Sizing of the Distribution Fleet for Client Orders' Delivery

The Case Study of Recheio

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ABSTRACT

Currently companies involved in supply chain management face a growing pressure to increase the service level provided to their customers while keeping costs at a minimum. The quality of the distribution service can be the key to increase this service level, where the size of the fleet operating this service is a crucial element to ensure not only a good performance of the service but also to minimize the costs associated – as transportation costs are one of the major costs associated with distribution.

Recheio offers their clients an order distribution service, handled by each of its stores spread across the country. The Operations Management department of Recheio wished to study a new approach for their fleet sizing. This Masters' dissertation aims to develop a new fleet sizing model for the fleet that operates the order distribution service offered by the stores, aiming at cost minimization while maintaining the service level agreed with their clients.

A mathematical model based on a Multi-Compartment Vehicle Routing Problem (MCVRP) was developed and implemented in the GAMS modelling system.

Lastly, two alternative scenarios for the demand volumes were evaluated, enabling the conclusion that the model created can be applied to different realities, while returning plausible results.

Key-words: Logistics, Distribution, Fleet sizing, Optimization Model

1. INTRODUCTION

Economic development and the increase of consumption are factors that stimulate the growing need to distribute goods so they can be brought closer to the end consumption location. Together with an increasing level of excellence required by customers, it has become necessary to bring closer all the levels of the supply chain.

The great competition that occurs in the in the many companies of the retail sector makes it essential for companies to expand their services while guaranteeing an acceptable quality level, as to, not only reach new clients, but also maintain the trust relationship they have with their existing ones.

Distribution activities have the main goal to guarantee the availability of the right product at the right places, in the right amount and the right moment, as to satisfy the needs of customers. Only with the efficient coordination and integration of all the elements of the supply chain is it possible to develop this operation. The transportation of goods, in particular, it's an essential point of the supply chain, being responsible for the success of the service. Considering the high cost it can account for, it is necessary to invest in its optimization and constant improvement.

The present work is developed under this context, at Recheio Cash and Carry, the Portuguese leader in the wholesaler food distribution sector, following the identification of some efficiency flaws in their logistics network, by its Operations Management Department, regarding the transportation of their customer orders by their order distribution service. This work aims to create a mathematical model that can optimise the fleet that is offered to the stores for the operation of this service, both in terms of its size and its composition, as to minimise the costs of transportation while preserving the service level agreed with the customers.

The structure of this paper is: Section 2, contains a relevant bibliographical review about supply chain management, transportation and distribution and performance indicators, having a focus on fleet sizing approaches found in academic literature; Section 3, presents the case study and describes its characteristics; Section 4, shows the mathematical model that was developed; Section 5, presents the results of the implementation of the model in three scenarios, to allow the study of the impact in the model of the variation of demand; lastly, in Section 6 some of the conclusions reached are presented and possible future studies are proposed.

2. Literature Review

Supply Chain Management

According to the Council of Supply Chain Management, "Supply chain management encompasses the planning and management of all activities involved in sourcing and procurement, conversion, and all logistics management activities. Importantly, it also includes coordination and collaboration with channel partners, which can be suppliers, intermediaries, third party service providers, and customers. In essence, supply chain management integrates supply and demand management within and across companies." (Council of Supply Chain Management Professionals, n.d.).

(Cristini, 2015) considers that SCM can be divided into three fundamental areas: purchasing, production and transportation, including decisions on raw-materials, amount to produce, levels of inventory and distribution network configuration. One important part of SCM is logistics management, presented next.

Logistics Management

Logistics Management is defined as the part of SCM that "plans, implements, and controls the efficient, effective forward and reverses flow and storage of goods, services and related information between the point of origin and the point of consumption in order to meet customers' requirements." (Council of Supply Chain Management Professionals, n.d.).

Nowadays, companies are using this new perspective on logistics to improve their profit, by differentiating themselves from competitors with the offering of additional services, that improve their customers' experience, but can add complexity and create new challenges to operations and logistics management.

Transportation and Distribution

Transportation directly impacts the state of the economy, the goods consumed and the mobility and diversity of services. Transportation thus takes on a leading role in the logistics network, by being responsible for the movement of goods along the supply chain and having a direct impact on the final cost of a product (Crainic & Laporte, 1997).

The implementation of strategic changes to the transportation and distribution operations is essential to reduce costs and improve the service level provided to the customer, without it having a negative impact on the total flow of the supply chain.

Cost and travel time reduction, the appropriate delivery of goods, with minimum variability of service, due to flawless transportation availability, minimizing late deliveries and loss, are key factors for an adequate logistics system functioning (Kasilingam, 1998).

Fleet sizing problems are considered to be some of the most important problems in logistics planning by focusing on the balance of customers' demand and the offer of the transportation system (Redmer, Sawicki, & Żak, 2008).

To be able to define future strategies to follow, it's essential to measure the performance of the system. This said, it is essential to define the metrics that allow the company to measure their transportation performance (Hamel & Prahalad, 1994). (Dumitrache, Kherbash, & Mocan, 2016) present some performance indicators for the transportation operation that can be divided into four main categories: fleet utilization, travel utilization, transportation capacity and speed.

Fleet Planning

To deal with the level of uncertainty associated with the planning of a distribution system, it's necessary to support the activity with information systems focused on fleet management, that allow the management team to act in a timely manner on any irregular situation that may occur. These systems can offer many tools in terms of cost analysis and legal compliance, ensuring the best possible use of the available resources, associated with cost reduction and service level maximization (Rushton, Croucher, & Baker, 2006).

According to (Ballou, 2004) there are three levels of transportation systems planning: strategic, tactic and operational. The strategic level deals with the long-time planning, namely the physical structure of the system – distribution centres location, human resources needs, definition of markets and service level –, the tactic level comprehends the medium-term, focused on the transportation network definition, in particular the fleet dimension and composition and the efficient allocation of the resources available, lastly, the operational level focuses on the short-term decisions, based on high uncertainty parameters – such as the route definition and distribution control. As in this work we are dealing with fleet sizing, we will focus on the tactical planning.

Tactical Planning

Companies have the objective of finding the most advantageous balance between the level of service provided to their customers and the costs associated with the distribution operation. The result of this balance is the transportation plan, that acts as the foundation for determining the policies that guide the daily operations and that allow the resolution of irregular situations.

(Crainic, 2000) states that the decisions taken at this level can be classified in four main aspects: service selection – route definition and service scheduling –, traffic distribution – used services and locations, and the activities to be carried out at each location –, terminal policies – consolidation activities determination – and empty balancing strategies – how to position empty vehicles as to be able to respond to the demand of the next period. Being these decisions based on aggregate data.

Fleet Selection and Sizing

An adequate fleet planning and management leads to economic efficiency and customer satisfaction. To determine the amount and characteristics of the vehicles that can respond to the customers' demand, the following aspects should also be considered: product characteristics, load and delivery, location restrictions, roads, fuel type, legal specifications and vehicle safety (Rushton, Croucher, & Baker, 2006).

Fleet Sizing Models

There are three main approaches to fleet sizing models: analytical models, simulation models and optimization models.

(Ostermeier, Henke, Hübner, & Wäscher, 2021) present a more operational approach to the fleet sizing problem, by using a multi-compartment vehicle routing problem (MCVRP) – an iteration of the Vehicle Routing Problem in which the vehicles have multiple separated compartments – to determine the optimal routes to satisfy customers' demand considering a mix of vehicles with separated compartments with different characteristics. The solution methodology is based on the development of a MILP model with an objective function that aims to minimize the costs of the vehicles' operation, subjected to restrictions that ensure demand satisfaction, the continuity of routes and the respect of the capacity of vehicles.

This variant of the VRP is applicable when considering industries where products are not considered homogeneous and have different needs of transportation. To save money on transportation costs, companies opt to use vehicles that can transport products with different needs together.

Conclusion

The literature review allowed us to reach the conclusion that the application of a VRP, thought usually applied on a different level of planning than the fleet sizing, can prove itself to be a useful, and easy to apply, tool to size a fleet for a store's order distribution service.

3. CASE STUDY

This challenge began with the identification by Recheio's Operations Management of some inefficiencies regarding the transportation of their customers' orders when it came to the composition of the fleet available at each of their stores.

The present work focuses on the distribution service provided by Recheio's Leiria store, in its component of the Leiria Hub – fully dedicated to the fulfilment of orders from the distribution channel. Every day, each store sends orders to its clients using the vehicles they have available at their facility – through contracts made with distribution companies. Operating in the wholesaler sector, Recheio's clients can be split into four main sectors: retailers (71% of sales), HoReCa companies (27% of sales), traders and warehousing companies (1% of sales) and others – which include public sector organizations and some private entities (1% of sales) –, being Leiria's store the only that is responsible for the fulfilment of orders of distribution clients belonging to all these sectors, after some changes to the operation of the distribution channel that Recheio's Operations Management recently implemented, in which HoReCa clients were diverted from the Recheio stores to the Caterplus Platforms – that specialize in the fulfilment and distribution of orders to make them available at the clients' location.

The distribution service operation can be described as follows: the client places an order (via e-mail, phone call, Electronic Data Interchange System or Call-centre) to its store; the store then receives the order and, according to the stock available, a picking list is created; the order is then produced at the store; after the order is completed, the number of pallets created is introduced in the Transportation Management System installed, which then allocates a route to the client; the transportation of the order to the client's location is done, finishing in the delivery of the order to the client's location.

While planning the fleet to operate this service it is necessary to take into account the following restrictions: the type of vehicle selected must be compatible with the client's characteristics, the order size and the transportation requirements of the products; the drivers operate a daily 8-hour shift; the distribution service operates every day from Monday to Friday; orders are placed at least 48 hours before being shipped to the client.

Currently Leiria's store operates with a fleet consisting of 9 vehicles, as presented in the Table 1.

Table 1: Leiria's Current Fleet (Source: Author)

Type of Vehicle	Number of Compartments	Number of Vehicles
8T	1	1
12T	2	2
19T	1	1
19T	2	4
26T	2	1

For the fleet sizing case presented, we consider that Recheio can hire any number of vehicles of the following types:

Table 2: Available Vehicle Types and Their Characteristics (Source: Author)

Type of Vehicle	Pallet Capacity	Weight Capacity (kg)	Comparative Cost
3.5T	6	1000	9
4.6T	6	1700	11
8T	10	2300	12
12T	12	6000	13
14T	12	7000	14
19T	14	9000	16
26T	14	15000	18

Once the aim of the current study is to size the fleet, this should be treated as a "not-scarce" resource, that should not be limited by the number of vehicles available.

The store this study focuses has a total of 300 clients of the distribution service and in a regular day it's common to serve 15 clients in the distribution service, thought the model created should be applicable for any number of clients to have their orders satisfied.

4. Mathematical Model

The model developed to solve this problem will be modelled as a MCVRP, which formulation is based on the work developed by (Ostermeier, Henke, Hübner, & Wäscher, 2021).

Consider a set of *n* clients that place orders (d_{ip}) to the distribution service. In this order, the index *i* refers to the client while index *p* refers to the type of product ordered. It was defined that p=1 represents room temperature products, p=2 refrigerated products and p=3 frozen products.

The fleet is composed of *m* vehicles with different characteristics and capacities that can be separated into 2 compartments (*c*). Each vehicle has a maximum capacity that needs to be respected, both in terms of number of pallets carried (qp_v) and weight carried (qm_v). Additionally, the vehicles can only be allocated to stores that can accommodate the vehicle (k_{iv}).

By going from location *i* to location *j*, the vehicle takes a certain amount of time ($tviagem_{ij}$).

All vehicles must start and end their travels at the Recheio store.

<u>Indexes and Sets</u>

i – visited location, $i \in L = \{0, \dots, n\}$

j – location to visit, $j \in L = \{0, \dots, n\}$

v – vehicle, $v \in V = \{0, \dots, m\}$

p – type of product, $p \in P = \{1,2,3\}$

c – compartment, $c \in C = \{1,2\}$

<u>Parameters</u>

qp_v – capacity of vehicle *v*, in number of pallets

qm_v – capacity of vehicle *v*, in weight (kg)

k_{iv} – capability of client *i* to receive vehicle *v*

$dpal_{ip}$ – quantity ordered by client *i* of product type *p*, in pallets

$dpeso_{ip}$ – quantity ordered by client *i* of product type *p*, in weight (kg)

$tviagem_{ij}$ – travel time from location *i* to location *j*, in minutes

ttot – total available time for the distribution service, per vehicle

$custo_v$ – cost of using vehicle *v*

$transp_{vc}$ – if vehicle *v* can have compartment *c*

<u>Variables</u>

x_{ijv} – binary variable that takes the value 1 if vehicle v travels from location *i* to location *j* and 0 otherwise.

y_{pvc} – binary variable that takes the value 1 if product type *p* is allocated to compartment *c* of vehicle *v*, and 0 otherwise;

$u_{ipv} \in [0,1]$ – auxiliary variable that translates the portion of the order of product type *p* that is delivered to location *i* by vehicle *v*;

pos_i – auxiliary variable that gives the positon of location *i* in the route;

vf(v) – binary variable that takes the value 1 if vehicle *v* takes part in the route, and 0 otherwise.

<u>Objective Function</u>

$$Min\ z = \sum_{i}^{n} \sum_{j}^{n} \sum_{v}^{m} custo_v \times x_{ijv} \qquad (1)$$

Constraints

$$\sum_{v} u_{ipv} = 1 \quad \forall\, i \in L\backslash\{0\}, p \in P \qquad (2)$$

$$u_{ipv} \leq \sum_{i} x_{ijv} \quad \forall\, i \in L\backslash\{0\}, p \in P, v \in V \qquad (3)$$

$$\sum_{j} x_{ijv} \leq 1 \quad \forall\, i \in L\backslash\{0\}, v \in V \qquad (4)$$

$$\sum_{j} x_{ijv} = \sum_{j} x_{jiv} \quad \forall\, i \in L\backslash\{0\}, v \in V \qquad (5)$$

$$\sum_{i}\sum_{j} x_{ijv} \leq |S| - 1 \quad \forall\, v \in V, S \subseteq L\backslash\{0\}, |S| > 2 \qquad (6)$$

$$\sum_{p}\sum_{i} dpal_{ip} \times u_{ipv} \leq qp_{v} \quad \forall\, v \in V \qquad (7)$$

$$\sum_{p}\sum_{i} dpeso_{ip} \times u_{ipv} \leq qm_{v} \quad \forall\, v \in V \qquad (8)$$

$$\sum_{p} y_{pvc} \leq\ transp_{vc} \quad \forall\, v \in V, c \in C \qquad (9)$$

$$\sum_{i} u_{ipv} \leq |L| \sum_{c} y_{pvc} \quad \forall\, v \in V, p \in P \qquad (10)$$

$$\sum_{i}\sum_{j} tviagem_{ij} \times x_{ijv} \leq ttot \quad \forall\, v \in V \qquad (11)$$

$$\sum_{i \geq 1} x_{oiv} = vf_{v} \quad \forall\, v \in V \qquad (12)$$

$$\sum_{i \geq 1} x_{i0v} = vf_{v} \quad \forall\, v \in V \qquad (13)$$

$$x_{ijv} \leq \min(k_{iv}, k_{jv}) \quad \forall\, v \in V, i \in L\,, i \neq j \qquad (14)$$

$$x_{ijv} \leq vf(v) \quad \forall\, v \in V, i \in L\,, i \neq j \qquad (15)$$

The objective function, equation (1), corresponds to the company request to minimize the cost associated with the fleet.

Equation (2) ensures that the demand for each product type is fulfilled. Equation (3) states that a client (location) is visited by a route, if at least a portion of its demand is allocated to vehicle *v*. Equation (4) guarantees that each vehicle visits each client at most once. Equation (5) states that the arrival location for the previous leg of the travel is the departure location for the next. Equation (6) eliminates possible subtours. Equations (7) and (8) ensure that the maximum capacity of the vehicles is not exceeded, both in number of pallets and in weight. Equation (9) states that each compartment, for each vehicle, is only carrying a single type of product. Equation (10) gives the relation between variables u_{ipv} and y_{pvc}. Equation (11) ensures that the maximum time available per shift, per car is respected. Equations (12) and (13) ensure that each route begins and ends at the Recheio's store. Equation (14) defines the accessibility conditions for the clients' locations, ensuring that they are only visited by vehicles compatible with their characteristics. Equation (15) defines if a vehicle is needed for the distribution service.

The model designed to solve the MCVRP is thus formed by the objective function (1) and by all constraints from (2) to (15). It is intended to find the set of vehicles that can ensure the satisfaction of the clients' orders, at minimum cost, respecting the conditions of the system.

5. RESULTS

To be able to implement the model in GAMS language and portrait the distribution operation of Recheio's service, it was needed to collect some data regarding the products, fleet, customers and operating hours. All this data, which is reflect in this paper, is the result of historical data analysis, collected for the Leiria store.

The model simulates a day – 8 working hours – in the operation of the distribution service, in which 15 customers are to have their orders delivered at their locations.

As the model aims at the selection of the vehicles to operate the service, an excess of vehicles was added to the model, so that the availability of vehicles would not be a limiting factor. Table 3 shows the vehicles considered for the model application.

Table 3: Vehicles Introduced in the Model Implementation (source: Author)

Vehicles	Pallet Capacity	Weight Cap. (kg)	Number of Compartments
v1, v2	6	1000	1
v3, v4	6	1700	1
v5, v6	10	2300	1
v7,v8	12	6000	1
v9,…, v11	12	6000	2
v12,…,v16	12	7000	2
v17,..,v21	14	9000	2
v22, v23	14	15000	2

After applying the model to the data selected, it returns the following results – as the composition of optimum fleet:

- 2 vehicles of 3.5T mono-temperature;
- 3 vehicles of 12T bi-temperature;
- 2 vehicles of 14T bi-temperature.

It is, however, important to consider that the volatility of demand is an important factor that should not be neglected.

To further test the model, two additional scenarios were considered and analysed.

A first alternative scenario was one where the considered customers place abnormally large orders. For this situation the model selects 8 vehicles to shape the fleet for the store, adding one 14T vehicle to the base scenario solution.

In the second alternative scenario considered, 2 customers were added to the existing 15 customers of the base scenario. From the application the model results a fleet of 9 vehicles, two more vehicles of type 14T and one 8T vehicle.

All the scenarios implemented have shown large gaps, depicted in Table 4, that support the conclusion that the model is quite computationally complex.

Table 4: Scenarios Resulting Optimality Gap (Source: Author)

Scenario	Gap
Base Scenario	34,54%
Alternative Scenario 1	36,00%
Alternative Scenario 2	36,19%

6. Conclusions

The developed model provides the optimum number of vehicles that should be included in the fleet of the Leiria store of Recheio, in order to fulfil the demand of the customers of their order distribution service. The model created proved itself to be applicable to different situations and, as such, be able to be used by the Operations Management of Recheio in different scenarios that may represent the reality of each of their stores and its distribution service. However, it is important to state that the final decision on the number of vehicles to include in the fleet should be further analysed, considering the fluctuation that demand can have, considering that it's dealing with customers that are highly influenced by the social-economic setting.

In the future, several suggestions may be considered, such as: adding new performance indicators to help better understand the situation of the distribution service, such as the level of utilization of the vehicles – considering their capacity – and the utilization of the available hours of the service – in terms of the shifts that the drivers can work.

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