distribution schedule

nT number of days of the cycle time (calculated as the least common multiple of all retailers' optimal cycle time)

F fixed daily cost per vehicle [in euros/day]

C_r cost for making the route r (includes the vehicle dispatching and loading cost, the transportation cost for driving and the retailer delivery (or unloading) cost) [in euros]

H cost of holding one unit of product one day either in the depot or in the retailers' warehouses [in euros/(unit·day)]

S fixed cost for replenishing the depot [in euros]

Dem_r demand of each route r [in units]

T_r optimal cycle time for replenishment of a route r [in days]

D_r duration to complete a given route r [in hours]

M maximum number of driving hours per day

K product capacity of each vehicle [in units]

The decision variables used in the model are presented in the same way as the data.

$X_{r\,v\,d}$ indicates whether or not the route *r* is done by the vehicle *v* on day *d*

Z_v indicates whether or not the vehicle *v* is used in the schedule from the outgoing delivery vehicles list

Y_d indicates de number of incoming delivery vehicles needed for the depot on day *d*

QI_d inbound product quantity in the depot on day *d*

$QO_{r\,d}$ outbound product quantity of the depot to the route *r* on day *d*

ID_d indicates the inventory level of the depot on day *d*

$IR_{r\,d}$ indicates the inventory level of the route *r* on day *d*

6.2. Mathematical model (version 1)

Once the notation is defined a solution for the distribution centre problem can be given. As it is already said, the model will create the schedule that minimizes the sum of all costs of the two-echelon supply chain. The first model takes into account the optimal cycle time for replenishment of each route. This means that each route $r \in R$ will be performed periodically every T_r days respectively.

As all the vehicles have the same characteristics, any of them can perform any of the specified routes. In accordance with the constraints, the binary decision variable $X_{r\,v\,d}$ shows the outgoing vehicles schedule for all the cycle time. It indicates if the route *r* is made by the vehicle *v* on the day *d* or not. From the maximum number of available outgoing vehicles *V* maybe not all of them are needed so the binary variable Z_v specifies which ones are needed.

One enhancement of the model is the existence of a real material flow. Firstly, the product is shipped to the depot where it can be stored or cross-docked. The next step is to transport the goods to the retailers before the deadline (retailers store the product) or on time. To clarify the product balance in the depot and in the routes four integer variables have been created. Two of them define the daily inbound/outbound product quantity deliveries from the depot (QI_d and $QO_{r\,d}$ respectively). With this values the number of vehicles needed is calculated easily. In the case of the outbound quantity $QO_{r\,d}$ the product quantity is scattered in all the possible routes $r \in R$. The other two integer variables indicate the daily inventory level in the depot ID_d or in the route $r \in R$ $IR_{r\,d}$. Moreover, the inventory level variables are defined from an initial condition which is $d = 0$.

The following equations form the first version of the mathematical model. Just below the model a few words of explanation are given for the objective function and for the constraints.

$$Minimize \sum_{v \in V} F \cdot nT \cdot Z_v + \sum_{r \in R} \sum_{v \in V} \sum_{d \in nT} C_r \cdot X_{r\,v\,d} + \sum_{d \in nT} H \cdot ID_d + \sum_{d \in nT} S \cdot Y_d + \sum_{r \in R} \sum_{d \in nT} H \cdot IR_{r\,d} \tag{1}$$

$$Z_{V+1} = 0 \tag{2}$$

$$Z_v \geq Z_{v+1} \quad \forall\, \mathrm{v} \in \mathrm{V} \tag{3}$$

$$ID_0 = 0 \tag{4}$$

$$IR_{r\,0} = IR_{r\,nT} \quad \forall\, \mathrm{r} \in \mathrm{R} \tag{5}$$

$$ID_d = ID_{d-1} - \sum_{r \in R} QO_{r\,d} + QI_d \quad \forall\, \mathrm{d} \in \mathrm{nT} \tag{6}$$

$$IR_{r\,d} = IR_{r\,d-1} - Dem_r + QO_{r\,d} \quad \begin{cases} \forall\, \mathrm{r} \in \mathrm{R} \\ \forall\, \mathrm{d} \in \mathrm{nT} \end{cases} \tag{7}$$

$$\sum_{v \in V} \sum_{d \in T_r} X_{r\,v\,d} = 1 \quad \forall\, \mathrm{r} \in \mathrm{R} \tag{8}$$

$$\sum_{v \in V} X_{r\,v\,d} = \sum_{v \in V} X_{r\,v\,d+T_r} \quad \begin{cases} \forall\, \mathrm{r} \in \mathrm{R} \\ \forall\, \mathrm{d} \in \{1, \dots, nT - T_r\} \end{cases} \tag{9}$$

$$QI \leq K \cdot Y_d \quad \forall\, \mathrm{d} \in \mathrm{nT} \tag{10}$$

$$QO_{r\,d} \leq \sum_{v \in V} K \cdot X_{r\,v\,d} \quad \begin{cases} \forall\, \mathrm{r} \in \mathrm{R} \\ \forall\, \mathrm{d} \in \mathrm{nT} \end{cases} \tag{11}$$

$$\sum_{r \in R} D_r \cdot X_{r\,v\,d} \leq M \cdot Z_v \quad \begin{cases} \forall\, v \in V \\ \forall\, d \in nT \end{cases} \qquad (12)$$

$$X_{r\,v\,d}, Z_v \in \{0,1\} \quad \begin{cases} \forall\, r \in R \\ \forall\, v \in V \\ \forall\, d \in nT \end{cases} \qquad (13)$$

$$Y_d, QI_d, QO_{r\,d}, ID_d, IR_{r\,d} \geq 0 \quad \begin{cases} \forall\, r \in R \\ \forall\, d \in nT \end{cases} \qquad (14)$$

The objective function (1) is stated as the total amount of costs for the distribution schedule. The considered costs are (according to the order of the terms in the expression):

1. Because the distribution centre requires a vehicle fleet, a daily fixed cost *F* is incurred. The maximum number of outgoing delivery vehicles is limited to *V* vehicles, which takes the same value as the number of routes *R* in each schedule. The fixed cost will be charged proportionally to the total number of outbound shipment vehicles. In this way, even if a vehicle is only used one time in the whole schedule, the cost will be the same as another vehicle that is used all days. Thus, the total fixed cost is defined as the number of vehicles used multiplied by the fixed cost and multiplied by the number of days of the cycle time.

2. The second term of the objective function takes into account the variable cost of making the routes. As described above in the problem formulation, this cost includes the vehicle loading and unloading cost, and the transportation cost for driving. That component is the most sensitive element of the cost as the cost of making the routes increases when the duration (an optimal cycle time) of the route is higher. The total value of the cost is obtained by counting each time a vehicle performs a route and multiplying it by the corresponding C_r cost.

3. The next cost is composed by the third and the last term and denote the entire supply chain inventory holding cost. The first of them indicates the holding cost for the depot and the other term the holding cost for each route *r*. A recount of all units each day of the cycle time in the depot and in each route, multiplied by the unitary holding cost *H* shows the amount of money dedicated to keep the inventory levels.

4. As the capacity of all vehicles is the same, more than one vehicle could be needed for inbound deliveries. The last cost taken into consideration is the fixed cost for replenishing the depot *S* more than once or only once per day. Additionally, the variable Y_d indicates de number of incoming shipment vehicles needed for the depot

every day. Therefore, the total inbound replenishment cost is obtained by multiplying the total number of vehicles needed in the entire cycle time by the replenishing cost.

Because a large list with identical outgoing delivery vehicles is presented, the model takes the needed ones unpredictably. In order to sort them (the used vehicles first), constraints (2) and (3) are introduced.

In the optimal point, at least one day in the total cycle time the inventory level in the depot must be equal to 0. Constraint (4) takes that day as the initial conditions (day 0) of the cycle time. On the other hand, the lack of inventory in the distribution centre does not mean that the inventory level of any route should be null. In this way, none constraint fixes the inventory level of the routes but equation (5) matches the inventory levels of two consecutive cycles.

Both material balance restrictions (6) and (7) represent the two types of material flow in a warehouse of the problem. The daily material balance is expressed as: the inbound deliveries in a warehouse in a day (in the routes' warehouses is the quantity of outbound products per route) plus the inventory level in the previous day must be equal than the outbound deliveries in the day plus the inventory level at the end of that day. Constraint number (6) represents the material balance in the depot. Similarly, constraints (7) are the material balances in the warehouses of each route.

The total cycle time is established on the basis of the optimal cycle time for replenishment of all the routes. Constraints (8) and (9) ensure the periodicity of all routes in the schedule as follows. Firstly, equation (8) implies that each route has to be done once during the optimal cycle time of each route $r \in R$. Furthermore, restriction (9) schedules each route replenishments equidistantly in time. The result is a rigorously periodical plan replenishment for each route every T_r days.

Finally, the limit capacity constraints are stated. As it was announced, a limit vehicle capacity restricts all deliveries. Equations (10) (for inbound deliveries) and (11) (for outbound deliveries) show that. The last restriction (12) determines that the total amount of driving time per vehicle does not exceed to the limit of M hours per day.

6.3. Non-periodic mathematical model (version 2)

In this point, a second version of the mathematical model is presented. A non-periodic schedule is assumed now; therefore, the solution is not forced to be repeated following the optimal cycle time of the routes. The possible solutions in the second model increase considerably respect the first one, as the cycle time is not fixed in advanced and lots of combinations can be done. Among all possible solutions, the optimal one of the first model is included. Hence the solution can be the same as in the first mathematical model or better. In contrast, the execution time could rise quite a lot and the solution approach may differ from the optimum or even from the previous solution.

The base of the mathematical model is the same but some adjustments must be done. The first update to the model is that the optimal cycle time T_r is no longer used so there is no need to introduce it into the model. Secondly, constraint (15) replaces constraints (8) and (9) from the previous model.

$$\sum_{v \in V} \sum_{d \in nT} X_{r\,v\,d} \leq nT \quad \forall \, \mathrm{r} \in \mathrm{R} \qquad (15)$$

The equation implies that the number of retail replenishments cannot exceed one per day. The model the one who decides and plans the outbound deliveries according to the minimum total cost.

7. Numerical results

In this section is presented how the datasets and the executions are made and some reflections about how the model works with the involved factors. Also are explained all characteristics about the obtained solutions.

7.1. Design of experiments

Because this model is an extension of the 'Fleet optimization for cyclic inventory routing problems' (B. Raa, 2014) paper, the same set of experiments are used. Then some conclusions of the fleet optimization model could be revalidated for a two-echelon supply chain distribution and so, in a more general context. Additionally, the presented model can come up with extra conclusions not seen in an optimum search for an individual party of the supply chain.

From the initial 10 x 2^4 factorial design used in the fleet optimization model, one of the four factors has been removed. On the other hand, two versions of the model are taken into account and both solutions will be analysed so the final group of experiments is formed by a 2 x 10 x 2^3 factorial design.

A brief explanation of the levels and values of the data is posted below. The majority of the following criteria have been extracted from *B. Raa, 2014*.

The first factor is the duration of individual routes (*dur*). Due to driving time regulations, the maximum number of driving hours is limited to M = 8 h per day. All individual route durations are set between 1 and 8 h. The small level of this factor is composed by probabilities closer to the lower bound and the other way around, the large level means the route length has a higher probability to be nearer the maximum limit. This factor is introduced to approve that the longer individual routes are, the more difficult to combine them into a schedule.

The second factor is the daily fixed cost per vehicle (*vc*). Both small and large levels are F = 20 €/day and F = 100 €/day, respectively. Fixed vehicle cost depends on the type of vehicle used, for example refrigerated vehicles require more expensive equipment than dry cargo ones. The value of that cost may reconsider the number of vehicles needed for outbound deliveries, as the objective functions looks for the minimum total cost.

The third and last factor is the holding cost (*hc*). The two levels of the factor express how much a product unit costs and which is its depreciation. The difference between the both levels can be determinant in order to reschedule the routes and the inventory in each echelon. The high value of holding cost H = 0,10 €/(unit·day) is thought to increase a lot the total holding cost and therefore the total cost. In that case, maybe a new schedule could balance the rising cost. Furthermore, a low value of holding cost H = 0,01 €/(unit·day) is thought to keep the products in the warehouses and take advantage of the tiny cost that represents.

The described factors represent a factorial design with 8 different groups. From each one of them, ten datasets are created so at the end, 80 datasets are available for the execution.

The number of routes (*nr*) per dataset is a number between 5 and 15. The large level in 'Fleet optimization for cyclic inventory routing problems' paper has not been taken into account for the difficulty of the problem. The NP-hard complexity made impossible to get reliable solutions in the high-level factor datasets.

The number of retailers delivered in each route is a random number between 1 and 10. The more retailers there are in a route, the more probable the whole route demand be higher. Demand is randomly generated per retailer and the accumulated value per route must be between 100 and 500 units per day.

Talking about delivery costs can be divided into two groups: outbound and inbound deliveries. On one hand, the transportation cost is fixed to 10 € per driving hour, dispatching and loading a vehicle is considered at a cost of 5 € and the retailer delivery cost is 1 € per customer. The sum of these three costs correspond to the cost of making a route (C_r) and is related with the outgoing shipments cost. On the other hand, the fixed cost for replenishing the depot (incoming shipments cost) is set to S = 35 € per shipment.

In each example, the capacity of the vehicles K is obtained from multiplying a random integer number (between 1 and nT) by the demand per route. From the R possible values, the higher one is rounded up to a multiple of 50 and this number is the vehicle capacity for that scenario. Additionally, the maximum number of vehicles V is equal to the number of routes in each experiment, thus in the worst-case scenario (all demands very similar to the vehicle capacity), each one will perform one route.

Finally, the optimal cycle time per route T_r is randomly generated between 2 and 12 and in some cases the number has been modified in order not to increase the global cycle time excessively. To obtain the global cycle time nT of the scenario, the least common multiple of all retailers' optimal cycle time is calculated.

From each instance, the two versions of the model are executed (the periodic and non-periodic case). A comparison of both models will be made to establish robustness, reliability and the best results obtained. Hence, the numerical results of the model are obtained from the 160 described scenarios. In the table annex, the solution for each dataset is provided. Moreover, in the last rows is calculated the average of the 80 scenarios depending on the studied factor. The effects and some conclusions of the factors are presented in the following points.

The mathematical model was developed with the IBM ILOG CPLEX Optimization Studio 12.6 software tool. Each dataset was executed with a time limit of 300 seconds. After that, if the optimal solution was not achieved the best solution was printed together with the existing GAP between the current solution and lower bound calculated. All datasets were realized in a Sony VAIO laptop with an Intel® Core™ i7-4500 CPU @ 1.80 GHz 2.39 GHz processor and 8.00 GB of RAM.

7.2. Effect of the route duration (*dur*)

Table 1 shows the cost distribution average of all experiments for the periodic and non-periodic models split into the two levels of the route duration. At first glance, seems that both levels of the factor *duration* (small and large) affect similarly the two proposed models. Furthermore, all obtained averages are higher when a long duration is established. Down below, a deep analysis is done for each model in which the differences among all costs, GAP values and free time of the used vehicles are discussed. Also, a brief conclusions of the factor are presented.

		Fixed vehicle cost	Cost of making the routes	Depot holding cost	Routes holding cost	Fixed shipment cost	**Total Cost**	GAP
Periodic	*Small*	1890.50 €	5215.60 €	33.69 €	2142.79 €	1162.00 €	**10444.58 €**	0.84 %
	Large	4217.00 €	6455.35 €	42.33 €	2560.08 €	1412.25 €	**14687.01 €**	2.19 %
Non-periodic	*Small*	1461.50 €	4795.02 €	25.69 €	2533.92 €	1161.12 €	**9977.25 €**	2.35 %
	Large	2998.00 €	5916.88 €	33.72 €	3119.18 €	1410.50 €	**13478.28 €**	3.74 %

Table 1. Cost distribution and GAP values according to the route duration factor

The first analysed model is the periodic one (version 1). As stated previously in this chapter, the factor *duration* "is introduced to approve that the longer individual routes are, the more difficult are to combine into a schedule". In order to verify that, the daily free time is calculated. Formula (16) indicates the number of free hours of all used vehicles in a day (if one day all vehicles of the schedule are not used, the non-used vehicles are not included in the formula).

$$\frac{\sum_{r\in R}\sum_{v\in V} X_{r\,v\,d}}{\sum_{r\in R}\sum_{v\in V} X_{r\,v\,d}} \cdot M - \sum_{r\in R}\sum_{v\in V} D_r \cdot X_{r\,v\,d} \qquad \left\{ \begin{array}{l} \forall\, d \in nT \\ \forall \sum_{r}\sum_{v} X_{r\,v\,d} \neq 0 \end{array} \right. \qquad (16)$$

Making the average in each scenario, the difficulty of combining the routes in the schedule can be quantified; as the longer routes are, the higher free time will be. The mean average for the small factor shows that the sum of free time of the used vehicles is 4.06 hours per day and the one for the large factor is 4.29 hours per day. Comparing averages, that difficulty in scheduling is hidden behind the trade-off of the associated costs. Is true that free time is almost the same in both factors but the number of used vehicles per schedule is higher in the scenarios with a longer duration (average of 1.67 daily used vehicles versus one of 2.33 vehicles).

	Fixed vehicle cost	Cost of making the routes	Depot holding cost	Routes holding cost	Fixed shipment cost	**Total Cost**
Small	1890.50 € (19 %)	5215.60 € (49 %)	33.69 € (0 %)	2142.79 € (21 %)	1162.00 € (11 %)	**10444.58 €**
Large	4217.00 € (25 %)	6455.35 € (46 %)	42.33 € (1 %)	2560.08 € (18 %)	1412.25 € (10 %)	**14687.01 €**
Diff	123.1 %	23.8 %	25.7 %	19.5 %	21.5 %	**40.6 %**

Table 2. Cost distribution of the periodic model (average of 80 samples)

Table 2 shows the values of all costs related to the level of the duration, as well as the percentage that represents from the total cost and the percentage difference between both levels. This table demonstrates that in long duration scenarios, each cost increases its value respect the short duration of the routes. As expected, the total cost of the large level is higher than the small one (40.6 % higher). This growth is due to the enormous increase of 123.1 % of the fixed vehicle cost. The rest of cost have a percentage participation more or less the same in both factor levels. So, in this model is proved that the longer the durations of the routes are, the schedule cannot do anything else than hire more vehicles.

Moreover, the difference between GAPs is 1.35, a quite positive information as both of them are less than 2.5 %.

The second analysed model is the non-periodic one (version 2). In the same way as in the periodic model analysis, the daily free time is calculated with the formula (16). In this model, the average of free time is lower in all cases. In the small level of the duration, vehicles are not used only 2.68 hours per day. In the large level, the daily free time is raised to 3.20 hours (but is still more than 1 hour less than the periodic model).

Half-hour is not enough to state that one level benefits the more compact schedule so, as in the last analysis, it is calculated the average of daily used vehicles and the distribution of all costs. On average, the used vehicles per day are 1.42 and 2.05 for the small and large durations respectively. This values are lower than the ones obtained in the periodic version.

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	Fixed vehicle cost	Cost of making the routes	Depot holding cost	Routes holding cost	Fixed shipment cost	**Total Cost**
Small	1461.50 € (15 %)	4795.02 € (48 %)	25.69 € (0 %)	2533.92 € (25 %)	1161.12 € (12 %)	**9977.25 €**
Large	2998.00 € (20 %)	5916.88 € (46 %)	33.72 € (0 %)	3119.18 € (23 %)	1410.50 € (11 %)	**13478.28 €**
Diff	105.1 %	23.4 %	31.3 %	23.1 %	21.5 %	**35.1 %**

Table 3. Cost distribution of the non-periodic model (average of 80 samples)

Table 3 states the cost distribution and the difference percentage between the small and the large factor. The highest cost of the distribution is the one of making the routes (as in the previous analysis). Also as in the other case, the fixed vehicle cost is the entry which increases the most; a 105.1 % respect the small factor level. Otherwise, the obtained values of the fixed vehicle costs are lower in the non-periodic model than in the periodic one. The difference between the models is 18 points. Then, is proved again that the longer the durations of the routes are, the overall costs increase, and so, total cost of the schedule increases too (35.1 %).

Besides, the difference between GAPs is 1.39, a similar number than the other model but in this case the values of the GAP are between 2 and 4.

In conclusion, the large level of the factor produces higher overall costs (especially the fixed vehicle cost). In the non-periodic model, total cost values are (in average) better than with the periodic one. Also, the difference between costs is reduced in the second version so the effect of having long route durations is mitigated. GAP values increase with long duration examples too.

7.3. Effect of the vehicle cost (*vc*)

Table 4 is a comparison of the averaged solution values for the two presented models according to the fixed vehicle cost for outbound deliveries. The same pattern is repeated than in the previous factor analysis, the non-periodic model achieves better solutions due to a high reduction of costs in the fixed vehicle and the making routes allocations. It is logic that in both models the cost which increases the most is the fixed vehicle cost, as the only difference between the small and large levels is the fixed daily cost per vehicle. Moreover, all individual costs (except holding costs) respond in a similar way indistinctly to the model used. Unlike the route duration factor (always going up), in the experiments of vehicle cost influence some costs some costs remain equal, some go down and some go up depending on the executed model. Down below all changes for both models are quantified as well as an analysis of the highlight allocations.

		Fixed vehicle cost	Cost of making the routes	Depot holding cost	Routes holding cost	Fixed shipment cost	**Total Cost**	GAP
Periodic	*Small*	1055.00 €	6038.43 €	38.17 €	2330.10 €	1340.50 €	**10802.20 €**	1.66 %
	Large	5052.50 €	5632.53 €	37.85 €	2372.76 €	1233.75 €	**14329.39 €**	1.37 %
Non-periodic	*Small*	857.00 €	5574.67 €	27.13 €	2709.72 €	1342.25 €	**10510.77 €**	3.71 %
	Large	3602.50 €	5137.22 €	32.28 €	2943.38 €	1229.38 €	**12944.76 €**	2.39 %

Table 4. Cost distribution and GAP values according to the vehicle cost factor

A first analysis of the periodic model provides the average of the obtained results (see Table 5). The table shows the proportion that represents each cost from the total and the difference between both factors. As mentioned previously, the most relevant cost is the fixed vehicle one. Whereas in the low factor level (*F* = 20 €/day) this cost represents only a 10 % of the overall cost, in the higher factor level (*F* = 100 €/day) it signifies almost the 35 % of the total cost. The obtained share is not the higher one in any of the cases, but is the most influent cost when switching the level factor. The difference between them is nearly five times higher in the large level (a 378.9 percentage difference). That increment matches with the increase in the vehicle cost level, from 20 to 100 € per day.

What is interesting to point out is the average of used outgoing vehicles in a schedule between both cases, small and large factor level. In the two scenarios the average is 2.58 (small level) and 2.53 (large level) vehicles per plan. As the difference is almost negligible could be underestimated, which means that a higher cost for hiring a vehicle does not reschedule the routes, only the difference of price is payed.

Fixed shipment cost and the cost of making the routes decrease with the high value of *F* 8.0 % and 6.7 % respectively. On the other hand, depot and routes holding costs remain practically identical.

The last thing that can be observed are the GAP values. These are very similar from each other and even in the large level the GAP is lower, so the solution is more probable to be the optimum one.

	Fixed vehicle cost	Cost of making the routes	Depot holding cost	Routes holding cost	Fixed shipment cost	**Total Cost**
Small	1055.00 € (10 %)	6038.43 € (55 %)	38.17 € (0 %)	2330.10 € (22 %)	1340.50 € (13 %)	**10802.20 €**
Large	5052.50 € (34 %)	5632.53 € (40 %)	37.85 € (0 %)	2372.76 € (17 %)	1233.75 € (9 %)	**14329.39 €**
Diff	378.9 %	- 6.7 %	- 0.8 %	1.8 %	- 8.0 %	**32.7 %**

Table 5. Cost distribution of the periodic model (average of 80 samples)

The second analysed model is the non-periodic one (version 2). Table 6 shows the proportion that represents each cost from the total and the difference between the two factors. In the same way as in the periodic analysis, the fixed vehicle cost increases as the factor does. In this case, the increment is slightly more than four times in the large level factor (a 320.4 percentage difference).

The difference from the previous analysis is in the number of vehicles for outbound deliveries in the schedule. On average, the number of used vehicles per schedule is 2.03 for the small level and 1.85 vehicles for the large level. Hence, compared with the results from the periodic study, the non-periodic model has a saving of 0.6 vehicles in the fleet of each schedule. Thanks to this, the assigned cost to outbound shipment vehicles is reduced to the given results.

Depot and routes holding costs increase slightly (19.0 % and 8.6 %) while the cost of making routes and the fixed shipment cost for inbound deliveries go the other way around; they decrease 7.9 % and 8.4 % respectively.

More accurate solutions are achieved with the large level of the factor, as it GAP value is 1.32 points lower than with the small level. In the same way as in the duration of the routes factor, GAP values for the non-periodic model are slightly higher, because the number of solutions checked is also higher and the execution time is limited to 5 minutes for all experiments.

	Fixed vehicle cost	Cost of making the routes	Depot holding cost	Routes holding cost	Fixed shipment cost	**Total Cost**
Small	857.00 € (8 %)	5574.67 € (53 %)	27.13 € (0 %)	2709.72 € (26 %)	1342.25 € (13 %)	**10510.77 €**
Large	3602.50 € (28 %)	5137.22 € (41 %)	32.28 € (0 %)	2943.38 € (21 %)	1229.38 € (10 %)	**12944.76 €**
Diff	320.4 %	- 7.9 %	19.0 %	8.6 %	- 8.4 %	**23.2 %**

Table 6. Cost distribution of the non-periodic model (average of 80 samples)

To sum up, the large level is distinguished from the small one by having a considerable larger fixed vehicle cost. The vehicle fleet is slightly altered by the price of the vehicle and neither the schedule so, the total cost is increased by the difference in the fixed vehicle cost. Hence, rewording the statement of the second factor, the value of the fixed vehicle cost does not reconsider the number of vehicles needed for outbound deliveries; the minimum total cost is obtained with practically the same fleet.

7.4. Effect of the holding cost (*hc*)

The cost distribution and GAP values obtained according to the holding cost levels can be seen in Table 7. Periodic and non-periodic models respond more or less in the same way. As in the other factors analysis, the non-periodic version gets lower overall costs. Particularly in the holding cost analysis, both large scenarios (periodic and non-periodic) provide better solutions: lower total costs with lower GAP values than in small scenarios.

Furthermore, variations in allocations are almost the same in both cases except the fixed vehicle cost, which is strongly reduced. In this case, the highlight difference between costs is the route holding cost. In addition, more characteristics are described for each model below the table.

		Fixed vehicle cost	Cost of making the routes	Depot holding cost	Routes holding cost	Fixed shipment cost	**Total Cost**	GAP
Periodic	*Small*	3302.50 €	6308.50 €	48.94 €	1428.30 €	1612.62 €	**12700.86 €**	2.43 %
	Large	2805.00 €	5362.45 €	27.08 €	3274.58 €	961.63 €	**12430.74 €**	0.60 %
Non-periodic	*Small*	2641.50 €	5746.55 €	37.07 €	1758.40 €	1619.63 €	**11803.15 €**	4.11 %
	Large	1818.00 €	4965.35 €	22.33 €	3894.70 €	952.00 €	**11652.38 €**	1.98 %

Table 7. Cost distribution and GAP values according to the holding cost factor

The periodic model is the first to be analysed. Table 8 provides the averaged results, shows the proportion that represents each cost from the total and the difference between both factors. As mentioned above, the most important cost in this study is the route holding cost. With the low factor level (H = 0,01 €/unit·day) this cost represents only the 12 % of the overall cost otherwise, in the higher factor level (H = 0,1 €/unit·day) it signifies almost the 27 % of the total cost. The obtained share is not the higher one in any of the cases, but is the most influent cost when switching the level factor. The percentage difference between them 129.3 %, a really high growth if it is taken into account that all other costs decrease its values when comparing with the small level of the factor.

That cost reduction compensates the routes holding cost increase and generates the benefits obtained with the large level factor. The cost reduction between the two factors is nearly 300 €, a saving of a 2 %. On the other hand, the GAP vale of the small level is quite higher than the large one, which means that the optimum value could be somewhere below the solution (even below the large level solution).

	Fixed vehicle cost	Cost of making the routes	Depot holding cost	Routes holding cost	Fixed shipment cost	**Total Cost**
Small	3302.50 € (24 %)	6308.50 € (51 %)	48.94 € (0 %)	1428.30 € (12 %)	1612.62 € (13 %)	**12700.86 €**
Large	2805.00 € (20 %)	5362.45 € (45 %)	27.08 € (0 %)	3274.58 € (27 %)	961.63 € (8 %)	**12430.74 €**
Diff	- 15.1 %	- 15.0 %	- 44.7 %	129.3 %	- 41.4 %	**- 2.1 %**

Table 8. Cost distribution of the periodic model (average of 80 samples)

The second analysed model is the non-periodic one. In Table 9 are represented the averaged values for the non-periodic model. As before, the routes holding cost increases as the factor level does. In this case, the increment is slightly higher than previously (2135.30 €). Apart from that holding cost, the rest of distribution are lower than the obtained values from the periodic model.

One of the reasons why the non-periodic model obtained better total costs is the reduction of the fleet for outbound deliveries. On average, 1.92 vehicles are used for the non-periodic version against the 2.55 outgoing vehicles in the periodic model. Also, a better schedule is performed in the second mathematical model, as the leisure time per used vehicle is reduced 1.2 hours per day.

Similarly to the periodic model analysis, more accurate solutions are achieved with the large level of the factor, as it GAP value is 1.98 % and the GAP for the small factor is 4.11 %. In the same way as in all non-periodic analysis, GAP values for the second version model are slightly higher, because the number of solutions checked is also higher and the execution time is limited to the same time for all experiments.

	Fixed vehicle cost	Cost of making the routes	Depot holding cost	Routes holding cost	Fixed shipment cost	**Total Cost**
Small	2641.50 € (22 %)	5746.55 € (49 %)	37.07 € (0 %)	1758.40 € (15 %)	1619.63 € (14 %)	**11803.15 €**
Large	1818.00 € (14 %)	4965.35 € (44 %)	22.33 € (0 %)	3894.70 € (33 %)	952.00 € (9 %)	**11652.38 €**
Diff	- 31.2 %	- 13.6 %	- 39.8 %	121.5 %	- 41.2 %	**- 1.3 %**

Table 9. Cost distribution of the non-periodic model (average of 80 samples)

In conclusion, the third factor deals with the trade-off among costs in a particular way. The high value of the holding cost does increase only the routes holding cost. Not only the rest of costs decrease its values (even depot holding cost), but also the overall sum is lower than with the low price of holding cost rate. Small level total cost solutions are more expensive solutions than with a higher holding cost rate. It is also true that small level GAP values are higher in both models so an optimal solution could be found with more time execution.

7.5. Effect of the periodicity

The analysis of the effect of the periodicity is made with the corresponding 80 samples for both models. Table 10 shows the cost distribution and GAP values for each model (periodic and non-periodic). Also the percentage difference between models is added in the last row.

	Fixed vehicle cost	Cost of making the routes	Depot holding cost	Routes holding cost	Fixed shipment cost	**Total Cost**	GAP
Periodic	3053.75 € (22 %)	5835.48 € (48 %)	38.01 € (0 %)	2351.44 € (19 %)	1287.12 € (11 %)	**12565.80 €**	1.51 %
Non-periodic	2229.75 € (18 %)	5355.95 € (47 %)	29.70 € (0 %)	2826.55 € (24 %)	1285.80 € (11 %)	**11727.77 €**	3.05 %
Diff	- 27.0 %	- 8.2 %	- 21.9 %	20.2 %	0 %	**- 6.7 %**	

Table 10. Cost distribution and GAP values according to the model

At first sight can be established that all costs contribute similarly in both models and that in most allocations the non-periodic model reduces the cost share. The cost of making the routes is the most expensive charge for both models and represents almost half of the overall cost. Actually the second version of the model achieves a solution with an 8 % cost reduction. Next to this cost, fixed vehicle and routes holding costs account for 20 % of the total cost (each one), and share the second position in the most expensive costs. On one side, the fixed price for outgoing vehicles saves a 30 % of its cost as the new schedules allow using less vehicles. On the other side, the cost generated for the stock kept in the routes increases a 20 % as a trade-off between the rest of costs. The cost of shipping incoming products signifies a 10 % of the total cost. As the value is hardly modified, in both models the same inbound delivery strategy is followed. Finally, the stock keeping units from the depot does not affect the full cost of the model. This can be translated as the vast majority of income products are cross-docked the same day, so the holding cost is not charged.

As already said, total cost is reduced with the non-periodic mathematical model by a 6.7 %. This is a very positive result because with the same time of execution, the second version of the model is able to reduce 840 €. Another aspect to keep in mind are the GAP values, the one for the periodic model is still in the confidence interval (1.51 %). On the other hand, the solution of the non-periodic model may still improve; as the Gap is the difference between the given solution and the lower bound calculated by the software, and in this case is 3.05 %.

Another interesting KPI to evaluate the performance of the model is the number of optimum solutions (GAP = 0 %) achieved from the 80 scenarios. With the periodic model, 22 out of 80 datasets were solved optimally in five minutes. With the non-periodic model, only 11 out of 80 got the minimum solution with a null GAP value.

Once analysed both models, the following conclusions can be stated. Both models are robust and reliable, as both of them provide feasible solutions. In the case of the periodic solutions, this one is more likely to be the optimum and also is easier to implement, as all routes are repeated every *X* days (where *X* is the optimal cycle time of each route). However, if it is looked for the minimum total cost, the non-periodic model is the ideal one.

8. Conclusions

Two set of conclusion can be taken once the project is completed. The two sets are presented below.

First set of conclusions: Concerning the model development.

This paper analyses a cyclic planning approach for a two-echelon distribution inventory system. In addition, a first mathematical model optimizes the fleet vehicle size according to the costs involved and the trade-off between the rest of expenses. In this model, the vehicle fleet is used for periodic replenishments regarding the optimal cycle time of each route. A second mathematical model non-periodic is presented in order to see if the optimal cycle time of each route does not fit with the global optimum. This assumption revealed that some route frequencies are altered from optimal values. Even more, some deliveries are performed with a non-periodic frequency, for example a route can be repeated days 1, 4 and 5 from a six-day schedule.

A 10 x 2^3 factorial design of experiments is repeated for both periodic and non-periodic models. Two levels were defined for each one of three presented factors (route duration, fixed cost per vehicle and holding cost rate). The results have been analysed and some factors were noticed to influence more than others in the schedule resolution:

The first studied factor is the duration of the routes. Comparing both small and large factor levels can be seen that all costs increase their values, especially the fixed vehicle cost. Logically, the overall cost also increases its value.

Secondly, the daily fixed cost per vehicle hardly influences the distribution cost. It effects particularly to the fixed vehicle cost, the higher the price per vehicle the higher cost is. Therefore, the total cost for a schedule is also higher with the large level factor of the fixed vehicle cost.

The third factor analysed is the holding cost rate. In this case, the large level of the factor influences not only increasing the routes holding cost, but also decreasing all other allocations. Moreover, the resulting total cost for the large level is lower than for the small one.

Finally, the last considered factor is the routes replenishment frequency. It has been seen that non-periodic solutions get cheaper schedules indistinctly the other factors. Because much more solutions have to be checked in the same time, GAP values are higher in the non-periodic model. One solution to this fact is to give more execution time to this model in order to reduce that value. Another alternative is to perform a warm-start. This means to start the non-periodic execution from the periodic model solution as initial conditions. With this technique, a good improvement of the solution could be done in fewer time. Unfortunately, the complex CPLEX programming language make it difficult to complete it.

Despite the character of this abstract, further applications can arise from the model and a personalization of it can be performed. More constraints can be added such as warehouse capacities, driving regulations or time windows for deliveries. In this problem, retailer clusters are already done and fixed during the schedule. One interesting improvement would be an automatic reorganization of the routes during the schedule and check how the overall cost change. Also, a more realistic situation would be accomplished introducing uncertainty in retailer's demand rates. Since a variability is introduced, safety stocks must be introduced, as well as backorder cost and lead times.

The second set of conclusions are my personal ones:

The main objective of the Master's Dissertation is to formulate and analyse a solution for a specific problem. In this particular case, a big scenario was decomposed in many little goals easy to fix. Personally I am glad to overcome that challenge and how I did achieve it. Withal, I take with me all new specific knowledge and cross skills learned carrying out the project.

The principal difficulty when performing the dissertation was to translate a real complex situation into a model. The first step was meeting all problems concerned in a supply chain environment and then change them into mathematical expressions. Like this, and one by one, all features of the problem were modelled.

9. References

9.1. Books

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9.2. Articles

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9.3. Websites

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Cross-docking. < http://www.ingenieriaindustrialonline.com/herramientas-para-el-ingeniero-industrial/log%C3%ADstica/cross-docking/ >

10. TABLE ANNEX

In the following pages is provided a table with the results of the 160 experiments and some calculations as the percentage of each cost, the average of used vehicles per day and the average of free time per day.

	dataset	R	vc	hc	T	Fixed Vehile cost 1	% Fixed V 1	Route Making cost 1	% Route M 1	Depot Holding cost 1	% Depot H 1	Route Holding cost 1	% Route H 1	Fixed Shipment cost 1	% Fixed S 1	Total Cost 1	GAP 1	av. Vehicle 1	max vehicle 1	min vehicle 1	av. Free time 1	max free time 1	min free time 1
1	nrS-durL-vcL-hcL-0.xlsm	6	100	0,1	30	9.000,00 €	44,15%	6.140,00 €	30,12%	59,50 €	0,29%	4.135,50 €	20,29%	1.050,00 €	5,15%	20.385,00 €	0,93%	1,70	3,00	1,00	6,00	14,90	1,50
	nrS-durL-vcL-hcL-1.xlsm	13	100	0,1	12	4.800,00 €	30,42%	5.912,00 €	37,47%	20,70 €	0,13%	4.274,10 €	27,09%	770,00 €	4,88%	15.776,80 €	0,35%	3,58	4,00	2,00	5,90	11,70	0,70
	nrS-durL-vcL-hcL-2.xlsm	8	100	0,1	12	3.600,00 €	32,66%	4.154,00 €	37,69%	4,00 €	0,04%	2.213,60 €	20,08%	1.050,00 €	9,53%	11.021,60 €	0,00%	2,58	3,00	2,00	4,80	14,10	1,10
	nrS-durL-vcL-hcL-3.xlsm	7	100	0,1	12	3.600,00 €	35,85%	3.649,00 €	36,34%	- €	0,00%	2.233,20 €	22,24%	560,00 €	5,58%	10.042,20 €	0,00%	2,17	3,00	1,00	3,26	7,80	0,10
	nrS-durL-vcL-hcL-4.xlsm	5	100	0,1	12	3.600,00 €	44,46%	2.600,00 €	32,11%	66,20 €	0,82%	1.341,00 €	16,56%	490,00 €	6,05%	8.097,20 €	0,00%	1,92	3,00	1,00	1,92	4,70	0,20
	nrS-durL-vcL-hcL-5.xlsm	14	100	0,1	12	4.800,00 €	29,29%	6.096,00 €	37,19%	- €	0,00%	4.584,00 €	27,97%	910,00 €	5,55%	16.390,00 €	0,50%	3,83	4,00	3,00	7,03	14,90	1,00
	nrS-durL-vcL-hcL-6.xlsm	7	100	0,1	60	18.000,00 €	33,22%	21.063,00 €	38,88%	99,90 €	0,18%	10.467,00 €	19,32%	4.550,00 €	8,40%	54.179,90 €	1,08%	1,97	3,00	0,00	5,36	11,30	0,00
	nrS-durL-vcL-hcL-7.xlsm	14	100	0,1	30	15.000,00 €	32,86%	16.669,00 €	36,51%	112,20 €	0,25%	10.299,00 €	22,56%	3.570,00 €	7,82%	45.650,20 €	9,98%	4,23	5,00	3,00	8,60	16,80	3,20
	nrS-durL-vcL-hcL-8.xlsm	15	100	0,1	12	6.000,00 €	30,90%	7.535,00 €	38,80%	- €	0,00%	4.730,40 €	24,36%	1.155,00 €	5,95%	19.420,40 €	0,30%	4,67	5,00	4,00	8,04	11,90	2,60
	nrS-durL-vcL-hcL-9.xlsm	6	100	0,1	6	1.800,00 €	41,23%	1.447,00 €	33,14%	35,20 €	0,81%	768,90 €	17,61%	315,00 €	7,21%	4.366,10 €	0,00%	2,17	3,00	1,00	5,22	9,80	0,80
2	nrS-durL-vcL-hcS-0.xlsm	6	100	0,01	40	8.000,00 €	53,70%	4.361,00 €	29,27%	- €	0,00%	1.347,40 €	9,04%	1.190,00 €	7,99%	14.898,40 €	0,65%	0,85	2,00	0,00	2,95	9,40	0,00
	nrS-durL-vcL-hcS-1.xlsm	13	100	0,01	30	6.000,00 €	32,34%	7.921,00 €	42,70%	137,43 €	0,74%	2.707,05 €	14,59%	1.785,00 €	9,62%	18.550,48 €	1,37%	1,77	2,00	1,00	2,43	7,60	0,00
	nrS-durL-vcL-hcS-2.xlsm	8	100	0,01	24	7.200,00 €	42,72%	6.998,00 €	41,52%	37,94 €	0,23%	622,00 €	3,69%	1.995,00 €	11,84%	16.852,94 €	0,52%	2,38	3,00	1,00	5,30	9,10	1,00
	nrS-durL-vcL-hcS-3.xlsm	7	100	0,01	60	18.000,00 €	54,33%	9.997,00 €	30,17%	55,15 €	0,17%	2.698,65 €	8,15%	2.380,00 €	7,18%	33.130,80 €	18,94%	1,20	3,00	0,00	1,77	7,80	0,00
	nrS-durL-vcL-hcS-4.xlsm	5	100	0,01	30	6.000,00 €	51,12%	3.820,00 €	32,54%	60,34 €	0,51%	807,52 €	6,88%	1.050,00 €	8,95%	11.737,86 €	1,22%	1,13	2,00	0,00	1,10	3,50	0,00
	nrS-durL-vcL-hcS-5.xlsm	14	100	0,01	24	4.800,00 €	32,17%	6.044,00 €	40,51%	74,28 €	0,50%	2.357,88 €	15,80%	1.645,00 €	11,02%	14.921,16 €	1,59%	1,79	2,00	1,00	2,73	7,80	0,10
	nrS-durL-vcL-hcS-6.xlsm	7	100	0,01	24	4.800,00 €	32,66%	7.602,00 €	51,73%	15,16 €	0,10%	633,84 €	4,31%	1.645,00 €	11,19%	14.696,00 €	0,37%	1,58	2,00	0,00	3,66	7,60	0,00
	nrS-durL-vcL-hcS-7.xlsm	14	100	0,01	12	3.600,00 €	33,55%	5.127,00 €	47,79%	26,01 €	0,24%	645,90 €	6,02%	1.330,00 €	12,40%	10.728,91 €	0,47%	2,75	3,00	2,00	3,11	7,30	0,10
	nrS-durL-vcL-hcS-8.xlsm	15	100	0,01	24	7.200,00 €	34,53%	9.431,00 €	45,23%	61,43 €	0,29%	1.953,27 €	9,37%	2.205,00 €	10,58%	20.850,70 €	6,23%	2,83	3,00	2,00	4,41	7,40	1,80
	nrS-durL-vcL-hcS-9.xlsm	6	100	0,01	30	9.000,00 €	52,37%	5.887,00 €	34,26%	120,04 €	0,70%	707,06 €	4,11%	1.470,00 €	8,55%	17.184,10 €	0,91%	1,87	3,00	1,00	5,11	10,30	0,50
3	nrS-durL-vcS-hcL-0.xlsm	6	20	0,1	30	1.800,00 €	13,65%	6.140,00 €	46,57%	59,50 €	0,45%	4.135,50 €	31,37%	1.050,00 €	7,96%	13.185,00 €	4,76%	1,53	3,00	1,00	4,67	12,40	1,50
	nrS-durL-vcS-hcL-1.xlsm	13	20	0,1	12	960,00 €	8,05%	6.065,00 €	50,83%	32,80 €	0,27%	4.104,60 €	34,40%	770,00 €	6,45%	11.932,40 €	0,37%	3,50	4,00	2,00	4,71	13,60	0,80
	nrS-durL-vcS-hcL-2.xlsm	8	20	0,1	12	720,00 €	8,84%	4.154,00 €	51,02%	5,40 €	0,07%	2.212,20 €	27,17%	1.050,00 €	12,90%	8.141,60 €	0,00%	2,58	3,00	2,00	4,80	10,80	1,30
	nrS-durL-vcS-hcL-3.xlsm	7	20	0,1	12	720,00 €	10,08%	3.464,00 €	48,51%	33,00 €	0,46%	2.398,80 €	33,59%	525,00 €	7,35%	7.140,80 €	0,00%	2,33	3,00	1,00	5,22	11,90	0,60
	nrS-durL-vcS-hcL-4.xlsm	5	20	0,1	12	720,00 €	13,80%	2.600,00 €	49,84%	52,20 €	1,00%	1.355,00 €	25,97%	490,00 €	9,39%	5.217,20 €	0,00%	1,92	3,00	1,00	1,92	4,70	0,20
	nrS-durL-vcS-hcL-5.xlsm	14	20	0,1	12	960,00 €	7,68%	6.232,00 €	49,86%	6,30 €	0,05%	4.425,60 €	35,41%	875,00 €	7,00%	12.498,90 €	0,52%	3,83	4,00	3,00	6,90	12,00	2,10
	nrS-durL-vcS-hcL-6.xlsm	7	20	0,1	12	480,00 €	6,20%	4.326,00 €	55,87%	31,30 €	0,40%	1.995,60 €	25,77%	910,00 €	11,75%	7.742,90 €	0,00%	1,67	2,00	1,00	2,62	7,10	0,10
	nrS-durL-vcS-hcL-7.xlsm	14	20	0,1	6	480,00 €	7,29%	3.285,00 €	49,88%	23,40 €	0,36%	2.132,70 €	32,38%	665,00 €	10,10%	6.586,10 €	0,00%	3,67	4,00	3,00	4,42	9,10	0,80
	nrS-durL-vcS-hcL-8.xlsm	15	20	0,1	12	1.200,00 €	8,19%	7.535,00 €	51,44%	5,70 €	0,04%	4.752,00 €	32,44%	1.155,00 €	7,89%	14.647,70 €	0,52%	4,50	5,00	3,00	6,71	12,20	1,20
	nrS-durL-vcS-hcL-9.xlsm	6	20	0,1	6	360,00 €	12,30%	1.447,00 €	49,45%	35,20 €	1,20%	768,90 €	26,28%	315,00 €	10,77%	2.926,10 €	0,00%	2,33	3,00	1,00	6,55	9,80	2,20
4	nrS-durL-vcS-hcS-0.xlsm	6	20	0,01	30	1.200,00 €	19,06%	3.172,00 €	50,39%	- €	0,00%	1.048,05 €	16,65%	875,00 €	13,90%	6.295,05 €	0,73%	0,80	2,00	0,00	2,69	11,80	0,00
	nrS-durL-vcS-hcS-1.xlsm	13	20	0,01	36	2.160,00 €	12,19%	10.368,00 €	58,51%	77,16 €	0,44%	2.875,77 €	16,23%	2.240,00 €	12,64%	17.720,93 €	12,78%	1,94	6,00	0,00	4,40	14,00	0,00
	nrS-durL-vcS-hcS-2.xlsm	8	20	0,01	24	1.440,00 €	12,98%	6.998,00 €	63,09%	29,74 €	0,27%	630,20 €	5,68%	1.995,00 €	17,98%	11.092,94 €	0,78%	2,29	3,00	1,00	4,63	9,10	1,00
	nrS-durL-vcS-hcS-3.xlsm	7	20	0,01	60	3.600,00 €	19,06%	9.853,00 €	52,16%	46,92 €	0,25%	2.976,23 €	15,75%	2.415,00 €	12,78%	18.891,15 €	8,98%	1,20	3,00	0,00	1,88	9,70	0,00
	nrS-durL-vcS-hcS-4.xlsm	5	20	0,01	24	960,00 €	16,88%	3.226,00 €	56,72%	42,24 €	0,74%	619,34 €	10,89%	840,00 €	14,77%	5.687,58 €	1,56%	1,17	2,00	0,00	1,10	3,50	0,00
	nrS-durL-vcS-hcS-5.xlsm	14	20	0,01	18	1.080,00 €	11,69%	5.438,00 €	58,88%	7,56 €	0,08%	1.484,64 €	16,08%	1.225,00 €	13,26%	9.235,20 €	4,92%	2,28	3,00	1,00	3,96	9,70	1,40
	nrS-durL-vcS-hcS-6.xlsm	7	20	0,01	24	960,00 €	8,84%	7.602,00 €	70,03%	16,50 €	0,15%	632,50 €	5,83%	1.645,00 €	15,15%	10.856,00 €	0,89%	1,58	2,00	0,00	3,66	7,60	0,00
	nrS-durL-vcS-hcS-7.xlsm	14	20	0,01	24	1.440,00 €	9,22%	10.115,00 €	64,74%	38,90 €	0,25%	1.369,53 €	8,77%	2.660,00 €	17,03%	15.623,43 €	0,87%	2,96	3,00	2,00	5,10	8,50	0,30
	nrS-durL-vcS-hcS-8.xlsm	15	20	0,01	24	1.440,00 €	9,54%	9.334,00 €	61,85%	93,68 €	0,62%	2.018,23 €	13,37%	2.205,00 €	14,61%	15.090,91 €	2,92%	2,75	3,00	2,00	3,86	7,30	0,40
	nrS-durL-vcS-hcS-9.xlsm	6	20	0,01	30	1.200,00 €	14,84%	4.407,00 €	54,49%	70,32 €	0,87%	940,68 €	11,63%	1.470,00 €	18,18%	8.088,00 €	1,39%	1,33	2,00	0,00	3,28	9,20	0,00
5	nrS-durS-vcL-hcL-0.xlsm	10	100	0,1	12	3.600,00 €	29,19%	4.774,00 €	38,71%	39,80 €	0,32%	3.255,20 €	26,39%	665,00 €	5,39%	12.334,00 €	0,62%	2,42	3,00	2,00	5,30	8,70	1,40
	nrS-durS-vcL-hcL-1.xlsm	9	100	0,1	6	1.200,00 €	23,93%	2.230,00 €	44,47%	- €	0,00%	1.164,60 €	23,22%	420,00 €	8,38%	5.014,60 €	0,00%	1,83	2,00	1,00	5,33	9,40	0,60
	nrS-durS-vcL-hcL-2.xlsm	6	100	0,1	12	2.400,00 €	30,15%	3.251,00 €	40,84%	12,00 €	0,15%	1.736,40 €	21,82%	560,00 €	7,04%	7.959,40 €	0,00%	1,67	2,00	1,00	4,66	10,10	1,00
	nrS-durS-vcL-hcL-3.xlsm	11	100	0,1	6	1.200,00 €	18,34%	3.026,00 €	46,26%	- €	0,00%	1.825,80 €	27,91%	490,00 €	7,49%	6.541,80 €	0,00%	2,00	2,00	2,00	3,07	5,90	0,70
	nrS-durS-vcL-hcL-4.xlsm	7	100	0,1	12	2.400,00 €	28,35%	3.501,00 €	41,36%	11,60 €	0,14%	1.956,60 €	23,12%	595,00 €	7,03%	8.464,20 €	0,00%	1,33	2,00	0,00	4,66	8,20	0,00
	nrS-durS-vcL-hcL-5.xlsm	9	100	0,1	12	2.400,00 €	22,43%	4.708,00 €	43,99%	32,00 €	0,30%	2.756,40 €	25,76%	805,00 €	7,52%	10.701,40 €	0,00%	2,00	2,00	2,00	4,35	7,50	2,50
	nrS-durS-vcL-hcL-6.xlsm	12	100	0,1	12	3.600,00 €	27,56%	5.042,00 €	38,59%	27,90 €	0,21%	3.274,80 €	25,07%	1.120,00 €	8,57%	13.064,70 €	0,52%	2,67	3,00	2,00	6,40	11,80	0,50
	nrS-durS-vcL-hcL-7.xlsm	12	100	0,1	12	2.400,00 €	20,18%	5.220,00 €	43,89%	17,80 €	0,15%	3.416,20 €	28,72%	840,00 €	7,06%	11.894,00 €	0,16%	2,00	2,00	2,00	3,67	5,70	1,30
	nrS-durS-vcL-hcL-8.xlsm	14	100	0,1	12	4.800,00 €	29,68%	6.343,00 €	39,22%	10,60 €	0,07%	4.037,40 €	24,97%	980,00 €	6,06%	16.171,00 €	0,21%	3,50	4,00	3,00	6,89	14,00	4,80
	nrS-durS-vcL-hcL-9.xlsm	6	100	0,1	12	2.400,00 €	38,07%	2.191,00 €	34,76%	13,90 €	0,22%	1.278,60 €	20,28%	420,00 €	6,66%	6.303,50 €	0,00%	1,42	2,00	1,00	4,66	11,60	1,80
6	nrS-durS-vcL-hcS-0.xlsm	10	100	0,01	24	4.800,00 €	35,87%	5.890,00 €	44,02%	32,44 €	0,24%	1.363,16 €	10,19%	1.295,00 €	9,68%	13.380,60 €	1,23%	1,38	2,00	0,00	2,33	5,90	0,00
	nrS-durS-vcL-hcS-1.xlsm	9	100	0,01	18	1.800,00 €	23,14%	3.856,00 €	49,57%	19,79 €	0,25%	913,47 €	11,74%	1.190,00 €	15,30%	7.779,26 €	0,99%	1,00	1,00	1,00	2,80	6,10	0,50
	nrS-durS-vcL-hcS-2.xlsm	6	100	0,01	9	900,00 €	28,13%	1.623,00 €	50,73%	35,43 €	1,11%	291,03 €	9,10%	350,00 €	10,94%	3.199,46 €	0,00%	1,00	1,00	1,00	1,86	3,20	0,40
	nrS-durS-vcL-hcS-3.xlsm	11	100	0,01	24	4.800,00 €	30,55%	7.413,00 €	47,17%	50,92 €	0,32%	1.525,44 €	9,71%	1.925,00 €	12,25%	15.714,36 €	0,71%	1,50	2,00	1,00	4,61	9,10	0,60
	nrS-durS-vcL-hcS-4.xlsm	7	100	0,01	18	1.800,00 €	27,79%	3.275,00 €	50,57%	8,11 €	0,13%	623,58 €	9,63%	770,00 €	11,89%	6.476,69 €	0,09%	0,56	1,00	0,00	1,03	6,40	0,00
	nrS-durS-vcL-hcS-5.xlsm	9	100	0,01	12	2.400,00 €	36,31%	2.880,00 €	43,58%	28,06 €	0,42%	600,90 €	9,09%	700,00 €	10,59%	6.608,96 €	0,65%	1,42	2,00	0,00	3,83	9,40	0,00
	nrS-durS-vcL-hcS-6.xlsm	12	100	0,01	12	2.400,00 €	32,23%	3.279,00 €	44,04%	26,41 €	0,35%	690,55 €	9,27%	1.050,00 €	14,10%	7.445,96 €	0,62%	1,75	2,00	1,00	3,68	5,60	0,60
	nrS-durS-vcL-hcS-7.xlsm	12	100	0,01	24	4.800,00 €	35,48%	5.427,00 €	40,12%	58,84 €	0,43%	1.807,10 €	13,36%	1.435,00 €	10,61%	13.527,94 €	1,13%	1,38	2,00	0,00	5,05	10,00	0,00
	nrS-durS-vcL-hcS-8.xlsm	14	100	0,01	24	4.800,00 €	30,27%	7.095,00 €	44,74%	78,60 €	0,50%	1.960,08 €	12,36%	1.925,00 €	12,14%	15.858,68 €	1,26%	1,88	2,00	1,00	3,27	7,90	0,40
	nrS-durS-vcL-hcS-9.xlsm	6	100	0,01	24	2.400,00 €	41,00%	1.824,00 €	31,16%	24,48 €	0,42%	905,76 €	15,47%	700,00 €	11,96%	5.854,24 €	1,05%	0,54	1,00	0,00	1,57	6,10	0,00
7	nrS-durS-vcS-hcL-0.xlsm	10	20	0,1	12	720,00 €	7,62%	4.774,00 €	50,50%	39,80 €	0,42%	3.255,20 €	34,43%	665,00 €	7,03%	9.454,00 €	0,54%	2,50	3,00	2,00	5,97	10,60	1,40
	nrS-durS-vcS-hcL-1.xlsm	9	20	0,1	6	240,00 €	5,92%	2.230,00 €	55,00%	- €	0,00%	1.164,60 €	28,72%	420,00 €	10,36%	4.054,60 €	0,00%	1,83	2,00	1,00	5,33	7,40	0,20
	nrS-durS-vcS-hcL-2.xlsm	6	20	0,1	12	480,00 €	7,95%	3.251,00 €	53,83%	12,00 €	0,20%	1.736,40 €	28,75%	560,00 €	9,27%	6.039,40 €	0,00%	1,50	2,00	1,00	3,33	10,10	1,00
	nrS-durS-vcS-hcL-3.xlsm	11	20	0,1	6	240,00 €	4,30%	3.026,00 €	54,21%	- €	0,00%	1.825,80 €	32,71%	490,00 €	8,78%	5.581,80 €	0,00%	2,00	2,00	2,00	3,07	5,30	1,30
	nrS-durS-vcS-hcL-4.xlsm	7	20	0,1	60	2.400,00 €	7,35%	16.914,00 €	51,80%	94,60 €	0,29%	10.196,60 €	31,23%	3.045,00 €	9,33%	32.650,20 €	1,78%	1,30	2,00	0,00	4,78	13,40	0,00
	nrS-durS-vcS-hcL-5.xlsm	9	20	0,1	12	480,00 €	5,47%	4.708,00 €	53,61%	20,60 €	0,23%	2.767,80 €	31,52%	805,00 €	9,17%	8.781,40 €	0,00%	2,00	2,00	2,00	4,35	7,50	2,50
	nrS-durS-vcS-hcL-6.xlsm	12	20	0,1	12	720,00 €	7,07%	5.042,00 €	49,51%	27,90 €	0,27%	3.274,80 €	32,15%	1.120,00 €	11,00%	10.184,70 €	0,69%	2,67	3,00	2,00	6,40	11,80	0,50
	nrS-durS-vcS-hcL-7.xlsm	12	20	0,1	12	480,00 €	4,81%	5.220,00 €	52,34%	17,80 €	0,18%	3.416,20 €	34,25%	840,00 €	8,42%	9.974,00 €	0,19%	2,00	2,00	2,00	3,67	5,70	1,30
	nrS-durS-vcS-hcL-8.xlsm	14	20	0,1	12	960,00 €	7,79%	6.343,00 €	51,45%	8,70 €	0,07%	4.037,40 €	32,75%	980,00 €	7,95%	12.329,10 €	0,07%	3,83	4,00	3,00	9,56	14,50	5,80
	nrS-durS-vcS-hcL-9.xlsm	6	20	0,1	12	480,00 €	10,95%	2.191,00 €	49,98%	13,90 €	0,32%	1.278,60 €	29,17%	420,00 €	9,58%	4.383,50 €	0,00%	1,42	2,00	1,00	4,66	11,90	1,50
8	nrS-durS-vcS-hcS-0.xlsm	10	20	0,01	60	2.400,00 €	10,23%	14.218,00 €	60,61%	110,00 €	0,47%	3.369,90 €	14,37%	3.360,00 €	14,32%	23.457,90 €	6,40%	1,48	2,00	1,00	3,37	8,40	0,40
	nrS-durS-vcS-hcS-1.xlsm	9	20	0,01	18	360,00 €	5,68%	3.856,00 €	60,83%	19,79 €	0,31%	913,47 €	14,41%	1.190,00 €	18,77%	6.339,26 €	1,03%	1,00	1,00	1,00	2,80	6,10	0,50
	nrS-durS-vcS-hcS-2.xlsm	6	20	0,01	36	720,00 €	7,98%	5.427,00 €	60,14%	63,98 €	0,71%	1.413,39 €	15,66%	1.400,00 €	15,51%	9.024,37 €	0,94%	0,83	1,00	0,00	1,62	3,20	0,00
	nrS-durS-vcS-hcS-3.xlsm	11	20	0,01	24	960,00 €	8,09%	7.413,00 €	62,45%	47,45 €	0,40%	1.525,44 €	12,85%	1.925,00 €	16,22%	11.870,89 €	0,85%	1,54	2,00	0,00	4,95	12,80	0,00
	nrS-durS-vcS-hcS-4.xlsm	7	20	0,01	40	800,00 €	6,97%	7.347,00 €	63,97%	73,60 €	0,64%	1.550,12 €	13,50%	1.715,00 €	14,93%	11.485,72 €	0,74%	0,70	1,00	0,00	2,36	7,00	0,00
	nrS-durS-vcS-hcS-5.xlsm	9	20	0,01	24	960,00 €	10,28%	5.673,00 €	60,73%	25,80 €	0,28%	1.246,92 €	13,35%	1.435,00 €	15,36%	9.340,72 €	1,23%	1,33	2,00	1,00	3,24	9,60	0,70
	nrS-durS-vcS-hcS-6.xlsm	12	20	0,01	12	480,00 €	8,70%	3.279,00 €	59,41%	20,69 €	0,37%	689,14 €	12,49%	1.050,00 €	19,03%	5.518,83 €	0,75%	1,75	2,00	0,00	3,68	12,90	0,00
	nrS-durS-vcS-hcS-7.xlsm	12	20	0,01	18	360,00 €	4,93%	4.462,00 €	61,07%	39,48 €	0,54%	1.219,35 €	16,69%	1.225,00 €	16,77%	7.305,83 €	0,82%	1,00	1,00	1,00	1,21	2,90	0,00
	nrS-durS-vcS-hcS-8.xlsm	14	20	0,01	60	3.600,00 €	11,32%	18.627,00 €	58,59%	182,74 €	0,57%	4.518,24 €	14,21%	4.865,00 €	15,30%	31.792,98 €	6,67%	2,27	3,00	1,00	5,92	14,50	1,80
	nrS-durS-vcS-hcS-9.xlsm	6	20	0,01	24	480,00 €	12,25%	1.775,00 €	45,29%	- €	0,00%	929,04 €	23,71%	735,00 €	18,75%	3.919,04 €	1,76%	0,71	1,00	0,00	2,98	6,10	0,00

	R	vc	hc	T	Fixed Vehile cost 1	% Fixed V 1	Route Making cost 1	% Route M 1	Depot Holding cost 1	% Depot H 1	Route Holding cost 1	% Route H 1	Fixed Shipment cost 1	% Fixed S 1	Total Cost 1	GAP 1	av. Vehicle 1	max vehicle 1	min vehicle 1	av. Free time 1	max free time 1	min free time 1
durS					1.890,50 €	18,61%	5.215,60 €	49,33%	33,69 €	0,30%	2.142,79 €	20,60%	1.162,00 €	11,16%	**10.444,57 €**	0,84%	1,67	2,00	1,05	4,06	8,61	0,90
durL					4.217,00 €	25,12%	6.455,35 €	46,20%	42,33 €	0,35%	2.560,08 €	18,14%	1.412,25 €	10,18%	**14.687,02 €**	2,19%	2,33	3,10	1,25	4,29	9,74	0,72
Diff					-123,06%		-23,77%		-25,66%		-19,47%		-21,54%		**-40,62%**							
vcS		20			1.055,00 €	9,65%	6.038,43 €	55,24%	38,17 €	0,36%	2.330,11 €	22,31%	1.340,50 €	12,44%	**10.802,20 €**	1,66%	2,00	2,58	1,13	4,16	9,39	0,82
vcL		100			5.052,50 €	34,08%	5.632,53 €	40,29%	37,85 €	0,29%	2.372,76 €	16,43%	1.233,75 €	8,90%	**14.329,39 €**	1,37%	2,00	2,53	1,18	4,19	8,96	0,80
Diff					-378,91%		6,72%		0,82%		-1,83%		7,96%		**-32,65%**							
hcS			0,01		3.302,50 €	24,02%	6.308,50 €	50,63%	48,94 €	0,39%	1.428,30 €	11,60%	1.612,63 €	13,35%	**12.700,86 €**	2,43%	1,54	2,15	0,60	3,23	8,04	0,31
hcL			0,1		2.805,00 €	19,71%	5.362,45 €	44,90%	27,08 €	0,26%	3.274,58 €	27,15%	961,63 €	7,99%	**12.430,74 €**	0,60%	2,46	2,95	1,70	5,12	10,32	1,30
Diff					15,06%		15,00%		44,65%		-129,26%		40,37%		**2,13%**							
model1					3.053,75 €	21,87%	5.835,48 €	47,76%	38,01 €	0,32%	2.351,44 €	19,37%	1.287,13 €	10,67%	**12.565,80 €**	1,51%	2,00	2,55	1,15	4,17	9,18	0,81
model2					2.229,75 €	17,89%	5.355,95 €	46,85%	29,70 €	0,23%	2.826,55 €	23,70%	1.285,81 €	11,34%	**11.727,77 €**	3,05%	1,73	1,94	1,16	2,94	7,03	0,45
Diff					26,98%		8,22%		21,85%		-20,21%		0,10%		**6,67%**							

Fixed Vehile cost 2	% Fixed V 2	Route Making cost 2	% Route M 2	Depot Holding cost 2	% Depot H 2	Route Holding cost 2	% Route H 1	Fixed Shipment cost 2	% Fixed S 1	Total Cost 2	GAP 2	av. Vehicle 2	max vehicle 2	min vehicle 2	av. Free time 2	max free time 2	min free time 2
3.000,00 €	20,76%	5.615,00 €	38,85%	83,00 €	0,57%	4.704,00 €	32,55%	1.050,00 €	7,27%	14.452,00 €	2,04%	1,00	1,00	1,00	1,28	5,50	0,00
3.600,00 €	24,41%	5.499,00 €	37,29%	3,40 €	0,02%	4.838,90 €	32,81%	805,00 €	5,46%	14.746,30 €	3,52%	3,00	3,00	3,00	3,18	7,60	1,00
3.600,00 €	32,69%	4.131,00 €	37,51%	2,00 €	0,02%	2.228,60 €	20,24%	1.050,00 €	9,54%	11.011,60 €	1,37%	2,67	3,00	2,00	5,24	13,20	1,30
2.400,00 €	27,02%	3.428,00 €	38,60%	22,60 €	0,25%	2.505,90 €	28,21%	525,00 €	5,91%	8.881,50 €	1,61%	1,92	2,00	1,00	2,02	6,20	0,20
2.400,00 €	34,89%	2.600,00 €	37,79%	40,40 €	0,59%	1.384,10 €	20,12%	455,00 €	6,61%	6.879,50 €	1,11%	1,92	2,00	1,00	1,92	3,50	0,20
3.600,00 €	23,08%	5.476,00 €	35,11%	6,80 €	0,04%	5.604,00 €	35,93%	910,00 €	5,83%	15.596,80 €	4,76%	3,00	3,00	3,00	3,78	7,40	0,80
12.000,00 €	24,32%	20.293,00 €	41,13%	182,50 €	0,37%	12.525,20 €	25,39%	4.340,00 €	8,80%	49.340,70 €	13,09%	1,75	2,00	0,00	4,00	11,90	0,00
9.000,00 €	21,05%	13.842,00 €	32,38%	139,00 €	0,33%	16.377,10 €	38,31%	3.395,00 €	7,94%	42.753,10 €	10,45%	2,97	3,00	2,00	3,56	8,30	1,00
3.600,00 €	20,26%	5.742,00 €	32,32%	8,10 €	0,05%	7.156,90 €	40,28%	1.260,00 €	7,09%	17.767,00 €	2,48%	3,00	3,00	3,00	2,15	4,20	0,50
1.200,00 €	31,80%	1.322,00 €	35,04%	5,80 €	0,15%	930,30 €	24,66%	315,00 €	8,35%	3.773,10 €	0,00%	1,67	2,00	1,00	2,47	7,30	0,50
4.000,00 €	37,03%	4.213,00 €	39,00%	20,60 €	0,19%	1.413,56 €	13,09%	1.155,00 €	10,69%	10.802,16 €	1,21%	0,63	1,00	0,00	1,32	3,80	0,00
6.000,00 €	33,10%	7.216,00 €	39,80%	61,66 €	0,34%	3.031,92 €	16,72%	1.820,00 €	10,04%	18.129,58 €	2,46%	1,73	2,00	0,00	3,15	7,80	0,00
4.800,00 €	33,93%	6.520,00 €	46,08%	15,12 €	0,11%	782,66 €	5,53%	2.030,00 €	14,35%	14.147,78 €	1,57%	2,00	2,00	2,00	3,33	7,40	0,30
12.000,00 €	44,13%	9.196,00 €	33,82%	84,08 €	0,31%	3.566,47 €	13,12%	2.345,00 €	8,62%	27.191,55 €	3,72%	1,17	2,00	0,00	2,26	9,60	0,00
6.000,00 €	52,21%	3.523,00 €	30,66%	17,41 €	0,15%	900,57 €	7,84%	1.050,00 €	9,14%	11.490,98 €	2,42%	1,03	2,00	0,00	0,99	3,50	0,00
4.800,00 €	31,45%	6.059,00 €	39,70%	109,83 €	0,72%	2.682,01 €	17,57%	1.610,00 €	10,55%	15.260,84 €	5,93%	1,92	2,00	1,00	3,71	8,70	0,70
4.800,00 €	34,52%	6.680,00 €	48,03%	23,32 €	0,17%	758,33 €	5,45%	1.645,00 €	11,83%	13.906,65 €	1,00%	1,63	2,00	1,00	4,75	9,70	0,30
3.600,00 €	33,93%	4.965,00 €	46,80%	16,77 €	0,16%	697,01 €	6,57%	1.330,00 €	12,54%	10.608,78 €	0,61%	3,00	3,00	3,00	5,46	11,10	1,20
7.200,00 €	35,05%	8.742,00 €	42,56%	41,55 €	0,20%	2.318,34 €	11,29%	2.240,00 €	10,90%	20.541,89 €	1,78%	2,58	3,00	1,00	3,62	7,40	1,10
3.000,00 €	30,59%	4.111,00 €	41,92%	0,00 €	0,00%	1.155,30 €	11,78%	1.540,00 €	15,70%	9.806,30 €	3,43%	1,00	1,00	1,00	1,10	6,50	0,30
600,00 €	4,99%	5.615,00 €	46,72%	- €	0,00%	4.754,50 €	39,56%	1.050,00 €	8,74%	12.019,50 €	1,93%	1,00	1,00	1,00	1,28	4,40	0,00
720,00 €	6,06%	5.453,00 €	45,87%	11,20 €	0,09%	4.899,30 €	41,21%	805,00 €	6,77%	11.888,50 €	2,49%	3,00	3,00	3,00	3,06	8,50	1,30
720,00 €	8,87%	4.184,00 €	51,54%	1,40 €	0,02%	2.163,20 €	26,64%	1.050,00 €	12,93%	8.118,60 €	1,12%	2,58	3,00	2,00	4,47	10,00	1,30
480,00 €	6,90%	3.428,00 €	49,24%	22,60 €	0,32%	2.505,90 €	36,00%	525,00 €	7,54%	6.961,50 €	1,36%	1,92	2,00	1,00	2,02	6,20	0,20
480,00 €	9,68%	2.600,00 €	52,42%	40,40 €	0,81%	1.384,10 €	27,91%	455,00 €	9,17%	4.959,50 €	1,06%	1,92	2,00	1,00	1,92	3,50	0,20
960,00 €	7,61%	6.131,00 €	48,59%	28,60 €	0,23%	4.657,90 €	36,92%	840,00 €	6,66%	12.617,50 €	3,23%	3,83	4,00	3,00	7,58	13,80	2,90
480,00 €	6,25%	4.266,00 €	55,53%	12,00 €	0,16%	2.083,80 €	27,13%	840,00 €	10,93%	7.681,80 €	0,86%	1,75	2,00	1,00	3,45	7,10	0,10
480,00 €	7,31%	3.187,00 €	48,56%	- €	0,00%	2.231,10 €	33,99%	665,00 €	10,13%	6.563,10 €	0,57%	3,83	4,00	3,00	6,55	10,10	2,20
960,00 €	6,61%	7.098,00 €	48,87%	2,40 €	0,02%	5.275,20 €	36,32%	1.190,00 €	8,19%	14.525,60 €	1,89%	4,00	4,00	4,00	4,52	7,80	1,30
240,00 €	8,53%	1.322,00 €	46,99%	5,80 €	0,21%	930,30 €	33,07%	315,00 €	11,20%	2.813,10 €	0,00%	1,67	2,00	1,00	2,47	7,30	0,50
600,00 €	10,55%	3.090,00 €	54,34%	5,80 €	0,10%	1.115,16 €	19,61%	875,00 €	15,39%	5.685,96 €	1,25%	0,73	1,00	0,00	2,30	5,50	0,00
2.160,00 €	12,47%	8.967,00 €	51,76%	57,98 €	0,33%	3.829,44 €	22,10%	2.310,00 €	13,33%	17.324,42 €	16,03%	1,86	3,00	0,00	3,73	8,70	0,00
960,00 €	9,34%	6.520,00 €	63,40%	34,47 €	0,34%	774,16 €	7,53%	1.995,00 €	19,40%	10.283,63 €	2,14%	2,00	2,00	2,00	3,33	7,40	1,00
2.400,00 €	13,50%	9.282,00 €	52,21%	28,30 €	0,16%	3.651,98 €	20,54%	2.415,00 €	13,58%	17.777,28 €	13,81%	1,13	2,00	0,00	1,96	7,80	0,00
960,00 €	17,82%	2.869,00 €	53,24%	9,51 €	0,18%	710,00 €	13,18%	840,00 €	15,59%	5.388,51 €	2,57%	1,04	2,00	0,00	1,00	3,10	0,00
720,00 €	8,22%	4.886,00 €	55,75%	22,25 €	0,25%	1.840,45 €	21,00%	1.295,00 €	14,78%	8.763,70 €	9,32%	1,89	2,00	1,00	2,69	6,00	0,40
960,00 €	9,53%	6.680,00 €	66,32%	17,17 €	0,17%	770,56 €	7,65%	1.645,00 €	16,33%	10.072,73 €	1,51%	1,67	2,00	1,00	5,08	10,50	0,10
2.400,00 €	14,66%	9.071,00 €	55,40%	84,47 €	0,52%	2.157,59 €	13,18%	2.660,00 €	16,25%	16.373,06 €	17,01%	2,83	4,00	1,00	5,75	11,30	0,20
1.440,00 €	9,70%	8.742,00 €	58,87%	80,60 €	0,54%	2.347,53 €	15,81%	2.240,00 €	15,08%	14.850,13 €	3,52%	2,71	3,00	2,00	4,62	9,40	0,50
600,00 €	8,14%	4.111,00 €	55,74%	0,00 €	0,00%	1.124,10 €	15,24%	1.540,00 €	20,88%	7.375,10 €	3,55%	1,00	1,00	1,00	1,10	5,90	0,50
2.400,00 €	21,46%	4.459,00 €	39,88%	12,50 €	0,11%	3.609,60 €	32,28%	700,00 €	6,26%	11.181,10 €	1,65%	2,00	2,00	2,00	2,93	7,00	0,50
600,00 €	12,87%	1.749,00 €	37,50%	2,30 €	0,05%	1.857,20 €	39,82%	455,00 €	9,76%	4.663,50 €	0,00%	1,00	1,00	1,00	0,85	2,40	0,10
1.200,00 €	17,26%	2.593,00 €	37,30%	14,40 €	0,21%	2.549,20 €	36,67%	595,00 €	8,56%	6.951,60 €	0,00%	1,00	1,00	1,00	1,31	2,20	0,40
1.200,00 €	18,34%	3.026,00 €	46,26%	- €	0,00%	1.825,80 €	27,91%	490,00 €	7,49%	6.541,80 €	0,00%	2,00	2,00	2,00	3,07	5,90	0,70
1.200,00 €	16,62%	3.420,00 €	47,36%	11,60 €	0,16%	2.029,80 €	28,11%	560,00 €	7,75%	7.221,40 €	0,00%	1,00	1,00	1,00	2,50	5,40	0,20
2.400,00 €	22,61%	4.528,00 €	42,66%	14,60 €	0,14%	2.971,80 €	28,00%	700,00 €	6,59%	10.614,40 €	0,94%	1,83	2,00	1,00	3,77	8,80	0,80
2.400,00 €	20,16%	4.801,00 €	40,33%	- €	0,00%	3.581,90 €	30,09%	1.120,00 €	9,41%	11.902,90 €	2,56%	2,00	2,00	2,00	1,49	5,60	0,10
2.400,00 €	20,13%	5.251,00 €	44,04%	- €	0,00%	3.431,50 €	28,78%	840,00 €	7,05%	11.922,50 €	3,21%	2,00	2,00	2,00	3,66	6,50	1,40
2.400,00 €	15,94%	4.656,00 €	30,92%	103,30 €	0,69%	6.849,10 €	45,48%	1.050,00 €	6,97%	15.058,40 €	5,61%	2,00	2,00	2,00	1,45	3,00	0,30
1.200,00 €	23,30%	2.130,00 €	41,37%	13,20 €	0,26%	1.386,00 €	26,92%	420,00 €	8,16%	5.149,20 €	0,00%	1,00	1,00	1,00	1,50	4,90	0,10
4.800,00 €	36,79%	5.402,00 €	41,40%	34,94 €	0,27%	1.516,06 €	11,62%	1.295,00 €	9,92%	13.048,00 €	1,61%	1,29	2,00	0,00	2,37	7,70	0,00
1.800,00 €	23,36%	3.797,00 €	49,27%	21,81 €	0,28%	898,00 €	11,65%	1.190,00 €	15,44%	7.706,81 €	1,44%	0,89	1,00	0,00	1,96	6,10	0,00
900,00 €	29,55%	1.459,00 €	47,91%	15,44 €	0,51%	320,78 €	10,53%	350,00 €	11,49%	3.045,22 €	0,00%	0,89	1,00	0,00	1,68	3,20	0,00
2.400,00 €	17,96%	6.969,00 €	52,16%	45,42 €	0,34%	2.020,21 €	15,12%	1.925,00 €	14,41%	13.359,63 €	3,78%	1,00	1,00	1,00	0,88	2,30	0,00
1.800,00 €	28,60%	2.995,00 €	47,58%	10,69 €	0,17%	718,60 €	11,42%	770,00 €	12,23%	6.294,29 €	0,97%	0,61	1,00	0,00	1,81	6,40	0,00
2.400,00 €	36,35%	2.880,00 €	43,62%	9,86 €	0,15%	611,98 €	9,27%	700,00 €	10,60%	6.601,84 €	0,67%	1,42	2,00	0,00	3,83	9,10	0,00
2.400,00 €	32,69%	3.160,00 €	43,04%	16,08 €	0,22%	715,38 €	9,74%	1.050,00 €	14,30%	7.341,46 €	0,63%	1,75	2,00	1,00	4,25	8,70	0,10
2.400,00 €	22,38%	4.678,00 €	43,62%	37,99 €	0,35%	2.137,22 €	19,93%	1.470,00 €	13,71%	10.723,21 €	3,97%	0,96	1,00	0,00	2,43	6,40	0,00
4.800,00 €	30,86%	6.588,00 €	42,36%	32,58 €	0,21%	2.208,28 €	14,20%	1.925,00 €	12,38%	15.553,86 €	2,18%	1,92	2,00	1,00	4,34	11,50	0,10
2.400,00 €	41,23%	1.775,00 €	30,49%	10,65 €	0,18%	935,72 €	16,07%	700,00 €	12,02%	5.821,37 €	1,65%	0,67	1,00	0,00	2,65	7,00	0,00
480,00 €	5,18%	4.459,00 €	48,15%	12,50 €	0,13%	3.609,60 €	38,98%	700,00 €	7,56%	9.261,10 €	1,45%	2,00	2,00	2,00	2,93	7,00	0,30
240,00 €	5,92%	2.230,00 €	55,00%	- €	0,00%	1.164,60 €	28,72%	420,00 €	10,36%	4.054,60 €	0,64%	2,00	2,00	2,00	6,67	9,30	3,70
240,00 €	4,01%	2.593,00 €	43,28%	14,40 €	0,24%	2.549,20 €	42,55%	595,00 €	9,93%	5.991,60 €	0,00%	1,00	1,00	1,00	1,31	2,20	0,40
240,00 €	4,30%	3.026,00 €	54,21%	- €	0,00%	1.825,80 €	32,71%	490,00 €	8,78%	5.581,80 €	0,00%	2,00	2,00	2,00	3,07	5,90	0,70
1.200,00 €	3,79%	15.794,00 €	49,94%	19,20 €	0,06%	11.599,80 €	36,68%	3.010,00 €	9,52%	31.623,00 €	2,78%	0,97	1,00	0,00	2,59	7,00	0,00
480,00 €	5,49%	4.290,00 €	49,11%	29,70 €	0,34%	3.200,70 €	36,64%	735,00 €	8,41%	8.735,40 €	1,38%	1,83	2,00	1,00	3,75	8,40	1,30
480,00 €	4,81%	4.965,00 €	49,75%	- €	0,00%	3.448,90 €	34,56%	1.085,00 €	10,87%	9.978,90 €	1,49%	2,00	2,00	2,00	1,13	3,40	0,10
480,00 €	4,82%	5.292,00 €	53,09%	4,60 €	0,05%	3.351,00 €	33,62%	840,00 €	8,43%	9.967,60 €	0,53%	2,00	2,00	2,00	3,40	4,80	0,80
720,00 €	5,92%	5.990,00 €	49,28%	9,90 €	0,08%	4.420,20 €	36,36%	1.015,00 €	8,35%	12.155,10 €	1,89%	3,00	3,00	3,00	4,17	7,50	1,30
240,00 €	5,73%	2.130,00 €	50,85%	13,20 €	0,32%	1.386,00 €	33,09%	420,00 €	10,03%	4.189,20 €	0,00%	1,00	1,00	1,00	1,50	4,90	0,10
2.400,00 €	10,11%	12.890,00 €	54,29%	64,29 €	0,27%	5.100,43 €	21,48%	3.290,00 €	13,86%	23.744,72 €	15,08%	1,25	2,00	0,00	2,47	10,20	0,00
360,00 €	5,74%	3.737,00 €	59,58%	19,21 €	0,31%	965,98 €	15,40%	1.190,00 €	18,97%	6.272,19 €	1,92%	1,00	1,00	1,00	2,91	7,00	0,20
720,00 €	8,73%	4.503,00 €	54,62%	- €	0,00%	1.621,44 €	19,67%	1.400,00 €	16,98%	8.244,44 €	1,31%	0,86	1,00	0,00	2,74	7,00	0,00
480,00 €	4,22%	6.969,00 €	61,25%	49,46 €	0,43%	1.919,56 €	16,87%	1.960,00 €	17,23%	11.378,02 €	3,94%	1,00	1,00	1,00	0,88	3,30	0,00
800,00 €	7,66%	6.143,00 €	58,81%	37,12 €	0,36%	1.716,18 €	16,43%	1.750,00 €	16,75%	10.446,30 €	3,36%	0,85	1,00	0,00	3,94	7,00	0,00
480,00 €	5,52%	5.178,00 €	59,51%	49,13 €	0,56%	1.558,67 €	17,91%	1.435,00 €	16,49%	8.700,80 €	5,35%	1,00	1,00	1,00	1,30	4,20	0,10
480,00 €	8,84%	3.160,00 €	58,23%	12,15 €	0,22%	724,69 €	13,35%	1.050,00 €	19,35%	5.426,84 €	0,97%	1,83	2,00	1,00	4,92	10,50	0,40
360,00 €	5,14%	3.973,00 €	56,70%	50,85 €	0,73%	1.397,69 €	19,95%	1.225,00 €	17,48%	7.006,54 €	2,77%	1,00	1,00	1,00	1,87	4,80	0,00
3.600,00 €	11,34%	16.388,00 €	51,64%	230,36 €	0,73%	6.684,67 €	21,07%	4.830,00 €	15,22%	31.733,03 €	16,32%	2,03	3,00	0,00	5,39	17,10	0,00
480,00 €	12,32%	1.775,00 €	45,55%	4,03 €	0,10%	937,44 €	24,06%	700,00 €	17,96%	3.896,47 €	1,83%	0,54	1,00	0,00	1,65	5,90	0,00
1.461,50 €	15,45%	4.795,02 €	47,80%	25,69 €	0,23%	2.533,92 €	24,84%	1.161,13 €	11,68%	**9.977,25 €**	2,35%	1,41	1,55	0,98	2,68	6,44	0,36
2.998,00 €	20,32%	5.916,88 €	45,89%	33,72 €	0,23%	3.119,19 €	22,55%	1.410,50 €	11,00%	**13.478,28 €**	3,74%	2,05	2,33	1,35	3,20	7,62	0,55
-105,13%		-23,40%		-31,28%		-23,10%		-21,48%		**-35,09%**							
857,00 €	7,91%	5.574,68 €	53,11%	27,13 €	0,23%	2.709,72 €	25,87%	1.342,25 €	12,89%	**10.510,77 €**	3,71%	1,79	2,03	1,23	3,19	7,29	0,55
3.602,50 €	27,87%	5.137,22 €	40,59%	32,28 €	0,23%	2.943,38 €	21,53%	1.229,38 €	9,79%	**12.944,76 €**	2,39%	1,67	1,85	1,10	2,70	6,77	0,36
-320,36%		7,85%		-19,01%		-8,62%		8,41%		**-23,16%**							
2.641,50 €	21,48%	5.746,55 €	49,43%	37,07 €	0,28%	1.758,40 €	14,51%	1.619,63 €	14,29%	**11.803,15 €**	4,11%	1,41	1,75	0,63	2,89	7,41	0,19
1.818,00 €	14,29%	4.965,35 €	44,27%	22,33 €	0,18%	3.894,70 €	32,88%	952,00 €	8,38%	**11.652,38 €**	1,98%	2,05	2,13	1,70	3,00	6,65	0,72
31,18%		13,59%		39,76%		-121,49%		41,22%		**1,28%**							

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Coordinating inbound and outbound deliveries in a distribution centre

Marc Alsina Marti

Supervisor: Prof. ir. Birger Raa

Master's dissertation submitted in order to obtain the academic degree of
Inkomende Gast- en Exchangestudenten

Department of Industrial Systems Engineering and Product Design
Chair: Prof. dr. El-Houssaine Aghezzaf
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