

Decision Support System for a rent-a-car Company

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Master's Dissertation

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Abstract

The dissertation presents a Decision Support System for a rent-a-car company that includes both fleet controlling and planning features. The goal is to be in control of the entire fleet while being able to accurately deploy it among the company's rental stations.

The Decision Support System delivered is composed by three interconnected areas:

- Operations Control;
- Fleet Deployment;
- Revenue Management.

The operations control area is displayed as a warning system, that notifies the user if a vehicle is either inadequate to be rented or if it has reached a certain threshold. The control tool necessity emerged with the rapid growth of the fleet size and the struggle to manually control whether all vehicle requirements were at a satisficing level.

To assist the fleet deployment planning an optimisation model was developed, validated and solved for real instances comprising company data. The model aims to maximize fleet occupation and deployment revenues, under consideration of vehicle transportation costs and expected earnings from forecasted demand.

The pricing team has been responsible to set reservation prices in order to enhance the company's revenue, following a process based on intense market research and professional intuition. In order to facilitate this process, the Decision Support System presents an occupation rate visualizer and a price elasticity display, which deliver critical information for the price setting process.

All the functionalities supported are highly flexible and automatically updated with the information system data. This project allows the company to spend less time in less value-adding fleet controlling tasks as well as improves both the quality and speed of the fleet deployment and revenue management planning.

Resumo

Esta dissertação apresenta um Sistema de Apoio à Decisão para uma empresa de rent-a-car que inclui ferramentas de controlo e planeamento de frota. O objetivo do sistema é apoiar o controlo da frota e ao mesmo tempo distribuir eficazmente a frota pelas estações de aluguer da empresa.

O Sistema de Apoio à Decisão criado pode ser decomposto por três áreas interligadas:

- Controlo de operações;
- Distribuição da frota;
- *Revenue Management*.

O controlo das operações é realizado através de um sistema de avisos, que notifica o utilizador no caso de um veículo se encontrar inadequado para aluguer ou caso este tenha atingido um limite previamente definido. A necessidade da ferramenta de controlo surgiu devido ao crescimento rápido da frota e a dificuldade de controlar os requisitos dos veículos de forma manual.

Foi criado um modelo de otimização para apoiar no planeamento da distribuição da frota, este foi validado com instâncias reais da empresa. O modelo procura maximizar a ocupação da frota e o rendimento associado à distribuição de veículos, tendo em consideração tanto os custos de transporte como as receitas associadas à procura prevista.

A equipa de definição de preço é responsável por definir os preços das reservas de modo a maximizar o rendimento da empresa, seguindo um processo baseado na análise de mercado e numa forte intuição profissional.

Todas as funcionalidades do sistema são extremamente flexíveis e atualizadas automaticamente com dados provenientes do sistema de informação. Este projeto permitiu que a empresa despendesse menos tempo em tarefas de controlo, e aumentasse a eficiência do processo de planeamento da distribuição de frota.

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*“To improve is to change
To be perfect is to change often.”*

Winston S. Churchill

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1 Introduction

The Portuguese rent-a-car market is becoming increasingly competitive due to the growth of multinational franchises. In order to fit the operation mode and the practical requirements of consumption patterns, car rental companies usually maintain advantages in their price, site distributions, vehicle differentiation, management feature and network efficiency. Thus, they can possess stronger environmental adaptability and anti-risk ability, and enhance their market competitiveness and customer satisfaction (Yang, 2009).

Grupo JAP, in order to further enhance their position in the rent-a-car Portuguese market, purchased the right to be master franchise of SIXT, renowned multinational rent-a-car brand. To adapt to the increase of demand, associated with the SIXT brand, the company has been expanding its fleet, which has more than doubled from 2015 (2.500 cars) to 2016 (5.300 cars). The problem addressed in this dissertation concerns the uneven growth of the fleet – and the consequent increase of the required operational control tasks and planning issues – when comparing with the growth of the number of collaborators and supporting tools.

The car rental business is becoming heavily dependent on operational efficiency. As holding costs of assets have been growing faster than the price level, it is important to assure optimal utilization of resources (Fink and Reiners, 2006). To do so, a decision support system was developed. This system analyses three mutually dependent areas of the business and delivers required actions, plans and insights to facilitate the decision-making process across the rent-a-car business. The above-mentioned areas are: operations control, fleet deployment and revenue management.

The operations control area was developed to identify problems in addition to anomalies within the fleet and the corresponding information system, and to deliver a thorough set of tasks that should be fulfilled in order to enable an optimal utilization of the resources. This is the first segment being analysed since the accuracy of the other two areas highly rely on the clear understanding of the fleet availability and status.

A fleet optimisation model was developed to tackle the second area. The solution obtained in this model is an optimal vehicle transfer policy that takes into account the demand history as well as an expected growth factor. Then, the tool presents the optimal fleet transfer plan in a simple and intuitive way to the user.

Lastly, to facilitate revenue management tasks, the system provides displays for price elasticity and occupation rate. These tools aim to assist the team that defines the price of the reservations throughout the year (pricing team) in understanding the price-demand function. Moreover, it allows an accurate visualization of the company's current sales position against the targets defined every month. The displays presented provide information in a clear and extremely flexible way, since the user has the possibility to investigate specific information, and not only the general overview of the company.

The structure of this dissertation is as follows. Chapter 2 presents an overview of the company and its rent-a-car business, while providing some insights that influence the solutions shown. In Chapter 3 the problems that the decision support system tackles are thoroughly presented. In order to frame the problem and proposed solutions, Chapter 4 presents a literature review of the fleet deployment problem for rent-a-car businesses, as well as for other relevant business areas. Chapter 5 shows how the data is retrieved from the information system and the pre-processing that takes place before it may be used by the system. The decision support system design, implementation and functionalities are described in Chapter 6. Lastly, in Chapter 7, the main conclusions are drawn and future improvements for the system are discussed.

2 Grupo JAP and the rent-a-car business

Grupo JAP was founded in 1904 as a carriage repair shop. Throughout the years this brand has managed to expand its business to most of car related businesses. As seen in Figure 1, the company has the retailing rights for several well-known vehicle brands, and has extended the enterprise to areas as vehicle insurance and financing.

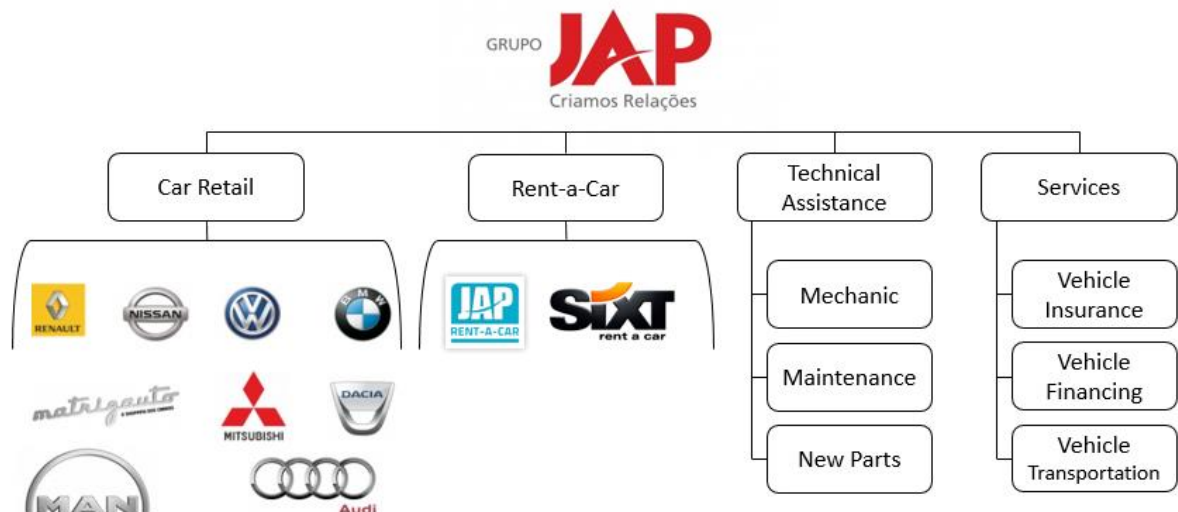


Figure 1 GrupoJAP - Business areas

Grupo JAP starts their rent-a-car business in 2001 with the purchase of Ceuta Rent-a-Car, rebranding it as JAP Rent-a-Car. In 2015, it acquires the rights to be Master Franchise of SIXT, renowned multinational rent-a-car brand, to further assimilate their position in the rent-a-car market.

To assist the car retail business, Grupo JAP created a transportation unit. Which is responsible for transporting large quantities of vehicles, and usually provides service for re-stocking the bigger car dealerships.

JAP Rent-a-Car and SIXT

JAP Rent-a-Car and SIXT remain as two different brands in Portugal in order to keep loyal customers and to distinguish different market segments and channels – Sixt is perceived as a premium brand, while JAP Rent-a-Car is more low cost. Nevertheless, both brands share the same vehicles, information system and supporting team.

SIXT has its own rental stations in the largest cities within Portugal, as well as in its international airports, whereas JAP Rent-a-Car kept all the stations in the smaller regions of Portugal, such as Famalicão, Alfragide and Lamego. With the annexation of the franchising, it was required to make some adjustments to the references used for the SIXT rental stations in the information system. The stations reference number was changed to standard references used in the reservation management system of SIXT – *Cobra*. Alongside these rearrangements, the company also adapted the clustering of vehicles in different groups to match the SIXT standard.

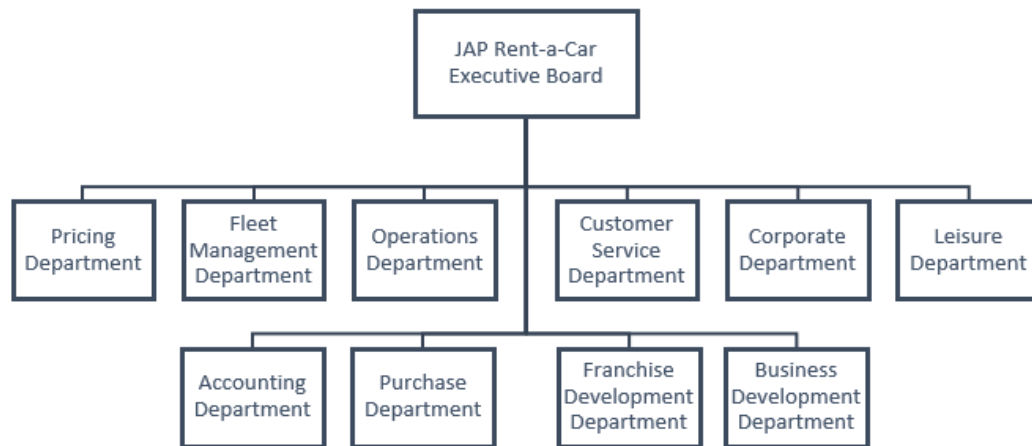


Figure 2 Car renting business organogram – Adapted from “JAP Rent-a-Car Organograma”

Grupo JAP’s rent-a-car business is branched into multiple departments, as it can be observed in Figure 2. The departments that will be referred throughout this study are:

- Pricing Department – responsible for setting the price of reservations;
- Fleet Management Department – responsible for the vehicles conditions;
- Operations Department – responsible for the operations;
- Customer Service Department – responsible for customer service;
- Corporate Department – responsible for vehicle reservations for companies and executives;
- Leisure Department – responsible for vehicle reservations for leisure clients and travel agencies.

Each department structure and responsibilities are clearly defined, even within the departments, every collaborator knows what’s the scope of their responsibilities. The problem is that the company’s information flow is still extremely vertical, and unless the departments are physically close to each other, there is little relevant information being transmitted across the departments. One of the reasons why this occurs is because of the nonexistence of standardised planning and control tools across departments, and sometimes even within a department.

The vehicles available for the rent-a-car business have all been acquired through either a leasing contract or a buy-back contract. A leasing is a contract between a lessee (rent-a-car) and a lessor (car retail), where the lessor is the legal owner of the vehicle, and the lessee has the right to use it in return for regular payments. In the buy-back contract, the car retail sells the vehicle to the rent-a-car with an agreement of future repurchase at a stated price and under specific conditions, such as complying with the vehicle’s return date and not exceeding the maximum number of kilometres. If any of the contractual requirements is broken, the legal agreement is considered void and the car retail may reject the repurchase of the vehicle. The advantage of buy-back contracts over leasing contracts is that the vehicle cost per day is lower, the disadvantage being that it has more strict requirements.

3 Problem description

To maximize revenue of the rent-a-car business, the company will have to enhance the profits and reduce the overall costs while maintaining a high customer satisfaction quota. To accomplish this, the company should sync its planning and operations tasks with the external events, while keeping its products at a satisficing level. The term satisficing, combination of satisfy and suffice, (introduced by Herbert Simon, 1956) means that the product satisfies the company's quality requisites and suffices the client's requisites. In the rent-a-car, a satisficing vehicle is a car that meets the quality and safety insurance criteria while it conforms with the client's expectations and requisites.

In this chapter, the current problems that the rent-a-car company faces, as well as the actual standards of operations are presented. Firstly, the current status of operational control will be analysed, both in terms of quality and process efficiency. In fact, in the rent-a-car business, ensuring that the vehicle supplied to a client is at a satisficing level of performance and maintenance is a basic necessity. Only after this basic requirement is set in place can the company start developing more advanced plans. In the second part of the chapter, the current standard for fleet deployment will be examined. For this, current considerations, constraints and requirements will be shown. Lastly, the price setting process will be introduced. This process is a key factor for the company's turnover, since it not only defines the earnings per rental but it is also critical when comparing the company with its competitors.

3.1 Operations Control

At the present time, most controlling tasks, such as checking the number of kilometres and verifying contractual requirements, have to be controlled vehicle by vehicle in the information system by either the maintenance or the logistics team, on a daily or weekly basis. This methodology was manageable for a fleet under 1000 vehicles. However, with the current fleet size (over 5000 vehicles) it is difficult to guarantee that no detail is overlooked.

In this subsection, the different vehicle requirements are presented. Firstly, the contractual requirements are analysed, which, if left uncontrolled, can lead to contract rupture and, consequently, a heavy penalty for the company. Lastly, the quality requirements, which are set by the company to ensure a high quality service, will be shown.

3.1.1 Contractual requirements

As previously described, the fleet available for renting has either been acquired through a buy-back contract or leased. This was the strategy followed by the management in order to reduce the overall liability of the company as well as reducing the fixed inventory for the accounting reports.

Leasing and buy-back contracts are set and uploaded to *Rent-Way* (information system designed for rent-a-car businesses used to manage the fleet and reservations) before the car arrives at the branch. These legal agreements have all the general car information as well as the agreement details. The buy-back contracts have two further mandatory fields than the leasing contract: returning date and maximum number of kilometres. If these values are exceeded, the company has to purchase the car at its current value. To prevent this from happening, different processes are applied.

To ensure that the returning date is not exceeded, the company sets a vehicle blocking date up to 30 days before. When the blocking date is reached, the vehicle is put into a non-available status – designated as Impro – and is sent to the mechanic to repair all damages and to run a final check-up. Nowadays, the blocking date can only be changed by the logistics team, but

previously it could be changed by the branch managers and by the rental agents. This led to issues with cars not being sent back to the mechanic on time and being put in a position of not meeting the returning date.

Every time a car is rented or transported to a different station, upon arrival to the station the vehicle's number of kilometres is uploaded to the system. Although it is uploaded, it is not compared with the maximum number of kilometres at the same time. If this limiter is exceeded, as in the case previously described, the vehicle has to be purchased at its current value.

3.1.2 Vehicle quality insurance requirements

Another metric uploaded to the system after every rental is the number of damages. Contrarily to what is the general expectation, if a vehicle has a small number of bumps or scratches they will not be immediately fixed. This decision is made by the branch manager, which can lead to a conflict of interest between sending a vehicle to maintenance or increasing revenue through sales.

Apart from controlling the damages of the vehicles, there is another key factor to ensure a high quality product: maintenance. Maintenance is performed on intervals of either time or kilometres, and is planned taking into account the vehicle's age and model. In the client's perspective, maintenance is a basic requirement. At the moment, the vehicle's quality insurance is controlled by the maintenance team on a daily basis, by comparing the data of multiple spreadsheets with data manually extracted from the information system.

3.2 Fleet deployment

Fleet deployment is an activity that, unlike price setting, the everyday customer is not aware of. This activity has the goal of forecasting the demand and ascertain where and when to have the cars deployed to a specific location, while maintaining high levels of customer satisfaction and maximizing the revenue.

This section will be subdivided into two different problems associated with the fleet deployment. Initially, the process and problem related with the deployment of newly acquired vehicles will be presented, and in the following the day-to-day fleet deployment is explained.

3.2.1 New vehicles' deployment

The fleet deployment is currently being planned by the logistics team with inputs from most of the other departments. The most influential input into this decision comes from the pricing team, with the annoyance of the operations manager and the branch managers, since they are the ones in direct contact with customers and aware of the location requirements.

The current process after acquiring vehicles is to assign them to one of the major areas (either Porto, Lisbon or Faro) following a predetermined ratio (for example: 30% to Porto 50% to Lisbon and 20% to Faro). After arriving to the city's main station, the vehicles will be forwarded to the local stations according to the current needs. The ratios are created by intuitively "forecasting" the demand for the different areas. The problem with this process is that the vehicle transferal cost between these areas is high, as a result of long distances and toll fees, thus making it important to accurately forecast the ratio values.

3.2.2 Day-to-day vehicle deployment

Grupo JAP, unlike many of their competitor companies, makes a commitment with their customers that if a reservation is accepted the client will definitely have the vehicle ready on the arrival to the site.

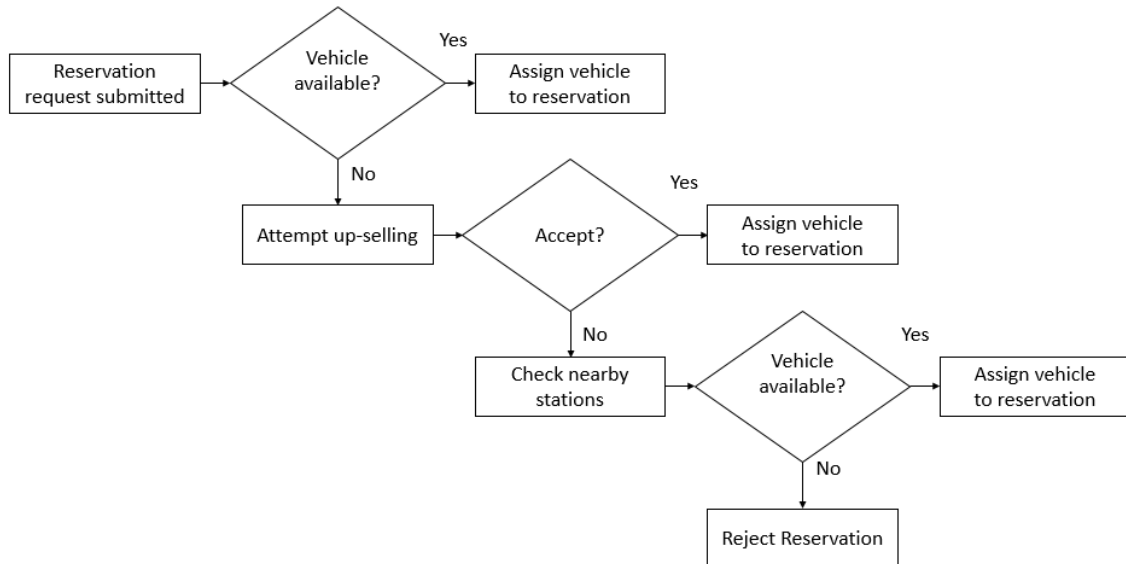


Figure 3 Reservation acceptance process

In Figure 3 the reservation acceptance process is presented. In case no vehicle is available at the desired station, and if the customer is not willing to rent a different vehicle, there is an option of having a vehicle reallocated (by an employee) to the desired station, in order to satisfy the customer request. This process, along with the company's policy that the client, when returning the car, is not obliged to return the car to the station where it was rented from, makes the fleet size allocated to a specific station vary throughout the year.

In this situation, two major problems emerge. Firstly, when reassigning a vehicle to a different station, there is no transportation cost analysis, which can result in negative revenue when renting a vehicle. Secondly, there is a very small control over the demand forecasting (mostly done station by station by the price setting team), which can have the consequence of loss of future revenues if higher priced reservations are cancelled, due to vehicle shortage.

3.3 Revenue Management

Before being presented to the final customer, the price undergoes several analysis steps. The basis for price setting is determined according to the specific rental season. Currently, the year is divided in 3 different, non-continuous, seasons. These seasons were created taking into account the larger holidays and non-holidays periods (as exemplified in Figure 4).

| Época | Início | Fim |
|-------|------------|------------|
| Baixa | 03/01/2016 | 17/03/2016 |
| Média | 18/03/2016 | 30/06/2016 |
| Alta | 01/07/2016 | 15/09/2016 |
| Média | 16/09/2016 | 30/09/2016 |
| Baixa | 01/10/2016 | 16/12/2016 |
| Média | 17/12/2016 | 02/01/2017 |

Figure 4 Example of different seasons throughout the year

Figure 5 presents the consolidated price setting process, in here it is possible to observe that the task that follows the identification of the season is the yield rate setting. This operation is extremely complex due to the amount of interdependent occurrences that must be taken into account, thus this is considered the most secretive and game changing process of revenue management. The price presented to the client is calculated following Equation (1).

$$Price_{Final} = Price_{Standard} \cdot Yield_{Applied} \quad (1)$$

$$Yield_{Minimum} \leq Yield_{Applied} \leq Yield_{Maximum} \quad (2)$$

The yield rate is defined taking into consideration both inside and outside factors, and by adjusting its value between a maximum and a minimum acceptable value (2), the pricing team can both stimulate the number of reservations submitted and slow it down. This happens as a result of the price and demand being positively correlated.

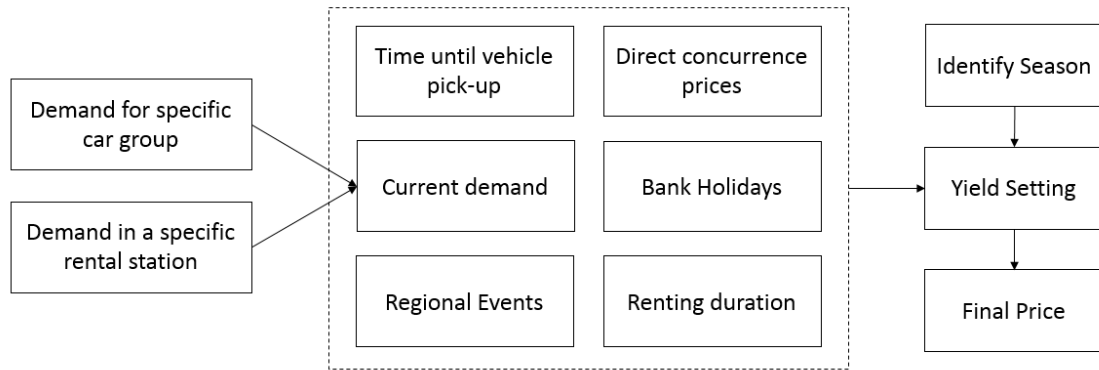


Figure 5 Price setting process

To maximize the earnings, it is required for the pricing team to have a constantly up-to-date knowledge of all national events and their effect on the car renting quantities. This process is currently being done by an extensive search and price comparison with the competitors and, most importantly, by a team with a keen sensibility to the price elasticity.

Currently, a data base with all the events and their effects on the business is being created by the pricing team. This will improve the price setting methodology, since it will become easier to understand the consequences of different events, thus getting a better perspective of the price elasticity. Still, besides the team's intuition and knowledge, there is little quantitative support for this decision making process, only taking into consideration reservations accepted for the future and occupation rate.

4 Literature Review

The rent-a-car industry is thriving, and the increasing competitiveness of this sector has been attracting the attention of the academic community. In this chapter, a review of the importance of support systems to the rent-a-car industry is presented, as well as a analysis on the fleet deployment problem. In order to further understand the width of these problems and the evolution of the approaches taken to tackle them in the transportation industry throughout time, the methods and models applied in this context will be analysed.

With the growth of the rent-a-car business and the complexity of the demand forecasting and planning methods, Edelstein and Melnyk (1977) developed a pool control system – “a timeshare based model-oriented system, [which] helps answering these questions for each city for the next few days: ‘How many cars will be needed? How many cars will be available or can be moved in from other pool cities? How many reservations can be accepted?’ among other questions” (p. 21). In fact, even in the primordial times of the rent-a-car business, these were key factors for a company’s development. Nowadays, with the evolution of the standard of acceptance of the client as well as the increase of competitiveness, these factors become even more important to fully grasp.

Geraghty and Johnson (1997) developed a revenue management system that combines capacity management, pricing and reservations control through a multi-step process, as seen in Figure 6.

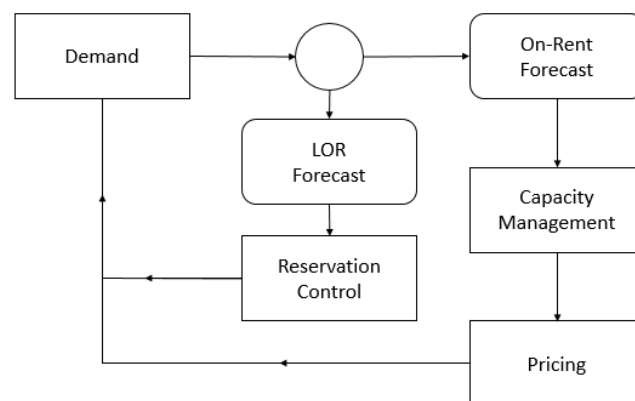


Figure 6 Revenue management process (Geraghty and Johnson, 1997)

The demand forecast derives from the spectral analysis of reservations history and takes into consideration factors such as seasonality. This function is analysed according to two levels of aggregation: on-rent and length of rent (LOR). The on-rent refers to the number of cars in use on a specific date, while the LOR relates to the number of cars in use for each potential length of rent. In the first process, the pricing model will generate new rates in accordance to the capacity level, this is, if a station is in risk of being overbooked the model will generate a higher rate. The second process tries to maximize the fleet occupation ratio by accepting or rejecting reservations to maximize the number of days on rental. After this, both solutions are combined, and a recommendation is generated.

Before the creation and implementation of this system the company “faced liquidation, with the loss of 7,500 jobs, unless it could show a profit in the short term” (Geraghty and Johnson, 1997, p. 107). This revenue management system improved revenues by \$56 million in the first year, and the company was later on sold for \$1.2 billion. This just brings to attention the overall potential impact of a revenue management system.

Guerriero and Olivito (2013) apply revenue management methodologies to the car rental industry. The authors propose dynamic programming models that tackle the problem of

accepting or rejecting a reservation, while taking into consideration forecasted demand and capacity constraints. These models were tested with instances from a rental company, and compared with the typical car rental policy of first-come first-served. And reveal that the policies could assist the operators to control the capacity level and maximize the revenue.

4.1 Fleet Deployment on the rent-a-car Industry

Pachon (2003) structures the fleet deployment process into a sequential hierarchical structure with three phases: pool segmentation, strategic fleet planning and tactical fleet deployment. The first phase consists in understanding the demand and clustering the stations in different pools based on the location and demand-load correlation. The fleet utilization can be improved by grouping the fleet into pools, since the vehicles from a station with surplus can freely move inside the pool to assist another station with shortage. The strategic fleet planning determines the fleet size to be allocated to each pool; this stage includes all the acquisition and vehicle return analysis and inter-pool transfers to meet seasonal demand. Lastly, the tactical fleet planning is responsible for the daily fleet management, with the task of setting the optimal fleet combination to be assigned to the different stations.

In Pachon et al.(2006) this structure is further analysed, by proposing methodologies that take into account the decision making process. The allocation of stations to pools is restricted by the following three constraints: maximum distance allowed between the stations geographical location, maximum number of stations per pool and maximum variability of aggregated daily demand for a pool. These constraints insure that the fleet can be deployed in a timely manner within the pool while not overloading the pool manager, and, lastly, they safeguard against stations with highly volatile demand functions. The tactical fleet planning problem is tackled by subdividing it into a fleet deployment sub-problem and a transportation sub-problem. The first finds the optimal inventory position for the stations at the start of the day, by maximizing the earnings function. The second finds the optimal fleet redistribution among the stations, by minimising the total cost function associated with vehicle transfers. After these processes, a heuristic that combines the results obtained with the decomposition of the problem to attain the global solution is presented.

Another approach taken to tackle the fleet deployment problem was developed by Haensel, et al. (2011), where a two-stage stochastic program is used to optimise the fleet deployment on the network and the capacity controls at station level. The possibility of having multiple car types and reservations with durations larger than a day are not addressed, and the cancellations and late returns are neglected. The stochastic model is tested for a small sample, and if it is implemented in a large scale high computational resources are expected to be necessary.

Fink and Reiners (2006) also present an approach to the short-term decisions about the transportation and fleet deployment, assuming that the strategic and tactical decisions, such as stations clustering and vehicle grouping, are given. The model solves the tactical fleet planning problem, while optimising the fleet utilization and preserving a high customer satisfaction level, by means of minimum cost network flow optimisation. The authors develop a decision support system that, through four main steps, delivers an optimised inventory level for every station for a period of a week, which can be re-optimised throughout the week. The first step, designated as supply, determines the vehicle availability for each group and station for the period. The second step forecasts the demand for the period, taking into consideration the reservations history; the authors, determine the forecasted demand by linear regression. Then, in the third step, by using a minimum cost time-space network model, the fleet deployment is optimised. Lastly, the results obtained in step three are validated by means of simulation. Fink and Reiners approach also took into consideration the possibility of upgrading a reservation due to not having the correct vehicle in the station, which was not taken into consideration in the works presented so far.

Comments

The reviewed literature presents several interrelated approaches to the vehicle fleet planning problem in the car rental business. Due to the scale of the problem approached in this dissertation, the only phase referred by Pachon et al. (2003) that will be studied is the third: tactical fleet deployment.

To optimise the fleet deployment, two objective functions were described: the first one maximizes the profit (which takes into account the reservation earnings and transfer costs), while the second one minimises the cost (which then goes through simulation to be validated). The maximization approach will be further analysed, since it optimises the fleet deployment while taking into account the connection between accepted reservations and transportation costs.

The assumptions taken by the authors are not the same, thus the model to be develop can combine the different approaches taken in order to better suit the problem. The only requirement for the fleet deployment not presented in the reviewed literature is the process to forecast the expected demand. Thus, hereinafter similar problems within the transportation sector will be analysed.

4.2 Fleet Deployment on other transportation sectors

Fan et al. (2008) approach an innovative mobility solution for the worsening traffic congestions in urban areas: carsharing. In Carsharing programs, the client pays hourly for the rented vehicle while having the option of returning it to any of the available locations (it is not required to give back the vehicle to the pick-up location).

The paper presents a multistage stochastic linear integer model to maximize the profits of the carsharing service provider, through cost minimisation. To approach the problem, the authors build a network flow which includes both empty and loaded vehicles' flow (as seen in Figure 7), and make the following assumptions: the transfer time between all the carsharing locations is one day; at the start of any day the fleet manager knows the demand of that day; the demand for every location follows a distribution (discrete or continuous) with known parameters; and the drop-off station is different from the pick-up station. The solution presented determines which reservations to accept and refuse in order to build the most advantageous reservations profile. Moreover, it defines the quantity of vehicles to be reallocated.

Having the network flow represented throughout time could assist with the fleet deployment problem. Also, when matched with other relevant indicators, it can help by presenting significant information to the user, such as dynamic fleet occupation rate.

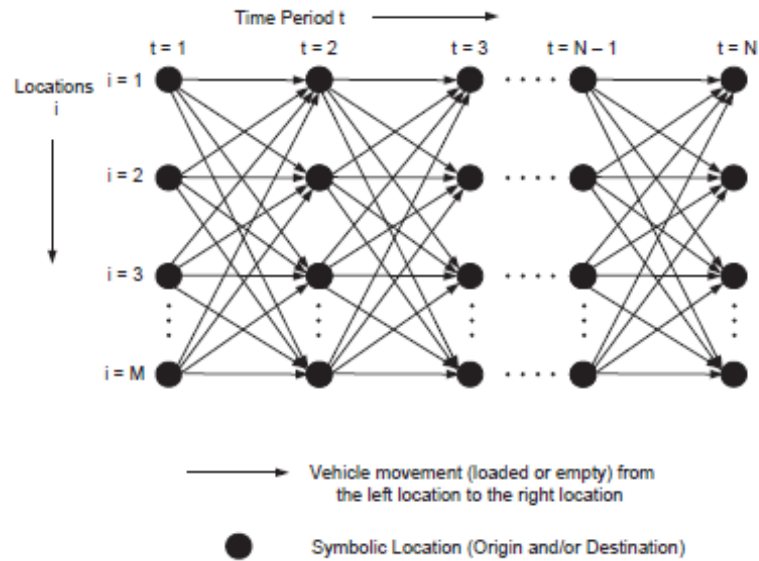


Figure 7 Network flow representation - adapted from Fan 2008

Nair et al. (2013) approach a large-scale bicycle sharing system fleet distribution asymmetry by minimising the fleet redistribution such that most-near future demand is satisfied. In the bicycle sharing system, the client picks-up a bicycle at the nearest station and drops it off at the station closest to his destination. Thus, the authors consider that there are two demand processes at each station: the demand for bicycles and the demand for empty spaces at the station, since it is not only required to have a bicycle at the pick-up station but it is also required to have a free space at the destination. The asymmetry in the fleet distribution is due to the flow from one station to another not being equal to the reverse flow throughout the day. The vehicle flow asymmetry is easily perceived in Figure 8, where the average outflow and inflow is displayed for one station at the peak hours.

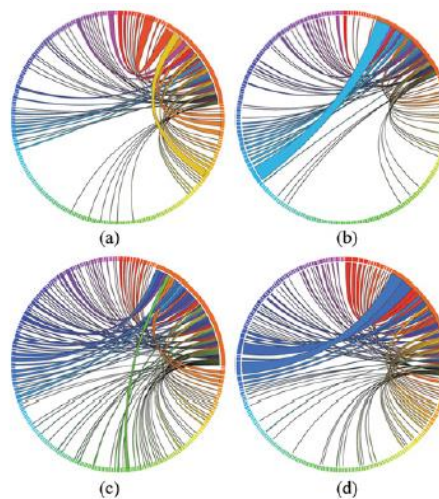


Figure 8 Average inter-station flows exceeding 10trips/day; (a) Average inflow from 8-9 am, (b) Average outflow from 8-9 am, (c) Average inflow from 5-6 pm, (d) Average outflow from 5-6 pm for one station - from Nair et al (2013)

To solve the problem, the authors take into consideration that during demand peaks the amount of resources may not be able to satisfy the future demand, and the opposite as well. This means that in supply peaks the station may not be able to accommodate all the vehicles, making the user unable to park the vehicle at the desired station. The data required by the system was divided in four sections: system configuration (station locations, capacity and fleet size),

inventory level of the station at the time, cost of vehicle transfer, and demand at each station, which, through an analysis of historical data, was observed to be a closest match with the negative binomial distribution. Using a chance-constrained, mixed-integer program, developed in prior work by the authors (Nair and Miller-Hooks, 2011), which minimises the vehicles reallocation costs while taking into consideration a penalisation cost for not meeting the demand, a redistribution plan is generated.

Comments

The problem presented by Nair et al. (2013) is quite interesting due to the large scale of the business. The company has a fleet of 20,000 bicycles spread across 1,450 stations, and the system accounts for as many as 120,000 trips daily. This means that in two days the company would have as many vehicles rented as in the entire history of the rent-a-car business being studied. Having such a strong history of vehicles' renting allows for a better understanding and forecasting of the demand function. The methodology taken to understand the demand probabilistic distribution could also be used in the future to better forecast the demand for the rent-a-car business. Also, Figure 8 visually presents the inflow and outflow of vehicles to a single station, which could also be used in the rent-a-car fleet deployment problem herein analysed, since solely through observation the user could better understand the fleet deployment necessities for each station.

5 Data Handling

The data handled is automatically extracted from the information system through SQL queries. This enables the tool to be accurate and easily updated. To solve the problems presented it is necessary to extract several different fields from multiple tables and cross-check some of the information, in order to get precise and valuable information.

The method used to access the SQL Server was through the Microsoft Office Excel's built-in tool of data retrieval from SQL Server, which gives access to the over five hundred different tables that contain all the company's information. Since the company does not have a log of the information inside every table, or a list of tables with the most important information, it was required to check table by table to verify the usefulness of the information provided. This was an extremely time consuming process which, sometimes, led to assuming irrelevant or misleading information. For example, to determine the fleet available, initially the tool was designed to extract data from seven different SQL tables and compile all the relevant information. However it was later verified that all the required information was present in a single table. One of the criteria that used to be extracted from one of the seven tables is the maximum number of kilometres accepted. The reason this criterion went unnoticed was because the first thousand vehicle entries did not have a value assigned to this criterion. This is just a small example of the complexity of the data finding process.

This chapter presents the information retrieved from the system and the data generated, as well as the process that it undergoes before being utilised in the decision support system. The data that is retrieved from the *Rent-Way* tables is: reservations, impros, vehicles, vehicles damages and repair. The prices of the reservations were obtained from the pricing team, while the vehicle transportation cost table is generated through ViaMichelin.com, as it will be later explained in more detail.

Reservations

When a reservation is created there are many fields to be filled such as dates, client information and requests made by the client. Every time there is a change in the reservation, a new log entry is created with the same reservation number and a different version.

For this study, the data retrieved from the system goes through two filters: reservation version and status. The version filter will keep only the latest version of the reservation while removing all the previous versions. The reservation status can be: *to be Confirmed*, *Confirmed*, *Cancelled*, *not Confirmed*, *Pending on Customer* and *Under Analysis*. Since these data will be used to build the demand forecast, the tool will only take it into consideration if the latest version status is *Confirmed*.

The indicators retrieved from the system are: reservation creation date, pick-up and drop-off dates as well as the respective stations, price charged per day (without taxes) and vehicle group and brand.

Impros

Impro is a technical term used to describe a vehicle that, for some reason, is not available for renting. A couple of examples would be: the vehicle is being transferred between sites or the vehicle is at the mechanic. Every time a vehicle is not available for renting an Impro report has to be created with all relevant information, such as motive and expected return date. This information is used to provide a more in-depth description of the problems. Moreover, if cross-

checked with the vehicles information, it can provide a better perspective of the fleet future availability.

Vehicles

For all the problems described, it will be necessary to have a full understanding of the size of the fleet as well as its availability, position and attributes. To do so the following data was extracted from the information system: plate number, status, blocking and returning date, current station, vehicle group and brand, current kilometres and maximum number of kilometres and both maintenance delimiters (date and kilometres). If the vehicle is currently being rented it will also retrieve the expected reservation finish date.

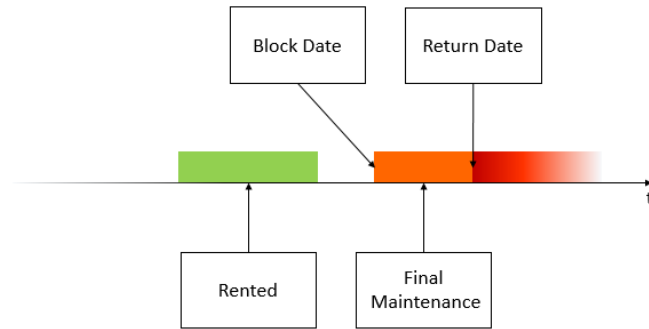


Figure 9 Vehicle's final operations

Every time a vehicle is acquired the maintenance delimiters, the return date and the block date are set. If either maintenance date or number of kilometres is reached, it is advised for the vehicle to be sent to maintenance. Upon returning from maintenance both delimiters are re-defined taking into account the model and age of the vehicle. Upon reaching the blocking date the vehicle must return to the mechanic, where it will undergo a full repair and maintenance to insurance that the vehicle meets the quality standards of the supplier so it can be returned/sold by the return date, as the Figure 9 exemplifies.

The status criterion is retrieved as an integer from 1 to 5, representing the following connotations: 1- *Free*, 2- *On Rental*, 3- *Impro*, 4- *Returned*, 5- *Sold*. The fleet size will be considered as the sum of statuses 1, 2 and 3. Even though vehicles in Impro are not available for renting, they are considered as part of the fleet since none of their returning criteria (return date or maximum number of kilometres) have been met.

Vehicles Damages and Repair

Every time a vehicle is returned to a rental station, a collaborator will check it for damages and log all the new damages, such as scratches, dents or parts missing. If the car accumulates a relevant number of damages or has some damages that could cause vehicle failure or damages to the company's reputation, the car will be sent to be repaired.

The damages are never removed from the damages log. Thus, to obtain an accurate perspective of the vehicles damages, it is necessary to cross-check the information with the vehicle repairs log. To address this, the program cross-checks all damages for each vehicle with the its repair history, and removes all the damages that do not follow equation (3).

$$Date_{Damage} \geq Date_{Repair} \quad (3)$$

Price

The tool takes into consideration two sets of prices: the price applied in the past, which was saved along with the reservation's information, and the price of future reservations. As previously seen, the price setting function is the most complex function of the car rental business. Since the price of future reservations is influenced by several different factors and would require a great understanding of the price elasticity as well as a complete knowledge of all future events, the price of future reservations is assumed to be equal to $Price_{standard}$. This means that the price will depend on group, station and season. This assumption will decrease the accuracy of the fleet deployment model, yet the tool allows the user to freely vary the $Price_{standard}$ to simulate different possibilities.

Vehicles transportation cost

Grupo JAP's transportation department focusses on large quantities transportation, unless there is a planned trip between two renting stations or a need to move several renting vehicles at the same time, this service will not be used, since it is not cost efficient. Thus, for the day-to-day fleet management the current practice is to have a collaborator transporting the vehicle in between sites.

There is no set regulation for single vehicle transportation between sites. Even though it is avoided as much as possible, it happens whenever an accepted reservation does not have a vehicle ready at the required rental station (and the vehicle group upgrade is not possible). Since there was no transportation cost matrix available, a program was created to generate the cost of driving from $Station_1$ to $Station_2$.

To accurately predict the cost of this trip, two options were considered. The first option was using *Google Maps*'s API, which returns to the user the "real" distance of the trip between two addresses. Afterwards, the distance can be multiplied by a fuel consumption rate and fuel price per litre, thus obtaining the fuel cost of the trip. The only constraint is that the API only allows 10 requests per second.

The second option analysed accessed the website www.ViaMichelin.com directly and inserted both addresses. After submitting the data, one can wait and retrieve the final cost. This cost already has gas rate included, as well as toll fares. The disadvantage of this option is that it takes approximately 4 seconds per request, depending on the internet speed, which is 50 times slower than the first option.

Since the stations are unmovable objects and the construction of a new station is not a daily occurrence, there is no need to update the table on a daily basis (or even weekly). Thus, the time consumed building this matrix has a low impact on the overall lead time of the tool. Therefore, since the data retrieved from the second option is much more accurate, due to the inclusion of toll fares and gas costs, the second option was selected.

| | $Station_1$ | $Station_2$ | $Station_3$ | $Station_4$ |
|-------------|-------------|-------------|-------------|-------------|
| $Station_1$ | $Cost_{11}$ | | | |
| $Station_2$ | $Cost_{21}$ | $Cost_{22}$ | | |
| $Station_3$ | $Cost_{31}$ | $Cost_{32}$ | $Cost_{33}$ | |
| $Station_4$ | $Cost_{41}$ | $Cost_{42}$ | $Cost_{43}$ | $Cost_{44}$ |

Figure 10 Transportation Cost Matrix

The Cost Matrix was generated following the structure presented in Figure 10. To decrease the time of retrieving data, it is assumed that a trip from $Station_1$ to $Station_2$ has the same cost as a trip from $Station_2$ to $Station_1$. For stations that are in the same location but have different station numbers (usually happens between a rental station and its warehouse) as well as for the costs in the diagonal of the matrix, the cost is assumed to be null.

$$Number\ of\ Requests = \frac{1}{2} (Number\ of\ Stations^2 - Number\ of\ Stations) \quad (4)$$

For a company with 56 stations the *Number of Requests* is 1540, and with a processing time of approximately 4 seconds per request, the tool would take 1h42min to complete. To avoid the user having to wait for such a long time every time a new station is created in the system, the tool allows the user to select which station to update.

6 Decision support system

A decision support system was created to tackle the problems at hand. This tool was created with the purpose of delivering meaningful results and insights while maintaining the highest level of flexibility possible. The concept of flexibility is to not only provide a good solution but also to let the user simulate different scenarios. Since all the data fields are editable, the user can freely increase or decrease any field in his accordance.

This flexibility can significantly improve both the solution and the usability of the tool, since every year there are new occurrences that will directly or indirectly change the demand function or the vehicle's availability. For example, an international conference that is being scheduled to Portugal will most likely increase the demand in stations near airports. This tool can also potentially allow the company to satisfy other non-quantitative criteria such as customer satisfaction, or even understand the full impact of switching from the currently used policy to an improved or optimised solution. Furthermore, flexibility is critical to allow the user to take into consideration data that is not covered in the information system.

In this chapter the approaches taken to solve the different issues are presented. Initially, the operations control problem is tackled by creating a warning system, as seen in Figure 11 and explained in the first section. The purpose of this system is to visually warn the user when actions need to be taken.

| Limite 3000 | Limite 20 | Limite 15 | Limite 20 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
|--|------------|-----------|---------------------------|--------|----------|---------|--------|---------|----------|--------|--------|-------|----------|--------|--------|---------|----------|--------|--------|---------|----------|--------|--------|---------|----------|--------|--------|-------|----------|--------|--------|-------|---|-----------|------|----------|--------|----------|------------|-------|-------|----------|------------|-----|-------|----------|------------|-----|-------|----------|------------|-----|-------|----------|------------|-----|-------|----------|------------|-----|-------|----------|------------|-----|-------|---|-----------|------|----------|--------|----------|------------|-----|-------|----------|------------|-----|-------|----------|------------|-----|---------|----------|------------|-----|---------|----------|------------|-----|-------|----------|------------|-----|-------|----------|------------|---|-------|---|-----------|------|----------|--------|----------|------------|----|---------|----------|------------|---|---------|----------|------------|----|---------|----------|------------|----|---------|----------|------------|---|---------|----------|------------|----|---------|----------|------------|---|-------|
| Kilometragem | Devoluções | Bloqueio | Revisões Planeadas (data) | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| <table border="1"> <thead> <tr> <th>Matrícula</th><th>Km Actual</th><th>Km Max</th><th>Status</th></tr> </thead> <tbody> <tr><td>41-QN-94</td><td>194 251</td><td>55 210</td><td>Alugado</td></tr> <tr><td>71-NV-40</td><td>89 557</td><td>90 000</td><td>Livre</td></tr> <tr><td>11-NX-32</td><td>88 300</td><td>90 000</td><td>Alugado</td></tr> <tr><td>71-NV-35</td><td>91 837</td><td>90 000</td><td>Alugado</td></tr> <tr><td>71-NV-33</td><td>90 378</td><td>90 000</td><td>Alugado</td></tr> <tr><td>03-QN-63</td><td>63 708</td><td>60 000</td><td>Livre</td></tr> <tr><td>03-QN-62</td><td>62 707</td><td>60 000</td><td>Livre</td></tr> </tbody> </table> | Matrícula | Km Actual | Km Max | Status | 41-QN-94 | 194 251 | 55 210 | Alugado | 71-NV-40 | 89 557 | 90 000 | Livre | 11-NX-32 | 88 300 | 90 000 | Alugado | 71-NV-35 | 91 837 | 90 000 | Alugado | 71-NV-33 | 90 378 | 90 000 | Alugado | 03-QN-63 | 63 708 | 60 000 | Livre | 03-QN-62 | 62 707 | 60 000 | Livre | <table border="1"> <thead> <tr> <th>Matrícula</th><th>Data</th><th>Daqui a:</th><th>Status</th></tr> </thead> <tbody> <tr><td>08-PV-95</td><td>28/12/2015</td><td>- 176</td><td>Livre</td></tr> <tr><td>05-QG-26</td><td>20/06/2016</td><td>- 1</td><td>Livre</td></tr> <tr><td>05-QG-34</td><td>20/06/2016</td><td>- 1</td><td>Livre</td></tr> <tr><td>05-QG-19</td><td>20/06/2016</td><td>- 1</td><td>Livre</td></tr> <tr><td>05-QG-21</td><td>20/06/2016</td><td>- 1</td><td>Livre</td></tr> <tr><td>05-QG-32</td><td>20/06/2016</td><td>- 1</td><td>Livre</td></tr> <tr><td>04-QG-84</td><td>20/06/2016</td><td>- 1</td><td>Livre</td></tr> </tbody> </table> | Matrícula | Data | Daqui a: | Status | 08-PV-95 | 28/12/2015 | - 176 | Livre | 05-QG-26 | 20/06/2016 | - 1 | Livre | 05-QG-34 | 20/06/2016 | - 1 | Livre | 05-QG-19 | 20/06/2016 | - 1 | Livre | 05-QG-21 | 20/06/2016 | - 1 | Livre | 05-QG-32 | 20/06/2016 | - 1 | Livre | 04-QG-84 | 20/06/2016 | - 1 | Livre | <table border="1"> <thead> <tr> <th>Matrícula</th><th>Data</th><th>Daqui a:</th><th>Status</th></tr> </thead> <tbody> <tr><td>87-NI-12</td><td>15/06/2016</td><td>- 6</td><td>Livre</td></tr> <tr><td>87-NI-19</td><td>15/06/2016</td><td>- 6</td><td>Livre</td></tr> <tr><td>87-NI-17</td><td>15/06/2016</td><td>- 6</td><td>Alugado</td></tr> <tr><td>75-NJ-96</td><td>15/06/2016</td><td>- 6</td><td>Alugado</td></tr> <tr><td>87-NI-18</td><td>15/06/2016</td><td>- 6</td><td>Impro</td></tr> <tr><td>30-NN-57</td><td>15/06/2016</td><td>- 6</td><td>Impro</td></tr> <tr><td>26-OB-09</td><td>24/06/2016</td><td>3</td><td>Livre</td></tr> </tbody> </table> | Matrícula | Data | Daqui a: | Status | 87-NI-12 | 15/06/2016 | - 6 | Livre | 87-NI-19 | 15/06/2016 | - 6 | Livre | 87-NI-17 | 15/06/2016 | - 6 | Alugado | 75-NJ-96 | 15/06/2016 | - 6 | Alugado | 87-NI-18 | 15/06/2016 | - 6 | Impro | 30-NN-57 | 15/06/2016 | - 6 | Impro | 26-OB-09 | 24/06/2016 | 3 | Livre | <table border="1"> <thead> <tr> <th>Matrícula</th><th>Data</th><th>Daqui a:</th><th>Status</th></tr> </thead> <tbody> <tr><td>28-QV-31</td><td>01/07/2016</td><td>10</td><td>Alugado</td></tr> <tr><td>36-QU-67</td><td>25/06/2016</td><td>4</td><td>Alugado</td></tr> <tr><td>28-QV-39</td><td>01/07/2016</td><td>10</td><td>Alugado</td></tr> <tr><td>42-QV-11</td><td>02/07/2016</td><td>11</td><td>Alugado</td></tr> <tr><td>37-QU-34</td><td>25/06/2016</td><td>4</td><td>Alugado</td></tr> <tr><td>28-QV-32</td><td>01/07/2016</td><td>10</td><td>Alugado</td></tr> <tr><td>37-QU-33</td><td>25/06/2016</td><td>4</td><td>Impro</td></tr> </tbody> </table> | Matrícula | Data | Daqui a: | Status | 28-QV-31 | 01/07/2016 | 10 | Alugado | 36-QU-67 | 25/06/2016 | 4 | Alugado | 28-QV-39 | 01/07/2016 | 10 | Alugado | 42-QV-11 | 02/07/2016 | 11 | Alugado | 37-QU-34 | 25/06/2016 | 4 | Alugado | 28-QV-32 | 01/07/2016 | 10 | Alugado | 37-QU-33 | 25/06/2016 | 4 | Impro |
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| 11-NX-32 | 88 300 | 90 000 | Alugado | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 71-NV-35 | 91 837 | 90 000 | Alugado | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 71-NV-33 | 90 378 | 90 000 | Alugado | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
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| 05-QG-19 | 20/06/2016 | - 1 | Livre | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 05-QG-21 | 20/06/2016 | - 1 | Livre | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 05-QG-32 | 20/06/2016 | - 1 | Livre | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 04-QG-84 | 20/06/2016 | - 1 | Livre | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Matrícula | Data | Daqui a: | Status | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 87-NI-12 | 15/06/2016 | - 6 | Livre | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 87-NI-19 | 15/06/2016 | - 6 | Livre | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 87-NI-17 | 15/06/2016 | - 6 | Alugado | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 75-NJ-96 | 15/06/2016 | - 6 | Alugado | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 87-NI-18 | 15/06/2016 | - 6 | Impro | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 30-NN-57 | 15/06/2016 | - 6 | Impro | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 26-OB-09 | 24/06/2016 | 3 | Livre | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Matrícula | Data | Daqui a: | Status | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 28-QV-31 | 01/07/2016 | 10 | Alugado | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 36-QU-67 | 25/06/2016 | 4 | Alugado | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 28-QV-39 | 01/07/2016 | 10 | Alugado | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 42-QV-11 | 02/07/2016 | 11 | Alugado | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 37-QU-34 | 25/06/2016 | 4 | Alugado | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 28-QV-32 | 01/07/2016 | 10 | Alugado | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 37-QU-33 | 25/06/2016 | 4 | Impro | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |

Figure 11 Segment of Warning System

In the second section of the chapter, a fleet deployment optimisation model is developed and integrated into the tool. And lastly, to assist the revenue management planning process an occupation rate planning display (Figure 12) and a price elasticity visualizer (displayed in Annex B) were developed and are presented in the final section.

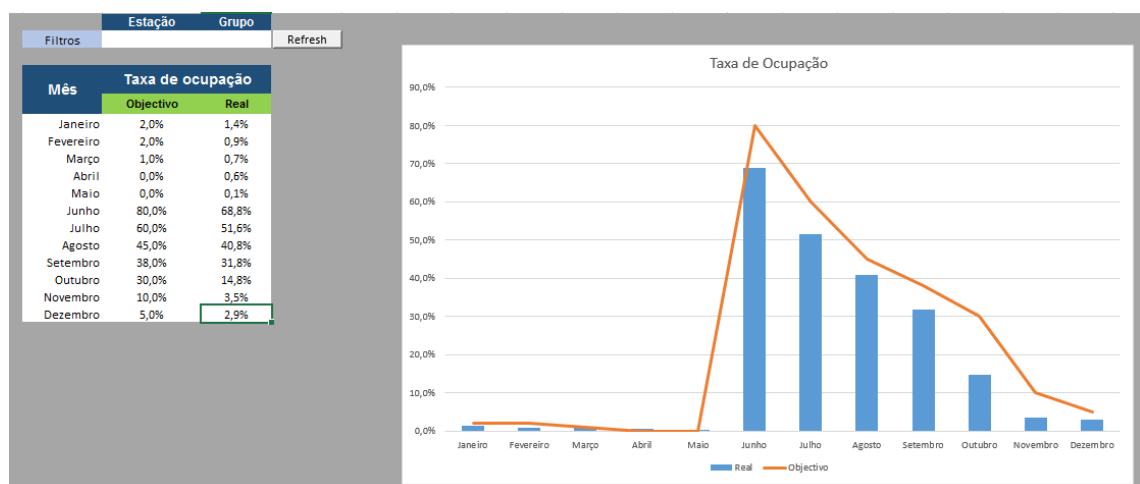


Figure 12 Occupation rate planning control panel and display

6.1 Operations Control

Before drawing advanced strategic plans for the company growth or designing a marketing strategy, it is essential for the company to have a firm grasp over all of its resources. To achieve this, it is key that the rent-a-car company has a clear set of control features to ensure that their products, the vehicles, are at a satisficing level as well as within the contractual agreements established upon the acquisition of the vehicle.

To comply with the customer satisficing level of vehicle there are two key issues to ensure: up-to-date vehicle maintenance and a non-existent or reduced number of damages. In fact, to ensure that the vehicle provided to the customer presents satisficing levels of conformance, the vehicle has to have its maintenance up-to-date as well as a non-existent or reduced number of damages. These criteria are the basic level of expectation that the client has when renting a vehicle, and non-compliance can negatively impact the company. For example, if a vehicle, without up-to-date maintenance, has an accident caused by a mechanical failure the company can be subjected to law-suits and loss of brand image. Even if no accident occurs, a rented vehicle with an overdue maintenance date, besides the fact that it can lead to more expensive repairs and other fees such as toeing, it can also put the life of the client at risk. If the rented vehicle presents several damages or even a few number of severe damages (such as deep scratches and/or dents), this can cause a loss for the company's image or, in more extreme cases, a loss of revenue due to the reservation's cancelation.

To control the vehicles' operational requirements, a Warning System was developed. This system compares the previously described customer satisfaction requirements and contractual requirements with the company's acceptance standard. To do so, it cross-examines updated data retrieved from the database and displays all vehicles that exceed the established limits. The warning system presents all the vehicles that either fail to meet the acceptance levels or exceed the established limits for the following criteria:

1. Return date: date when the vehicle is contractually required to return to the car retail;
2. Block date: date when the vehicle is required to be sent to the mechanic for final maintenance;
3. Planned maintenance - date: date when the vehicle should be sent for maintenance
4. Planned maintenance - kilometre: limit number of kilometres before maintenance is required;
5. Maximum number of kilometres: maximum number of kilometres contractually allowed for the vehicle to be repurchased by the car retail;
6. Damage: damages that exceed the minimum quality standard allowed;
7. Vehicles information: critical information missing from the information system.

Date control

The control of the first three criteria (related with the return, block and planned maintenance dates) is done by following Equation (5) in which the tool performs a direct comparison between the current date and the requirements date.

$$t_{Max} < t_{Current} + Limit \quad (5)$$

The formula (5) depicts the process followed, where $t_{Current}$ represents the current date and t_{Max} represents the date agreed upon setting the contract. For example, for criterion 1 (return date) the general practice of the business is to set a $Limit = 30$ days, so if $t_{Max \text{ Return Date}}$ exceeds $t_{Current} + 30$ then the vehicles information will be presented in the warning system.

According to the logistics team, which will be the main user of this system, the relevant information for this criteria is vehicle's plate number, t_{Max} , days until t_{Max} and vehicle's status. The status represents the vehicle's availability, and it can either be *Free*, *On Rental* or *Impro*. If the status is *On Rental*, a comment box will automatically appear specifying the date when the vehicle is going to be returned to the rental station, this way the user knows when it is possible to take action. If the status is *Impro*, the tool will also create a comment specifying the reason for the vehicle unavailability as well as the date when the impro was generated.

The status cells are colour coded according to the degree of actions that have to be taken in order to address the issue. Therefore, a vehicle that is currently on *Impro* will be coded as green, since there is an action already being taken, such as vehicle being in the mechanic or being sent to it. If the status is *Free*, the colour coding will be red, since the manager should immediately take action as in sending the vehicle to the mechanic or to the supplier. Lastly, if the status is *On Rental*, the colour coding will be yellow, meaning that the issue cannot be addressed at the moment, yet it requires control of the reservation finishing date, as seen in Figure 13.

Limite

15

| Bloqueio | | | |
|-----------|------------|----------|---------|
| Matricula | Data | Daqui a: | Status |
| 87-NI-12 | 13/06/2016 | 1 | Livre |
| 87-NI-17 | 14/06/2016 | 2 | Alugado |
| 75-NJ-96 | 15/06/2016 | 3 | Alugado |
| 87-NI-19 | 15/06/2016 | 3 | Alugado |
| 30-MN-57 | 15/06/2016 | 3 | Impro |
| 87-NI-18 | 15/06/2016 | 3 | Impro |

Revisão

Matricula: 72-OT-82

Aluguel termina a: 12/06/2016

Figure 13 Warning system On Rental example

Kilometres control

Criteria 4 and 5 (maximum number of kilometres and planned maintenance by kilometres) follow the inequality below, similarly to the process previously described. Here, Km_{Max} represents either the maximum number of kilometres. If the inequality is verified, the vehicle's relevant information will be displayed in the warning system. For example, the general practice of the business is to do maintenance when the vehicle reaches 30000km (Km_{Max}), and the standard limit used is 3000km, so if $Km_{Current} > 27000km$ the vehicle's information will be displayed in the information system.

$$Km_{Max} < Km_{Current} + Limit \quad (6)$$

The relevant information displayed refers to the vehicle's plate number, Km_{Max} , days until $Km_{Current}$ and vehicle status. As seen in Figure 14, the status is displayed in the exact same way as previously seen in the date control.

| Limite | | 3000 | |
|--------------|-----------|--------|---------|
| Kilometragem | | | |
| Matricula | Km Actual | Km Max | Status |
| 41-QN-02 | 21228 | 22 140 | Livre |
| 71-NV-40 | 88 840 | 90 000 | Livre |
| 11-NX-92 | 88 300 | 90 000 | Alugado |
| 71-NV-33 | 90 378 | 90 000 | Alugado |
| 71-NV-35 | 91263 | 90 000 | Alugado |
| 03-ON-63 | 63 096 | 60 000 | Livre |
| 03-ON-59 | 59 749 | 60 000 | Alugado |
| 03-ON-65 | 59 539 | 60 000 | Alugado |
| 03-ON-62 | 62 639 | 60 000 | Impro |
| 86-NA-80 | 104 453 | 90 000 | Livre |

| Matricula |
|-----------|
| 41-QN-02 |
| 08-PV-95 |
| 05-QG-26 |
| 05-QG-34 |
| 05-QG-19 |
| 05-QG-21 |
| 05-QG-32 |
| 04-OC-84 |

Colisão - Aberto a:
04/06/2016

Figure 14 Warning system Impro comment

Damages control

When reporting the damages of a vehicle, the user has to define a damage status that characterises the damage level, with three possible classifications: light, serious and part missing. If a part is missing, it will be replaced before the vehicle is rented again.

In order to characterize a damage as light or serious, the rental station agent (that inserts the data into the system) has to take into account several different factors, such as damage depth, area affected and damage repair cost. Since the damage status depends on the perception of the rental station agent the seriousness of the problem may be inaccurately characterised. Therefore, a new classification for damage type was created. This classification differentiates the light and serious damages according to expected repair cost. If the expected repair cost exceeds the value set in the tool, it will be considered as a serious damage (independently of the characterization set by the rental station agent).

$$\sum Damages_{Light} + \sum Damages_{Serious} < Limit_{Total} \quad (7)$$

$$\sum Damages_{Serious} < Limit_{Serious} \quad (8)$$

$$\sum Cost(Damages_{Serious}) + \sum Cost(Damages_{Light}) < Limit_{Cost} \quad (9)$$

The formulas above represent the three types of damage control analysed by the tool. The first formula controls the total quantity of damages, while the second one controls the number of serious damages, and lastly, the third one controls the overall expected repair cost. If a vehicle exceeds any of the limits set in (7), (8) or (9), the vehicle's relevant information will be displayed in the warning system.

The vehicle's relevant information is: plate number, total amount of damages, amount of series damages, value of damages and status. As seen in Figure 15, the status is displayed in the exact same way as in previously seen in the date control and kilometres control.

| Limite | 8 | 5 | 1000 | 250 |
|-----------|------------|--------|-----------|---------|
| Danos | | | | |
| Matricula | Quantidade | Graves | Valor | Status |
| 14-OQ-44 | 13 | 0 | 605,69 € | Alugado |
| 13-OX-00 | 10 | 0 | 888,90 € | Alugado |
| 37-OZ-74 | 11 | 0 | 1178,70 € | Livre |

Figure 15 Warning system Damage Control

Vehicle information

The last criterion is related with vehicle information and is set to retrieve all vehicles that have critical information missing in the database. Not having all the information correctly inserted into the system may disable the operations control utility as well as induce inaccuracy into the strategic planning.

To insert a new vehicle into the database there are certain mandatory fields, such as plate number and brand, and other fields that depend on the type of contract, such as return date and maximum number of kilometres. The vehicle's block date is not within these mandatory fields, since it is a date established by the logistics team, and it is the last important field to be fulfilled. So, in order to control if the vehicle's information has been inserted into the system, the tool verifies the existence of the blocking date.

At the moment, there is a person that is responsible to manually check and control all the information inserted in the system, including the block date. However, there are still vehicles not verified, so in order to both assist this person and to guarantee the functionality of the tool, whenever a vehicle does not have a block date, the system will assume that it is 3 years after the current date. At the same time, it will report that this vehicle has missing information in the warning system, as seen in Figure 16.

| Informação em Falta | |
|---------------------|-----------|
| Unit Nr | Matricula |
| 10603 | 18-RG-56 |
| 11580 | 21-RJ-87 |
| 11848 | 32-RL-97 |
| 11873 | 32-RL-89 |
| 11925 | 33-RL-44 |
| 11926 | 33-RL-45 |

Figure 16 Warning system "Information Missing"

6.2 Fleet deployment

With the detailed understanding of the fleet status provided by the warning system, the company can start designing a clear plan to increase its revenue. In the rent-a-car business, a company is able to control two key areas that can boost its revenue. Firstly, it can decide on how to distribute its fleet between the rental stations in order to better meet demand (fleet deployment) and, secondly, it can control the prices charged for the reservations.

Currently, the day-to-day fleet deployment is done by the logistics team, which coordinates the transfer of vehicles to comply with the accepted reservations before the client arrives at the station. Besides this, a fleet deployment plan is done, by region, to attend to high demand peaks, such as increasing significantly the fleet in Faro during summer season, and to consider in-fleets (acquisition of new vehicles to the fleet), since these situations require a more structured strategy to better optimise the vehicle occupation rate.

To enhance the fleet deployment process, an optimisation model was developed. This model was created taking into consideration the company's specific setting and constraints, and was implemented in CPLEX/OPL in order to obtain the optimal solution.

6.2.1 Model

The objective of the model is to deliver a fleet deployment plan that takes the past demand and expect growth into consideration, and delivers a clear and detailed vehicle transportation plan for a single day, in order to optimise the company's revenue. A mixed integer programming model was thus defined as follows.

Indexes and parameters

| | |
|--------------------------|--|
| S | Number of stations considered |
| G | Number of groups considered |
| D | Maximum number of days of rental |
| $i, j \in \{1 \dots S\}$ | Index for rental stations |
| $g = \{1 \dots G\}$ | Index for vehicle groups |
| $d = \{1 \dots D\}$ | Index for days on rental length |
| P_{gd} | Price for a reservation of d days for a vehicle of group g |
| C_{ij} | Cost for transferring a vehicle from station i to j |
| D_{igd} | Demand of reservations requiring a vehicle of group g , for d days, available at station i |
| $Qmax_i$ | Station i maximum capacity (in number of vehicles) |
| A_{ig} | Available fleet of group g at station i (excludes occupied vehicles and impros) |

Decision variables

| | |
|-----------|--|
| x_{ig} | Stock of vehicles of group g at station i |
| y_{ijg} | Number of vehicles from group g transferred from station i to j |
| r_{igd} | Number of reservations of d days of group g fulfilled from station i |

Optimisation model

Objective function:

$$\text{Max} \quad \sum_{g=1}^G \sum_{d=1}^D P_{gd} \left(\sum_{i=1}^S r_{igd} \right) - \sum_{i=1}^S \sum_{j=1}^S C_{ij} \left(\sum_{g=1}^G y_{ijg} \right) \quad (10)$$

Subject to:

$$\sum_{g=1}^G x_{ig} \leq Qmax_i \quad \forall i \quad (11)$$

$$r_{igd} \leq D_{igd} \quad \forall i, g, d \quad (12)$$

$$\sum_{d=1}^D r_{igd} \leq x_{ig} \quad \forall i, g \quad (13)$$

$$x_{ig} \leq A_{ig} - \sum_{k=1}^S y_{ikg} + \sum_{k=1}^S y_{kig} \quad \forall i, g \quad (14)$$

$$x_{ig} \in \mathbb{Z}_0^+ \quad \forall i, g \quad (15)$$

$$y_{ijg} \in \mathbb{Z}_0^+ \quad \forall i, g, d \quad (16)$$

$$r_{ijg} \in \mathbb{Z}_0^+ \quad \forall i, g, d \quad (17)$$

The objective function (10) aims to maximize the profit. To do so, the function determines the total earnings by multiplying the number of reservations by their price, as seen in (18), and subtracts the total transferral costs, as represented in equation (19).

Constraint (11) ensures that the maximum capacity of the station is not exceeded, to ensure that there is always a parking spot for the vehicle at the rental station.

Constraints (12) and (13) delimit the number of reservations fulfilled, to ensure that it does not exceed neither the available capacity nor the demand.

Constraint (14) determines the stock size of the station by group. This is calculated by subtracting the number of vehicles that leave the station and adding the vehicles that arrive to the station to the existing available fleet.

$$\sum_{g=1}^G \sum_{d=1}^D P_{gd} \left(\sum_{i=1}^S r_{igd} \right) \quad (18)$$

$$\sum_{i=1}^S \sum_{j=1}^S C_{ij} \left(\sum_{g=1}^G y_{ijg} \right) \quad (19)$$

6.2.2 Data requisites

To run this model, specific data is required, which is retrieved from its sources and pre-processed by the tool in an automated way. Another pre-processing step is related to the demand forecast. Initially, the demand forecast function was equal to the sum of the reservations accepted in the previous years. Even though this is a rudimentary method, the data supplied was insufficient to develop more advanced forecasting methods. The problem observed was that, with the annexation of the SIXT brand to the JAP Rent-a-Car, the logistics team changed some of their groups' naming in order to align them with the SIXT brand. Moreover, some stations' references were changed to meet with the Cobra information system designation.

Therefore, the initial demand forecasting function for a day_x followed the equation (20), where the demand is considered to be equal to the sum of demand for the same day in the previous years. However, taking into account that the groups' naming changed, the stations' reference changed and that there was a large increase of the available fleet, the demand forecasting function presented in (20) will not deliver a reliable forecast.

$$D_{igd}(\text{day}_x) = \sum_{\text{Year start of operations}}^{\text{Current year}} D_{igd}(\text{day}_x) \quad (20)$$

To tackle this inaccuracy and to be able to insert an expected business growth in to the forecast, a yearly demand ratio was created. As seen in (21), the tool forecasts the demand by multiplying the demand of a specific year by a ratio provided.

$$D_{igd}(\text{day}_x) = \text{Factor}_{\text{year}} \sum_{\text{Year start of operations}}^{\text{Current year}} D_{igd}(\text{day}_x) \quad (21)$$

| Year | Factor | Demand |
|------|--------|--------|
| 2015 | 160% | 24 |
| 2014 | 80% | 17 |
| 2013 | 50% | 12 |

For example, if the table above represents the past demand and the factors for day_x , station i , group g and duration d , then, $D_{igd} = 24 \times 1,6 + 17 \times 0,8 + 12 \times 0,5 = 58$.

Another pre-processing issues is related with corporate contracts that require the vehicle to be available to only one client-company. This is usually the case when corporate clients require fast and easy car access without having to worry about maintenance and other issues. For this to happen, a virtual rental station is created in the information system, and these vehicles are allocated to it. When running the fleet deployment data compiler, the tool will not take these into account since they have been fixed to a single station.

6.2.3 Implementation and results

The initial objective of the tool was to deliver a daily transfer plan. When running the fleet deployment tool, an issue found was that, when considering the reservations for just one day of the year, it was not economically viable to transfer a vehicle from Station_i to Station_j . This is due to both high transportation costs as well as a small reservations history. To tackle this, the tool allows the user to select an interval of time to be analysed. To do so, the system considers that the demand is equal to the sum of the demand forecast for the days within the interval, as represented in equation (22). As for the available fleet, two different values based on the historical data, may be used: maximum and average number of vehicles in a station throughout the interval of time. The first scenario is more liberal, since the program will calculate a solution taking into account the maximum number of vehicles located in every station throughout the given time frame. This solution, as it will be analysed, allows the user to know the potential profit for the time frame. The second scenario gives a more realistic solution for the fleet optimisation problem, since it takes into consideration the average number of vehicles in every station.

$$D_{igd} = \sum_{\text{Start of interval}}^{\text{End of interval}} D_{igd} \quad (22)$$

The processor used to run the model was an Intel® Core™ i7-2630QM with a 2GHz CPU and a 8,00BG RAM memory.

The characteristics of the instances run for the first scenario are displayed in Figure 17. In order to understand the importance of having a growth ratio for the forecasting demand function and its effect on the optimised solution, there are two instances displayed: the first presents the solution for parameters without taking into consideration the ratio, while the second one considers it. As it is observed, the only parameter that changes is the number of forecasted

reservations. As expected, the number of reservations is higher for the instance which considers the ratio, since it takes into consideration the forecasted growth. The ratio gives a higher importance to the year 2015, the year when the SIXT's franchising was bought, than to the year 2001, when Grupo JAP's rent-a-car business was initiated, after all, the fleet size and the market reached was completely different from what it is now.

The profit obtained is, as previously stated, calculated only taking into consideration the transportation costs (in the cost-side of the profit function). The profit in the instance with ratio is 278.086€ (which is 28,9%) higher than in the instance without ratio. This is mainly due to a higher number of reservations accepted (906 more) and, consequently, a higher percentage of fleet occupation (23,5% higher). It also has a slightly lower number of transfers.

| Interval | from | to |
|---|---------------|-------------|
| | 01-07-2016 | 07-07-2016 |
| | Without Ratio | With Ratio |
| Number of stations (S) | 52 | 52 |
| Number of groups (G) | 56 | 56 |
| Number of Available vehicles (A) | 3852 | 3852 |
| Maximum number of days on rental (D) | 86 | 86 |
| Number of reservations forecasted | 2924 | 3923 |
| Number of vehicles Transferred | 438 | 352 |
| Reservations Accepted | 2787 | 3690 |
| Total duration of Reservations Accepted | 19971 | 27102 |
| Profit | 961.468 € | 1.239.554 € |
| Average profit of a reservation (per day) | 48,14 € | 45,74 € |
| Occupation Ratio | 72,35% | 95,79% |
| Processing time (s) | 52,37 | 55,66 |

Figure 17 Maximum number of vehicles - instances comparison

In the second scenario, characterised in Figure 18, a comparison between instances with and without taking the demand forecast ratio is also performed, yet considering that the number of available vehicles is the average number of vehicles available in a station throughout the interval of time selected (from 01-07-2016 to 07-07-2016). When comparing the two instances presented in Figure 18, the conclusions taken are the same as the conclusions taken in Figure 17: an increase of profit due to an increase of the reservations accepted as well as a decrease of transfers.

| Interval | from | to |
|---|---------------|-------------|
| | 01-07-2016 | 07-07-2016 |
| | Without Ratio | With Ratio |
| Number of stations (S) | 52 | 52 |
| Number of groups (G) | 56 | 56 |
| Number of Available vehicles (A) | 3761 | 3761 |
| Maximum number of days on rental (D) | 86 | 86 |
| Number of reservations forecasted | 2924 | 3923 |
| Number of vehicles Transferred | 456 | 374 |
| Reservations Accepted | 2782 | 3687 |
| Total duration of Reservations Accepted | 19963 | 27094 |
| Profit | 960.668 € | 1.238.645 € |
| Average profit of a reservation (per day) | 48,12 € | 45,72 € |
| Occupation Ratio | 73,97% | 98,03% |
| Processing time (s) | 55,21 | 51,63 |

Figure 18 Average number of vehicles - instances comparison

As expected, the number of vehicles taken into consideration is slightly lower when considering the average number of vehicles in the station throughout the interval than when considering the maximum number of vehicles. The optimal profit decreases, in both situations, a bit more than a thousand euros, which constitutes less than 1% of the total profit.

6.2.4 Extended model

Currently, the company has some rental stations annexed to specific brands' dealerships. For example the rental station 08 in Paredes is a Renault dealership. In order to keep the brand's image, the company tries to match the rental vehicle's brand with the dealership brand when reallocating the vehicles. Since this preference is not a mandatory constraint and the rent-a-car business does not have a strict quantification of this preference, a new, extended version of the model was developed to address this problem. This model includes the nomenclature referred in 6.2.1 and adds a brand constraint for certain stations, as represented in Constraint (23).

Index and parameter

$b=\{1\dots B\}$ Index for vehicle groups (with a specific brand)

B_i Set of groups (with a specific brand) accepted in station i

Constraint

$$\sum_{g=1}^G x_{ig} \leq \sum_{b=1}^B x_{ib} \quad \forall i \quad (23)$$

In order to segregate the vehicles according to their brand, the tool would be required to create a new set of groups that takes into consideration the brands that have specific requirements. For example, Audi vehicles are one of the car brands preferred by stations 6 and 26, and in the company there are only three different groups with Audi vehicles, which are CCMR, FWAR and LTAR. Therefore, the tool created three extra groups: CCMR A, FWAR A and LTAR A, which would also result in the following constraints of type (23):

$$\begin{aligned} \sum_{g=1}^G x_{i_6g} &\leq x_{i_6 \text{ CCMR A}} + x_{i_6 \text{ FWAR A}} + x_{i_6 \text{ LTAR A}} \\ \sum_{g=1}^G x_{i_{26}g} &\leq x_{i_{26} \text{ CCMR A}} + x_{i_{26} \text{ FWAR A}} + x_{i_{26} \text{ LTAR A}} \end{aligned}$$

The demand function would also have to be changed to include the new groups, to do so the tool would have to retrieve the plate number attached to the accepted reservations and compare it with the vehicles information to know which brand was used for the reservation.

6.3 Revenue Management

This section emerges as a complement to the fleet deployment problem tackled in the previous section. The basic fleet deployment solution is obtained only taking into consideration the past demand and the expected growth ratio. Even though the tool allows the user to manipulate part of the data in order to deliver a better solution by, for example, creating extra reservations for an important event date, the tool still fails to take into account the effect of price fluctuations in the demand function. This is a challenge transversal to the entire rent-a-car industry, and this is a theme widely explored in different papers, for example, Madden and Russel (2012).

“An organisation’s ability to generate even as little as a few extra cents per sale, when it comes within minimal or no additional cost, can make a noticeable impact on the bottom line.” (Lieberman, 2004, p. 97). Within the SIXT pricing team, not many supporting quantitative methods are used to tackle this problem. The team mostly relies on the experience obtained throughout the years, while doing a constant price comparison with the competitors. Still, there is a lack of understanding of what is the client sensitivity to the price.

In this section, two revenue management supporting tools will be presented. Firstly, a fleet occupation rate visualizer is presented and, secondly, a price elasticity display is presented as well as its advantages and the possibilities that it enables.

6.3.1 Fleet Occupation Rate

In the rent-a-car business, just like in the airline industry “if customers make reservations early, low fares might be available, but if customers call at the last minute, they will probably have to pay the full fare” (Kimes, 1989, p. 348). This way, the company can capitalize on a smaller availability of vehicles as well as promote early bookings, which will improve fleet deployment planning. In this setting, a critical question arises: how should the price be increased throughout the time? In fact, the price should be increased if the actual fleet occupation rate is higher than a previously planned occupation rate, which is done in order to keep an available stock for last minute reservations that have a higher profit margin.

Without taking into account special offers or discounts, which are out of the scope of this analysis, the prices are either constant or raised (never decreased). This fluctuation depends on the company’s strategy. Every month, the company defines goals for the occupation rates for the following months, and according to these objectives the prices are changed throughout the month to either increase or decrease the occupation rate growth. This is especially important for the high season months, where, as mentioned above, last minute reservations have a profit margin multiple times higher than reservations booked months before.

To assist the pricing team in controlling this important metric, the tool provides a clear graph that only requires one click to generate. This graph seen in Figure 19, displays the current occupation rate against the objective. The graph in this Figure was generated on the 7th of June for the entire fleet and taking into consideration all the rental stations, and as it is possible to observe both expected occupation rate (line) and the actual occupation rate (bars) are decreasing with the increase of time, as it would be expected.

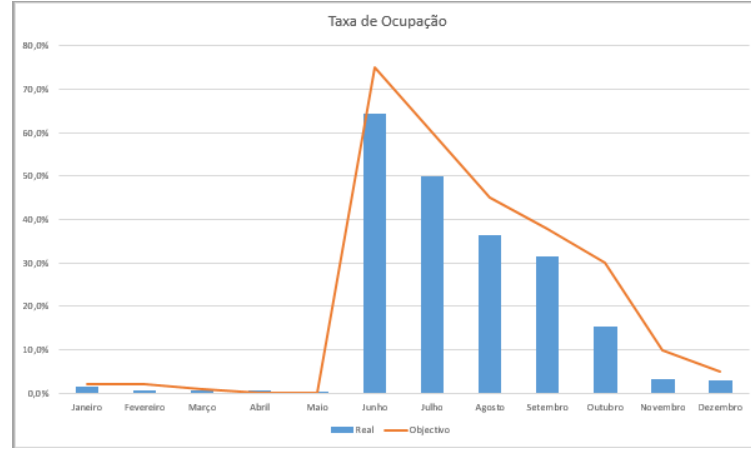


Figure 19 Occupation rate graph

The data used to obtain this graph is automatically calculated for every vehicle group and station separately and saved in a *.txt* file. This allows the tool to run faster when processing several different queries as well as to keep a log for future reference.

The occupation rate presented by the support system is calculated by equations (24) to (27) presented below. In equation (24), both nominator and denominator are calculated in number of days, and t represents the current number of the month, for example $t = 1$ represents January. Equation (25) returns the number of the days of the month t , where the number of days of the current month is equal to the amount of days left until next month. While equation (26) calculates the amount of vehicles available, by adding new vehicles (in fleet) and subtracting the vehicles sold (returned). And lastly, the equation (27) calculates the current size of the fleet, taking into account vehicles with status equal to: *Impro*, *On Rental* and *Free*.

$$t = \{1; 2; 3; \dots; 12\}$$

$$Occupation\ Rate(t) = \frac{\sum Reservations_{length}(t)}{Days(t).Vehicles(t)} \quad (24)$$

$$Days(t) = \begin{cases} Date_{last\ day\ of\ the\ month} - Date_{Current} & , t = Month(Date_{Current}) \\ Month_{length} & , t \neq Month(Date_{Current}) \end{cases} \quad (25)$$

$$Vehicles(t) = \sum Cars_{Available} - \sum Cars(t)_{Returned} + \sum Cars(t)_{In\ Fleets} \quad (26)$$

$$\sum Cars_{Available} = \sum Cars_{Impro} + \sum Cars_{On\ Rental} + \sum Cars_{Free} \quad (27)$$

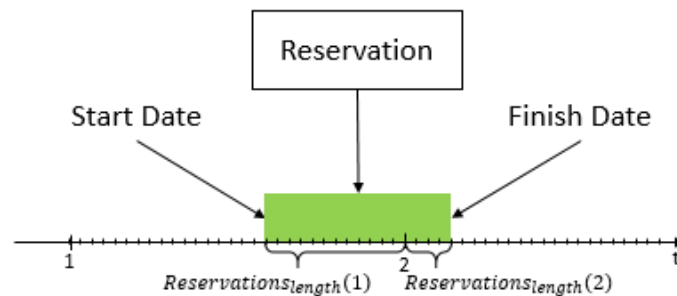


Figure 20 Reservation length exemplification

Figure 20 displays how a reservation that extends across different months is split and considered for the $Reservations_{length}(t)$ function, which is critical for the occupation rate calculation.

The possibility of having occupation rates visually and intuitively displayed for any station and group brings an opportunity not only for the pricing team but also for the marketing team, since it is easier to understand which market segment to target.

6.3.2 Price Elasticity Visualisation

The price elasticity function is extremely complex, and currently the pricing team is only using perception and intuition to understand it. To assist this crucial operation, the support system presents the evolution of the reservation price average against number of reservations and occupation rate. Therefore, the reactions of demand to the changes in prices can be visualized and analysed with a more quantitative support. To ensure that this functionality delivers the information in the most relevant way, the tool allows the user to select three different filters: group, station and reservation length.

Calculation

As mentioned above, price elasticity is an extremely complex function. Therefore, before the tool starts to calculate the price elasticity throughout the time, there are two points that need to be established: analysis interval and step. The analysis interval defines the period of time that is going to be analysed. It is important to notice that the tool will only take into consideration reservations that have a start date between the $Interval_{Beginning}$ and $Interval_{End}$, as it is seen in Figure 21. The $Step(n)$ is the interval of time used to group the data. This interval, for example, can be 30 days (to represent a month), 7 days (to represent a week) or one day. In the example provided in Figure 21, the information regarding the reservation will be assigned to the $Step(6)$.

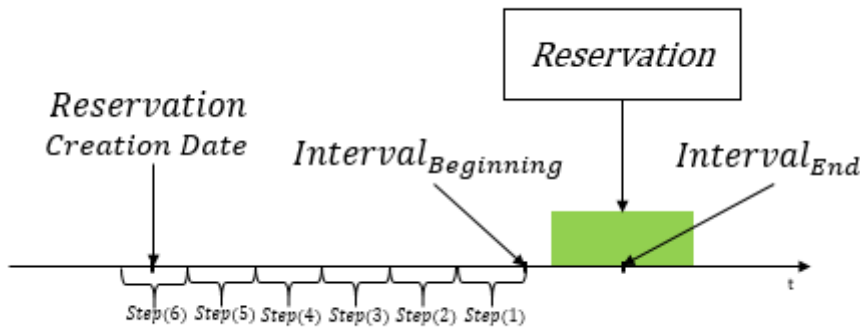


Figure 21 Reservation analysis for Elasticity

The reservation's price saved in the information system is the price per day, so in order to calculate the total value paid by the customers, this value is multiplied by the reservation length. To calculate the average of the price per day in each step, the tool calculates the overall price (paid by the customers) and divides it by the total length of the reservations accepted and, as is represented in (28), where s represents the step being analysed.

$$\overline{Price_{per\ day}}(s) = \frac{\sum (Reservation_{price\ per\ day}(s) \times Reservation_{Length}(s))}{\sum Reservation_{Length}(s)} \quad (28)$$

The occupation rate calculation for this problem will be different than the displayed in equation (24) used in the occupation rate section, this is because in this section it is calculated the past occupation rate whereas in the previous section it is calculated the future occupation rate. The equation (29) calculates the occupation rate considered, where both *Reservations(s)* and *Vehicles(s)* are calculated in number of hole days.

$$Occupation\ Rate(s) = \frac{Reservations(s)}{Vehicles(s)} \quad (29)$$

The reservations that are analysed in this section, as previously explained, have to be created within the interval limits. However if a reservation finishes during the interval defined, then a vehicle will be added to the available fleet in the remaining days of the interval, as can be observed in Figure 22.

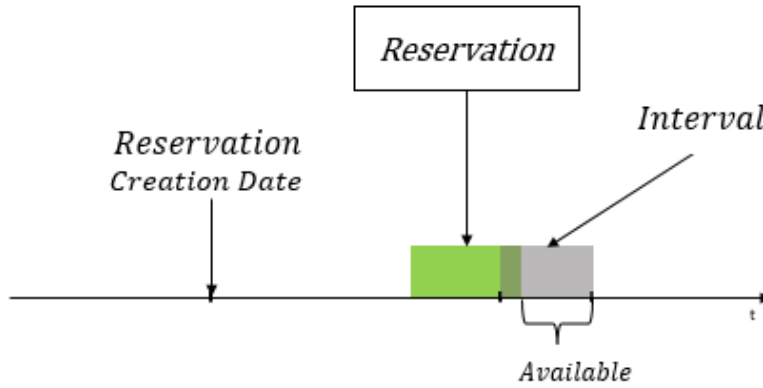


Figure 22 Vehicle Availability scenario

To calculate the number of vehicles available (in days) for every group and station, the equation used is (26), which is introduced in the fleet occupation ratio section. This equation calculates the amount of vehicles available - by adding new vehicles (in fleet) and subtracting the vehicles sold (returned).

$$Vehicles(s) = Cars(s)_{Available} - \sum Cars(s)_{Returned} + \sum Cars(s)_{In\ Fleets} \quad (26)$$

Since the tool delivers an analysis for station level, it is also important to take into consideration the fleet movements caused by the pick-up station being different from the drop-off. For a specific station the $Cars_{Available}$ function will be calculated according to (30), which calculates the fleet size by adding all the cars that arrive to the station and removing the ones that leave to the existing fleet size of the station.

$$Cars(s)_{Available} = Cars(s-1)_{Available} + \sum Cars(s)_{Arrive} - \sum Cars(s)_{Leave} \quad (30)$$

Visualizer

The price elasticity visualizer shows, by default, the three indicators previously calculated, these indicators can be selected in the price elasticity's control panel, as shown in Annex B.

The graph presented in Figure 23 was generated with data retrieved on the 1st of June, and as it is possible to observe, the average price paid by the customer by rental day is represented by an orange line, the occupation ratio by a blue line and the number of reservations made by a bar graph for each step. As it is possible to observe in the example displayed, the occupation ratio has a high correlation with the number of reservations accepted, as would be expected. The consequences of the price fluctuations are not clear in the scenario presented, with both price

increase and decrease leading to similar results. This could be due to peaks caused by occasional events. These possibilities will be further analysed in a more detailed example presented below.

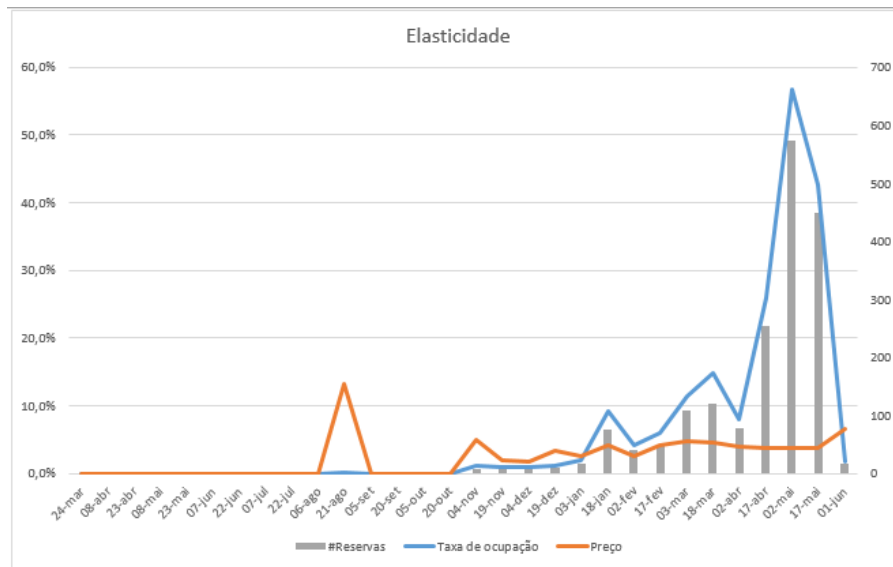


Figure 23 Elasticity analysis graph

The data used to generate the graph displayed in Figure 24 was obtained on the 5th of June, with a reservation interval from the 7th to the 15th of July, a step of 15 days, and the option presented is the general overview of the company (which selects the data for every group, station and reservation duration).

As it is possible to observe, there is a large increase of reservations (displayed in the bar graph) with the increase of time. The highest increase of demand is in the 15 days leading to the 1st of April, which could be justified by both the price reduction trend and because it was Easter break and the customers had more available time to plan their holidays.

The number of reservations presented before the 1st of April is extremely small, which leads to the step value being zero or having extremely high and low spikes. These spikes can be caused by, for example, reservations for luxury vehicles for one day or reservations for low cost vehicles for a long period of time, since the price per day decreases with both the decrease of vehicle's quality and with the increase of duration.

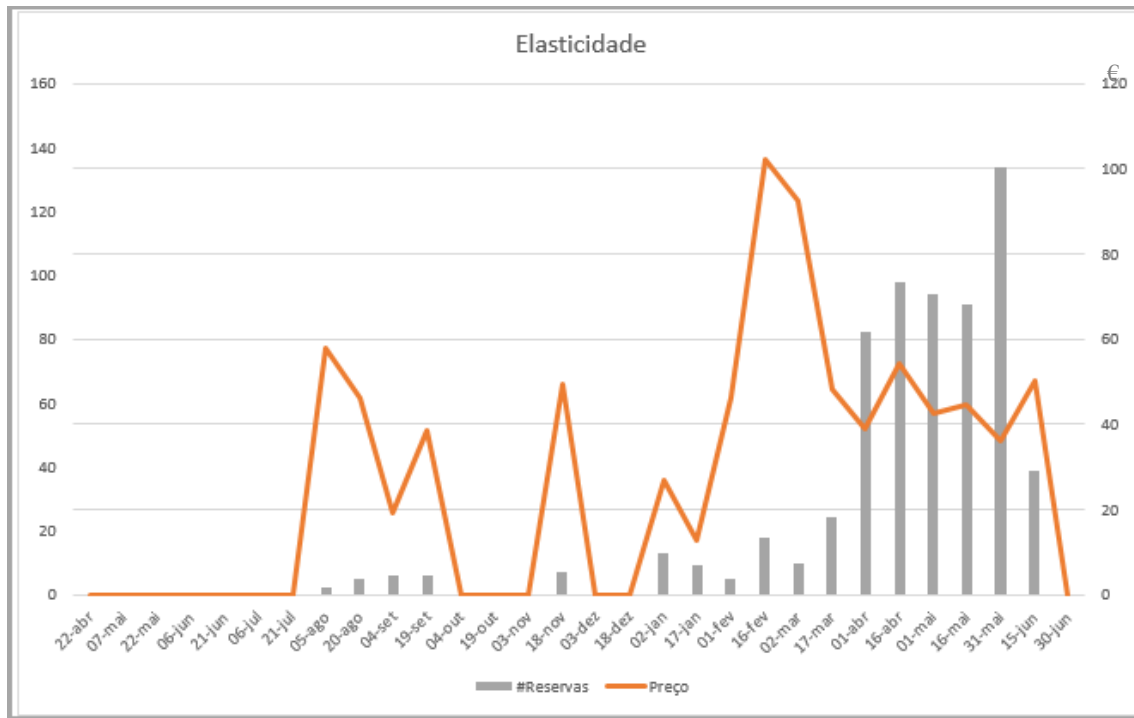


Figure 24 Elasticity analysis - price and number of reservations comparison

Since the reservation's history is not yet rich enough, the price elasticity analysis becomes highly susceptible to noise in the data. But with the recent fleet size growth, which is expected to result in a growth of accepted reservations, the quality of the price elasticity analysis provided is expected to improve. Therefore, the utility of the price elasticity visualizer is expected to grow with time.

7 Conclusions and future work

This dissertation presented the problem faced by a Portuguese rent-a-car company in accurately and efficiently controlling and planning its fleet. The approach taken in this dissertation was to develop a decision support system that controlled the fleet and assisted with the plan setting by providing relevant insights for the decision making process. This system was divided into three interconnected areas: operations control, fleet deployment and revenue management.

In the operational control area, a comparison between the vehicle's contractual requirements and quality insurance requisites against the company's standards was displayed in a warning system, which delivered all the information that the user required to take an action. A task that used to take over 8 hours per week between the different teams, now it takes less than 5 min and gets more reliable and insightful information.

To tackle the fleet deployment problem an optimisation model was developed, validated and solved for real instances consisting of company data. Due to the lack of time there are no real results to quantify the improvement brought by the model, yet it is expected that it will, at least, reduce the planning time.

Both occupation rate and price elasticity visualizers bring valuable information to assist the pricing team in planning and controlling the company's objectives in terms of revenue management. Even though, it was not possible to extract valuable conclusions from the price elasticity visualizer yet, due to the small quantity of data available, it is expected that, in the future, the quality of the information provided will be much higher.

All the functionalities supported by the decision support system were developed with the objective of being highly flexible and automatically updatable with the information system data. This project has allowed the company to spend less time in less value-adding operations while improving the efficiency and quality of their planning.

On a more extended time frame, it would be possible to improve the efficiency of the data handling and consequently improve the overall processing time. It would also be interesting to allow the revenue management displays to filter the information used according to the client type (corporate or leisure), this would allow the user to better understand the price elasticity. Furthermore, even though the system analyses both fleet deployment and the price elasticity function, it would also be interesting to build a model that interconnects these two in order to obtain a more accurate demand forecast and reliable fleet deployment plan.

References

- Edelstein, M., & Melnyk, M. (1977). The Pool Control System. *Interfaces*, 21-36.
- Fan, W., Machemehl, R., & Lownes, N. (2008). Carsharing: Dynamic Decision-Making Problem for Vehicle Allocation. *Transportation Research Record*, 97-104.
- Fink, A., & Reiners, T. (2006). Modeling and solving the short-term. In *Transportation Research* (pp. 272-292).
- Geraghty, M., & Johnson, E. (1997). Revenue Management Saves National Car Rental. *Interfaces*.
- Haensel, A., Mederer, M., & Schmidt, H. (2011). Revenue management in the car rental industry: A stochastic programming approach. *Journal of Revenue and Pricing Management*.
- Kimes, S. E. (1989). Yield management: A tool for capacity-considered service firms. *Journal of Operations Management*, 343-363.
- Lieberman, W. H. (2004). Revenue management trends and opportunities. *Journal of Revenue and Pricing Management*, 91-99.
- Maden, T., & Russell, R. A. (2012). Modelling the rental car pricing and relocation. In *Int. J. Revenue Management*, Vol. 6 (pp. 246-257).
- Nair, R., Miller-Hooks, E., Hampshire, R., & Bušić, A. (2013). Large-Scale Vehicle Sharing Systems: Analysis of Vélib". *International Journal of Sustainable Transportation*, 85-106.
- Pachon, J. E. (2003). A synthesis of tactical fleet planning models for the car rental industry. In *IIE Transactions* (pp. 906-917).
- Pachon, J., Iakovou, E., & Ip, C. (2006). Vehicle fleet planning in the car rental industry. *Palgrave Macmillan Ltd*, 221-236.
- Simon, H. A. (1956). Rational Choice and the Structure of the Environment.
- Yang, Y. (2009). Dynamic Pool Segmentation Model and Algorithm in the Car Rental Industry. *Journal of Computers*, 1202-1208.

ANNEX A: Decision support system's control panel

| | |
|------------------|-----------------------------|
| Pasta | C:\Users\Utilizador\Desktop |
| Reservations | Reservations.xlsx |
| Vehicles | Vehicles.xlsx |
| Damages | Damages.xlsx |
| Impros | Impros.xlsx |
| Reservations Aux | Reservations_Aux.xlsx |
| Frota | Frota.xlsx |

| | | |
|-----|------------|------------|
| Dia | 01-07-2016 | 07-07-2016 |
|-----|------------|------------|

Update Total

Importar Custos

Avisos

Danos

Distribuição da frota

Importa Solução

Taxa de Ocupação

Elasticidade do preço

Figure annex 1 Decision support system's control panel

ANNEX B: Price elasticity’s visualizer and control panel

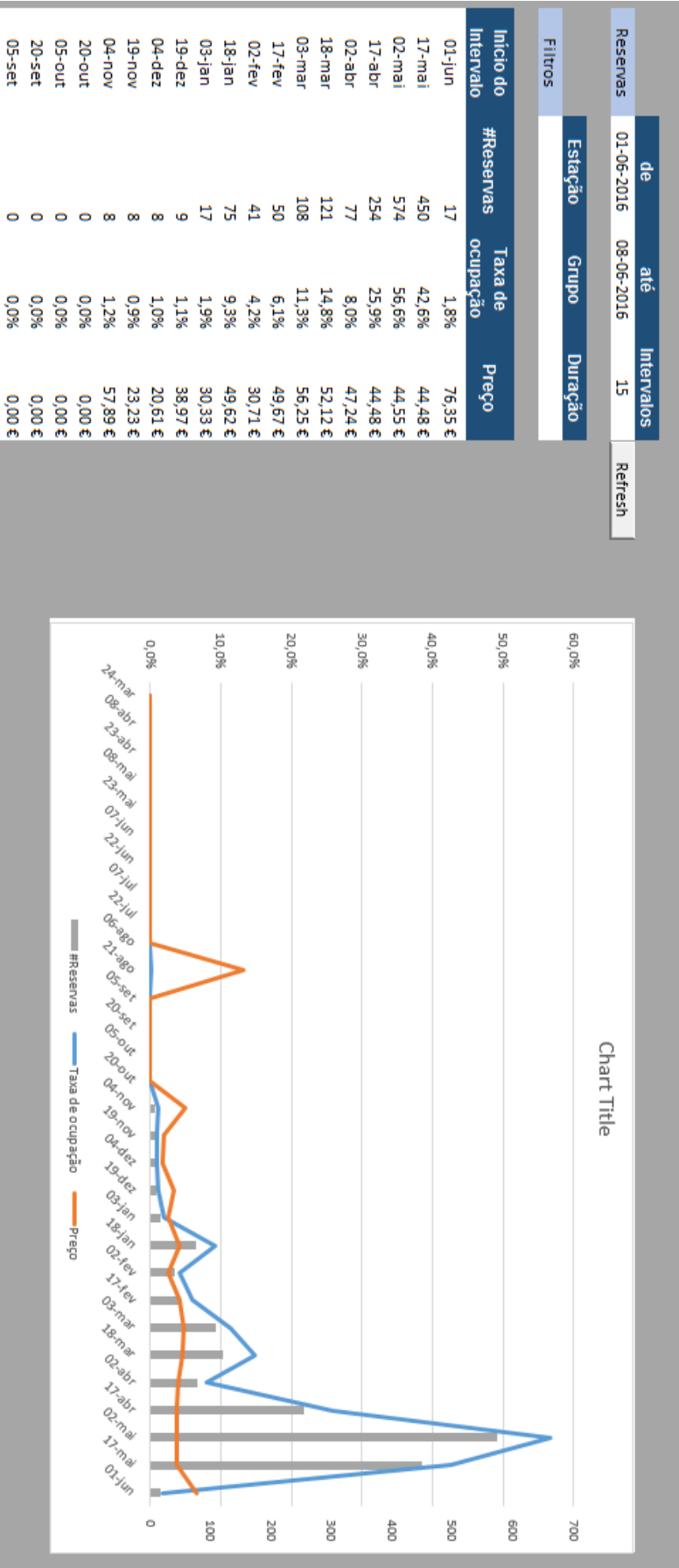


Figure annex 2 : Price elasticity’s visualizer and control panel