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Optimization model for water supply in the Northeast of Brazil

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Ana Luisa Oliveira da Nóbrega Costa

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Report submitted to undergraduate course of Industrial Engineering at Universidade de Brasília, as partial requirement of Industrial Engineering Bachelor Degree.

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This thesis is dedicated to my sister and parents, Ariadna, Alexandre and Ana Paula Costa.

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The good life is one inspired by love and guided by knowledge.

- Bertrand Russel

Abstract

The Brazilian Northeast is experiencing a prolonged drought worrying both federal and state levels. The World Bank conducted on 2014 evaluations on Brazilian drought preparedness and the analysis showed that long-term and short-term decisions are increasing water scarcity, creating a burden on public programs and wasting millions of euros every year. This work proposes an analytical model of water supply routing under an emergency situation in the Northeast of Brazil. A model is developed and implemented in Matlab, Python, R and Julia languages. The implementation of the model takes into account different market power and capacity restrictions. The optimal solution is obtained for each scenario by determining how much water volume must be sent from the sources to the delivery points through the Vehicle Routing Problem application. Finally, a data visualization is given showing the feasibility of the implemented model.

Keywords: Water scarcity; Vehicle Routing Problem; Brazilian Northeast Drought.

Resumo

O Nordeste brasileiro está vivenciando uma prolongada seca que preocupa os ambos governos estaduais e federais. O World Bank realizou em 2014 uma série de avaliações referentes à preparação do Brasil no combate a seca e mostrou que as atuais decisões de curto e longo prazo estão aumentando a escassez de água, sobrecarregando os programas públicos e desperdiçando milhões de euros todo ano. Essa monografia propõe um modelo analítico de roteamento de abastecimento de água em situação de emergência no Nordeste brasileiro. Foi desenvolvido e apresentado o modelo nas linguagens Matlab, Python, R e Julia. O modelo foi implementado em três cenários, levando em consideração diferentes restrições de demanda e capacidade do mercado. A solução ótima foi encontrada e caracterizada para cada cenário determinando quanto volume de água deve ser entregue para cada localidade por meio da aplicação do Problema de Roteamento de Veículos. Por fim, uma visualização de dados foi construída usando o software QGIS e foi analisado cada estado envolvido.

Keywords: Escassez de água; Problema de roteamento de veículos; Seca no Nordeste brasileiro.

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List of abbreviations

ACVRP	Asymmetric Capacitated Vehicle Routing Problem
CEMADEN	Centro Nacional de Monitoramento e Alertas de Desastres Naturais
CENAD	Centro Nacional de Gerenciamento de Riscos e Desastres
COTER	Comando de Operações Terrestres
CVRP	Capacitated Vehicle Routing Problem
DS	Drought Severity
ETA	Estação de Tratamento de Água
MRD	Ministério do Desenvolvimento Regional
OCP	Operação Carro-Pipa
OME	Organização Militar
OR	Operations Research
SEDEC	Secretaria de Desenvolvimento da Cidade
VRP	Vehicle routing problem
VRPB	Vehicle routing problem with Backhauls
VRPPD	Vehicle routing problem with Pick up and Delivery
VRPTW	Vehicle Routing Problem with Time Windows
VRPPDTW	Vehicle routing problem with Pick up and Delivery and Time Windows

List of symbols

Z	Overall measure of performance;
x_j	Level of activity j (for j = 1,2,…,n);
c_j	Increase in Z that result from each unit increase in the level of activity j;
b_i	Amount of resource I that is available for allocation to activities (for I = 1,2,…,m);
a_{ij}	Amount of resource I consumed by each unit of activity j;
$distances_{i,j}$	Distance between the supply point *i* and the delivery point *j*;
$demand_j$	Number of deliveries requested by the delivery point *j*;
$x_{i,j}$	Relation between the supply point *i* and the delivery point *j;*
$capacity_i$	Demand capacity of the supply point *i;*
f	Column matrix, with *i* and *j* elements, where each element represents the association between the supply point and the delivery point;
$demand_j$	Number of deliveries requested by the delivery point *j*;
x	Column vector, with *i* and *j* elements, where each element represents the association between the supply point and the delivery point;
A	Matrix with *i* lines and $i \cdot j$ columns;
B	Column matrix, with *i* elements, where each element represents the maximal withdraw quantity of a supply point;
Aeq	Matrix with *j* rows and $i \cdot j$ columns;
Beq	Column matrix, with *j* elements;
lb	Empty line matrix, with $i \cdot j$ elements;
ub	Line matrix, with $i \cdot j$ elements.

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1. INTRODUCTION

The climate changes caused by devastation are constantly affecting ecosystems and livelihoods. The social systems and human vulnerability to climate events is a result of the longterm change and the droughts in the Northeast of Brazil are just a small part of a large problem (EAKIN, 2006). According to Lemos (2007), it is necessary to investigate how institutions respond to climate variability and how the systems adjusts themselves to climate changes. The design of anticipated impacts adaptation it is a challenge because attributes need to be precisely defined but in future scenarios the aim is to focus on capacities rather than adaptations (FOLKE, 2002; SMIT et al., 2000; LEMOS, 2007).

Since 2010 the Brazilian Northeast is experiencing a prolonged drought worrying both federal and state levels. The World Bank conducted on 2014 evaluations on Brazilian drought preparedness and the analysis showed that long-term and short-term decisions involve planning, monitoring, forecasting and mitigation policies with national and subnational growing interest. The drought in the Semi-arid Northeast is causing agricultural, industrial producers and livestock devastation. Moreover, during times of shortage, water scarcity affect every year about 15 million people (GUTIÉRREZ, 2014; MAGALHÃES, 2011; ANA, 2017).

To minimize the damage caused by prolonged drought and water scarcity, the Federal Government started an emergency water supply program called 'Operação Carro-Pipa', that serves monthly about 4 million people and 900 small regions using vehicles distribution. Although risk management in this case would anticipate the impacts rather than adaptions (YOHE, 2002; TOMPKINS, 2005), everyday there are 80 thousand points needing water supply.

The program investment was 98.9 million euros in 2012, 186.7 in 2013, 219.6 thousand million euros in 2016 and 263.5 in 2018 (ANA, 2017). The drought impacts and the institutions emergency response is causing not only dams, lack of drinking water in residential wells, vicious cycle of clientelistic politics and misappropriation of public funds for private gain (LEMOS, 2007; LEMOS, 2004; GUTIÉRREZ 2014) but also constant increasing costs during the last decade.

The Vehicle Routing Problem (VRP) plays a central role in physical distribution and logistics fields and strongly contributes with an effective use of important techniques proposed for the solution of hard combinatorial problems (TOTH, 2002; LAPORTE, 1992). With the purpose of finding a set of routes for minimizing the travel time or distance, demands are satisfied, vehicles loading limitations are not exceeded and costs are reduced (BORGULYA, 2008; CHEN, 2006; BELFIORE, 2007; KUO, 2011).

Water supply optimization by VRP application in the 'Operação Carro-Pipa’ program contributes to minimize the total transportation distance, satisfy the demand fulfillment, cost reduction, build resilience beyond climate impacts with focus on drought hazards, prevent adaptations, give space to future risk management policies and decrease overall vulnerabilities among involved groups.

1.1. Objective

This project aims to reduce costs of water supply routing under an emergency situation in the Northeast of Brazil by implementing an optimal solution algorithm..

1.1.1. Main objective

The main objective of this project is:

Implementation of a mathematical model with the purpose of identifying the optimal routing for water supply in the Northeast of Brazil, by analyzing different scenarios.

1.1.2. Specific objectives

This study has several objectives:

- Build an optimization model to the studied vehicle routing problem;
- Implement the model in three scenarios taking into account the different market power and capacity restrictions;

• Find and characterize the optimal solution for each scenario. Given a realization of the current distribution, this optimization should determine how much volume must be send from the sources to the demand points, minimizing the costs.

• Build a data visualization with the results.

1.2. Methodology

This study is a descriptive quantitative research because it aims to describe the Brazilian Northeast disaster drought management phenomena, focuses on objectivity and deals with numbers and measurable predict by using linear programming (LEEDY, 1993; GERHARDT, 2009; ANDER-EGG, 1978). The research is an applied case study since it is an in-depth analysis with interaction between the researcher and the research object. It also aims to generate knowledge for practical application and specific problem solution (MORABITO et al., 2008; TRIVIÑOS, 1987).

The structure follows the research modeling approach proposed by Hillier and Liebermann (1995):

A. Defining the problem and gathering data:

With the aim of determining appropriate objetives, constraints, interrelationships between the study and other organization fields, alternative courses of action and time limit for making the decision, it was performed a detailed technical analysis with the Centro Nacional de Gerenciamento de Riscos e Desastres (CENAD) managers to identify the attractive alternatives under different assumptions and range of values. The approach of long-run cost minimization was chosen to circumvent the problem and the relevant data was gathered by CENAD members using a computer-based internal management information system.

B. Formulating a mathematical model:

The formulation of the problem was made by constructing a mathematical model in a convenient, concisely and comprehensible form for analysis. It started with a simple version and moved to a more elaborated model that could nearly reflect the problem complexity. The objective function required the development of a quantitative measure of performance related to the CENAD managers objectives, being the mathematical function of the decision variables.

C. Deriving solutions from the model:

A computer-based procedure was developed applying an algorithm implemented firstly in Matlab to make able the postoptmality analysis.

D. Testing the model:

After the first computer program version, the program was tested to find and correct bugs, improved to increase its validity and documented to increase confidence for subsequent users. Besides Matlab, the algorithm was applied in R, Python and Julia languages.

E. Preparing to apply the model:

In order to install a well-documented system for applying the model under three different scenarios, the Project Jupyter was used to develop an open-source software, and services for interactive computing. Moreover, this decision support system was applied to help the managers in their decision making.

F. Implementation

The implementation was made together with the CENAD managers and throughout this period, there was constant feedback on whether the model assumptions continued to be satisfied. Furthermore, a state visualization with heat maps was developed to successfully represent the results.

1.3. Assumptions, limitations and project structure

The project results will contribute to VRP theory, governmental institutions development and implementation of policies, efficient optimized disaster management and cost reduction.

Assumptions involve VRP conditions, such as (i) each station is visited exactly once by one vehicle, (ii) all vehicle routes starts and end at a depot and (iii) demand and supply constraints are satisfied. Besides, there are capacity and distance restrictions explained in the literature review, possible consideration of time windows and precedence relations and the number of stations on any route is bounded.

This thesis is organized as follows. In Chapter 1 there is a introduction and problem presentation, Chapter 2 presents a review of previous literature, Chapter 3 describes in detail the implemented model. In Chapter 4 the results for each scenario are presented and discussed together with the optimal identified policy. Finally, Chapter 5 give the conclusion, results and future studies.

2. LITERATURE REVIEW

2.1. Drought in the Northeast of Brazil

The extreme climatic events that promoted natural disasters in South America, such as drought in the Northeast of Brazil between 2010 - 2018, droughts in Amazonia in 2005, 2010, 2016 and 2019, floods in Amazonia in 2009 and 2014 and drought in Bolivia in 2016 (MARENGO, 2018) have caused a lack of drinking water, manifests throughout the economy, an exacerbation of social problems, intensify diseases, migration and malnutrition among the population (GUTIÉRREZ, 2014).

As a natural disaster, drought occurrence in the Northeast of Brazil affect water and energy security, strongly impact the biodiversity and the population in Amazonia and increase in the risk of fires in the Amazon forest (MARENGO, 2018). The sequence of fires that ravage Amazonia in 2019 are consequence of the longest and most intense drought in decades in the Brazilian Northeast.

The Northeast of Brazil comprises 9 states and 1800 municipalities, with 1048 municipalities located in semiarid region (LINS, 2008; ROCHA, 2015). The semiarid Northeast is a very poor region, it's economy is based on extensive forms of substance agriculture (AB'SÁBER, 1999; ARIDAS, 1994; LINS, 2008; CIRILO, 2008; ROCHA, 2015) and it's low average historical precipitation characterizes the region as one of the driest in the world (MARENGO, 2008).

According to Vieira et al. (2015) the region is characterized by cultural and economic differences and it is strongly affected by land degradation and desertification. In the second half of 21st century, the region will be affected by rainfall deficit and increased aridity, consequence of the vulnerability to the extreme of inter-annual climate variability and climate change scenarios (MARENGO et al., 2015). In addition, the social and economic differences combined with land degradation, desertification and rainfall variability can make the the Northeast of Brazil one of the most vulnerable world's region to climate change (FIELD, 2012; MARENGO, 2017).

Such characteristics have resulted in high levels of water stress and there is a constant struggle to inhabit the region. The millions lives lost during the past two centuries are related to climate variability and water stress (VILLA, 2000; ENGLE, 2007), and because of that one of the highest priorities of the Brazilian government is the successful water management.

The semiarid is a result of the variability of rain over time and the composition of soil formed from crystalline rocks. These two characteristics combined results in little accumulation of water and low exchange between rivers, making a network of intermittent rivers. Most part of the water used by households is obtained from rainwater ponds and dams, that accumulate water during the rainy season and use it during the year. Because of evaporation in the dry season, this scenario results in high levels of water salinity and low consumption quality (CIRILO 2008; REBOUÇAS 1997; ROCHA, 2015).

2.1.1. The Northeast drought in the last century

According to the United States National Drought Mitigation Center of the University of Nebraska, drought is the deficiency of precipitation over an extended period of time that results in water shortage for determined sector. Marengo et al. (2015) showed that the Brazilian Northeast rainfall exhibits a marked inter annual variability and a high seasonal predictability, what makes possible a future risk management in the region. In figure 1, there is a compilation of rainfall events and anomalies between 1961 and 2016.

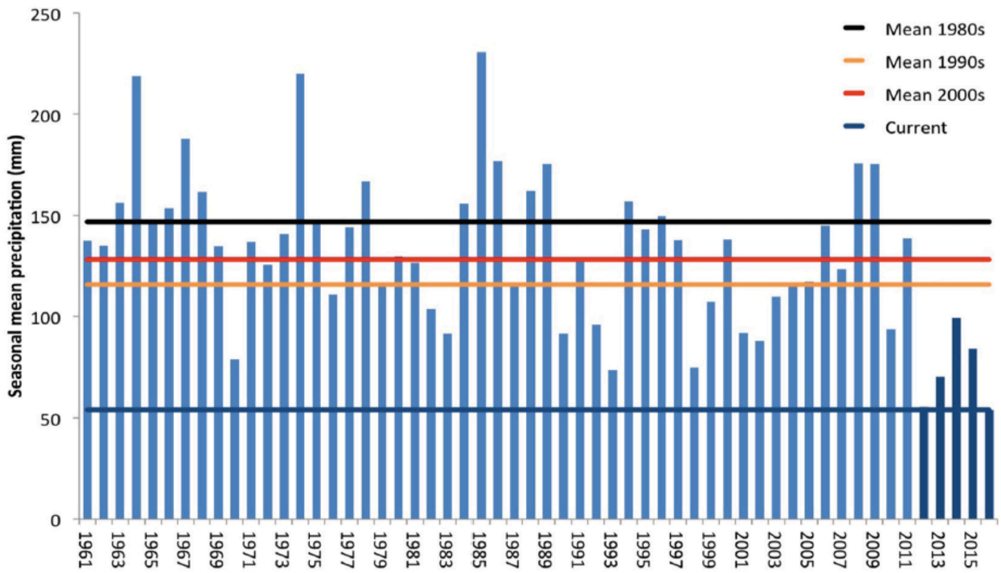


Figure 1 - Rainfall anomalies in the Brazilian Northeast from 1961 to 2016

Font - MARENGO et al. 2017

As a result of drought, in 1958 around 10 million people fled from the Brazilian Northeast and between 1979 and 1981 there was 70% of reduction in commodities production and a decrease of 80% in livestock. In 1998 the total agricultural production of the region was lost and the extended drought that started in 2010 has taken more than 1100 towns. Therefore, in 2012 a state of emergency was declared in 997 of the 1794 Northeast districts by the Brazilian government (MARENGO et al., 2015; NAMIAS 1972; FEDERAL-BRASIL, 2007).

Between 2012 and 2016, the drought estimated damage was around US $ 30 billion and affected 33.4 million people. In that period, the accumulated rainfall was below 500 mm, resulting in water stress, less water supply, affecting the level of reservoirs and leading to a huge water crisis. As stated by Centro Nacional de Monitoramento e Alertas de Desastres Naturais (CEMADEN), in 2016 the drought was reflected in the levels of the San Francisco River (MARENGO et al., 2015). Figure 2 shows the drought severity (DS) maps in the Northeast of Brazil for (a) 1981-1986, (b) 1986-1991, (c) 1991-1996, (d) 1996-2001, (e) 2001-2006, (f) 2006-2011 and (g) 2011-2016, respectively.

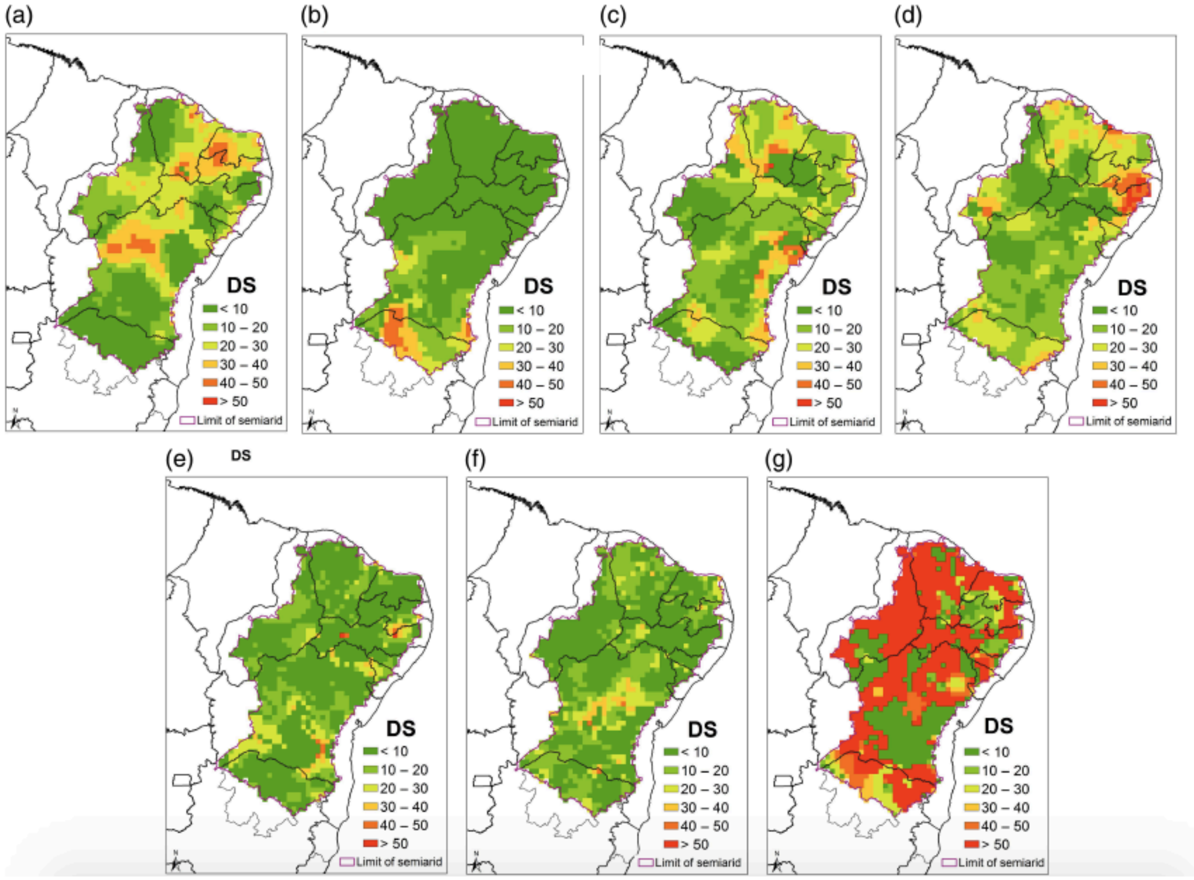


Figure 2 - Drought severity in the Brazilian Northeast from 1981 to 2016

Font - Brito et al., 2018

The Northeast is the poorest region in Brazil and has one of the most rural populations throughout the country. Most part of the rural parts still lack proper sanitation infrastructure. In 2000, 35.3% of the rural Brazilian population didn't have access to sanitation. The poverty in the region also is manifested in education rates. In in the same year of 2000, 42.5% of people over 15 years old had less than four years of schooling (ENGLE, 2007). During the past centuries, the Northeast inhabitants have experienced famines, migrations and massive deaths (VILLA, 2000) and in the next years the region will experience temperature increases, decreases in precipitation and increases in magnitudes of extreme events (ENGLE, 2007).

2.1.2. The Northeast drought projections

Marengo et al. (2017) made future climate projections for the region and showed the future occurrence of more frequent and intense droughts, represented in figure 3.

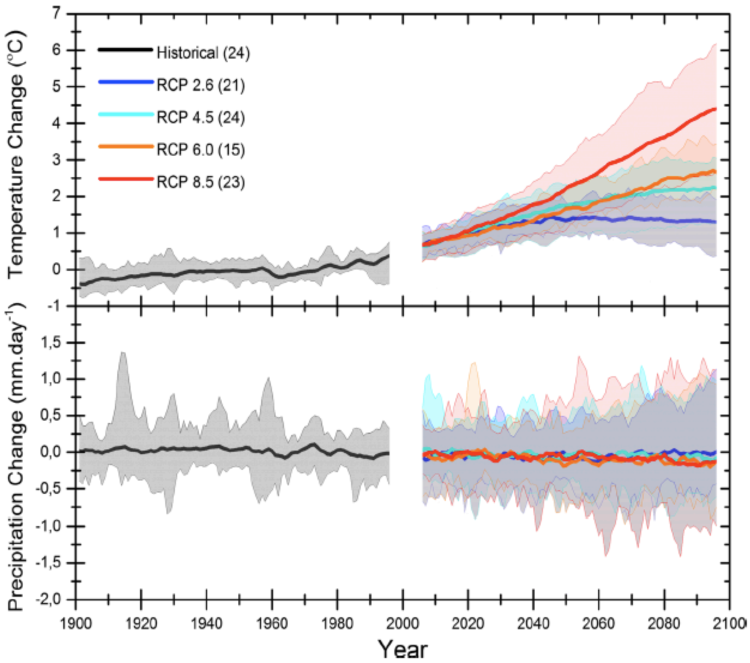


Figure 3 - Time series of rainfall and temperature anomalies in the Brazilian Northeast in the period of 2000-2100

Font - MARENGO et al., 2017

The projections show the high level of anomalies of rainfall in the next years and according to Rocha et al. (2015), lack of adequate access to water increases also the susceptibility to climatic shocks. The water scarcity can also reduce agricultural production, and increase the incidence of infectious diseases (WORLD HEALTH ORGANIZATION, 2012; ROCHA et al., 2015).

The Northeast of Brazil scenario is historically plagued by drought and the Brazilian Government has given high priority on policies and decision making agendas to minimize the water scarcity and vulnerability to drought. The emergency water supply public policy 'Operação Carro-Pipa' can minimize the impacts in short term and open doors for an efficient risk management policy in the long term.

2.2. Operation pipe trucks - *Operação Carro-Pipa* (OCP)

Operação Carro-Pipa is a public policy instrument aiming to distribute emergency drinking water to the drought-affected population, mainly for people living in the Brazilian semiarid rural areas. This operation started on 1988, but on august 2005 was made official by the Interministerial Ordinance 7 between the Ministério da Integração Nacional and Ministério da Defesa (ROCHA, 2017).

In 2012, when landslides caused the deaths of hundreds of people in Rio de Janeiro (AVELAR, 2013), natural disasters became prominent on the national policy agenda and the Law 12608 was formulated (JÚNIOR, 2018), which structure the assistance system in case of natural disasters at the municipal, state and federal levels (ROCHA, 2017). According to Rocha (2017), the drought issue has been on the state policies agenda during years, but the characteristic of the emergency actions lacks cognitive innovations. Lemos (2007) also states that for over a century, the government tried to alleviate the drought negative effects but it is been unsuccessful because it is not addressing the deeper causes of vulnerability to drought.

2.2.1. OCP actors

OCP is coordinated by the National Center for Risk and Disaster Management (CENAD), which plan, coordinate and oversee the water search, transportation, disinfection and distribution (VILLAR, 2019). One of the main CENAD objectives is to reduce OCP costs, action that will allow an efficient long term re-distributive drought policy implementation.

CENAD responds to the Secretaria de Desenvolvimento da Cidade (SEDEC), being part of the Ministério do Desenvolvimento Regional (MDR). CENAD's main objective is disaster preparedness and response in national territory with the aim of reducing impacts and preparing the population. The institution processes are based on receiving information from federal government institutions responsible for climatic, environmental and chemical predictions or relationships, evaluation of this information and forwarding relevant data to the Civil Protection and Defense institutions with risk of disasters, according to the disaster intensity. Thereafter, prevention, mitigation and preparatory actions are carried out through federal support. SEDEC and CENAD structures are represented in figure 4.

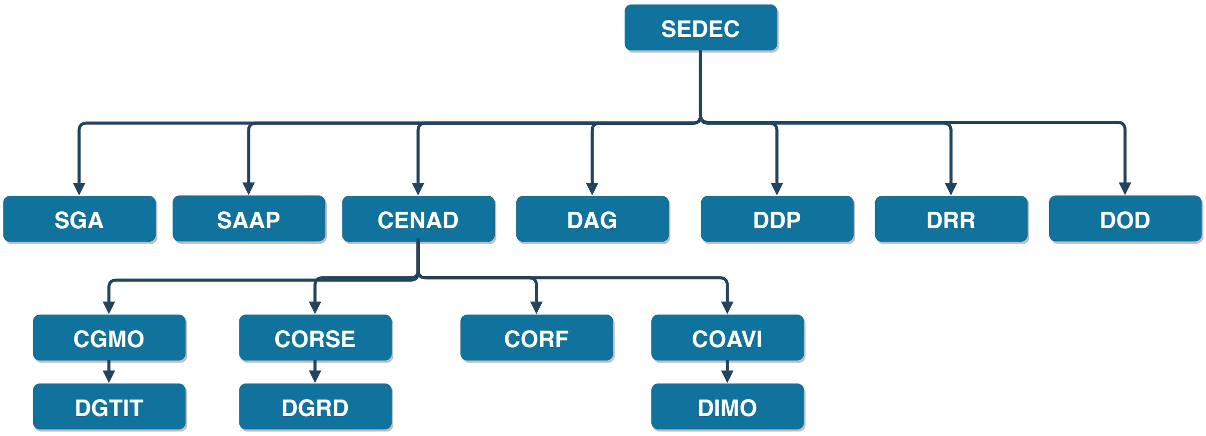


Figure 4 - SEDEC and CENAD structures

Font - adaptation of ROCHA, 2017

Municipalities can register on OCP by sending an emergency situation decree to SEDEC. This documentation is sent to the Comando de Operações Terrestres (COTER) that forward to the Organização Militar (OME) of each region. Thereafter, OMEs hire trucks drivers, that start the distribution to each municipality. The water carried by pipe trucks is collected from springs or reservoirs of the urban supply system and when they reach the communities, the water is transferred to cisterns, where it is stored and later distributed to the population (ROCHA, 2017).

2.2.2. OCP systems

Two main systems are used by CENAD: S2ID Platform (Integrated Disaster Information System) and GPIPABRASIL. The first, (figure 5) integrates all Brazilian natural disasters and it is through this system that the municipalities can request funds from SEDEC.

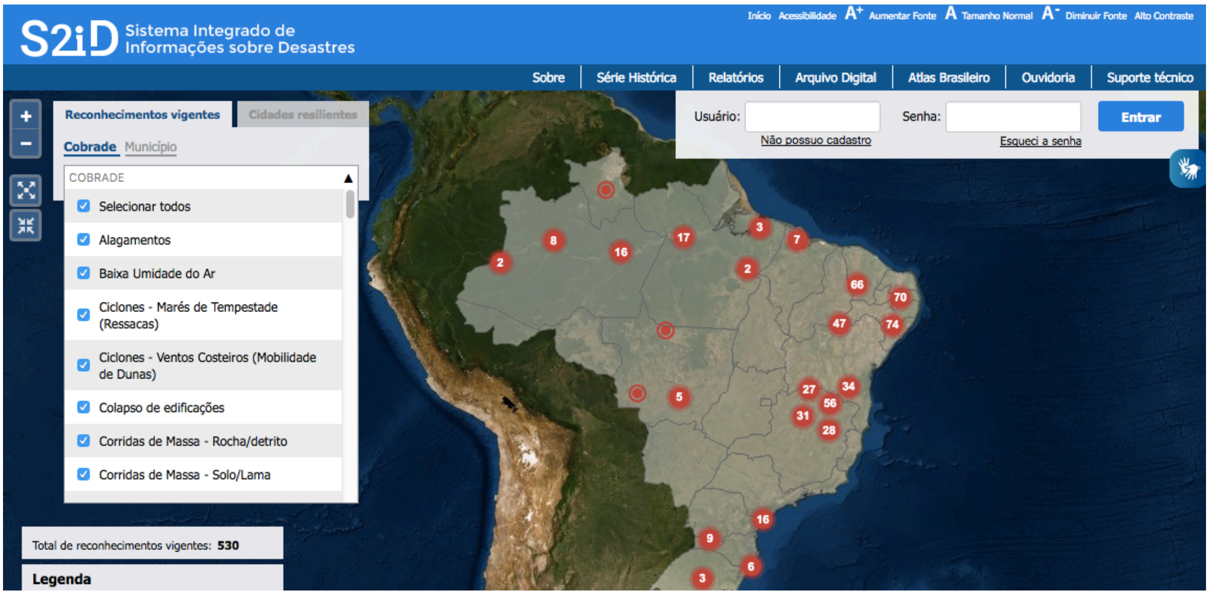


Figure 5 - Plataforma S2ID

Font - Rocha, 2017

Individuals can consult S2DI system, what makes it an important transparency tool, but cannot request OCP services. Furthermore, only municipalities, state authorized institutions and CENAD can feed the natural disasters system database. However, if a community is out of OCP attendance for political reasons, the army has autonomy to implement the service (ROCHA, 2017).

GPIPABRASIL (figure 6, 7 and 8) is the Water Delivery Logistics Monitoring System, an internal system used by staff and administrators, having aim to ensure water receipt, to track the vehicles involved, to enable transparency in processes and to optimize drivers supervision.

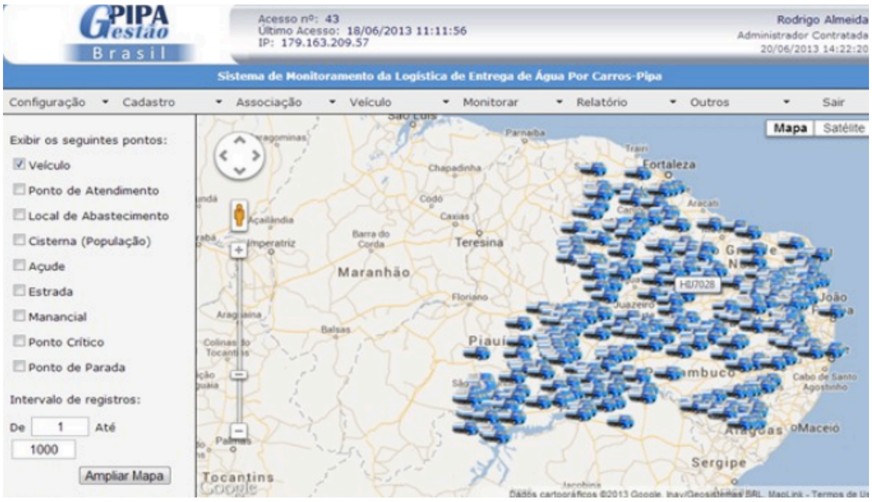


Figure 6 - GPIPABRASIL vehicles visualization

Font - Rocha, 2017

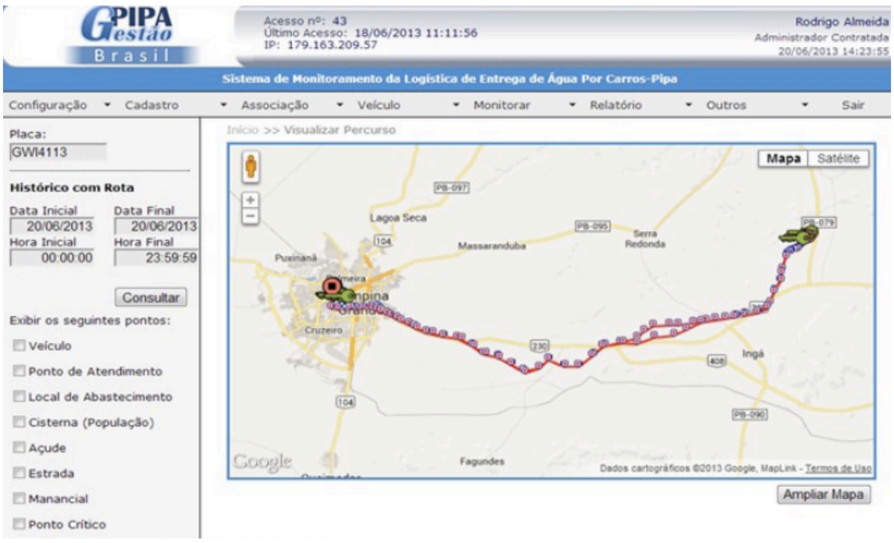


Figure 7 - GPIPABRASIL route visualization

Font - Rocha, 2017

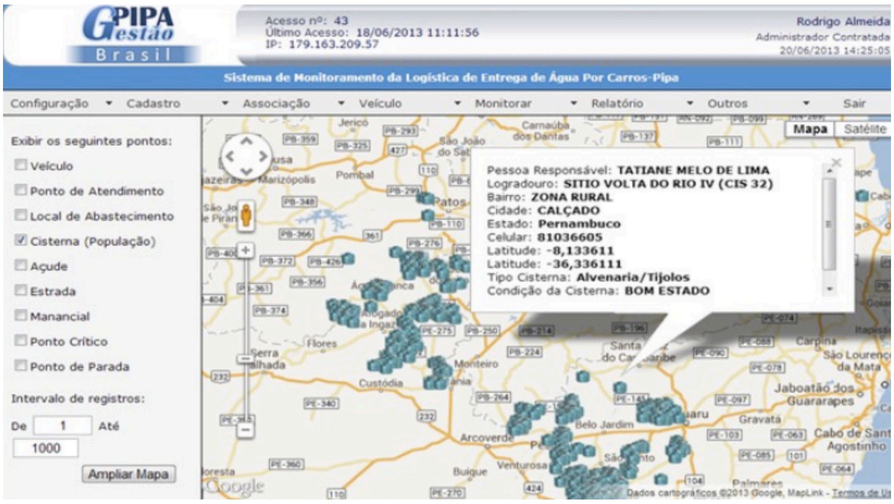


Figure 8 - GPIPABRASIL cistern details

Font - Rocha, 2017

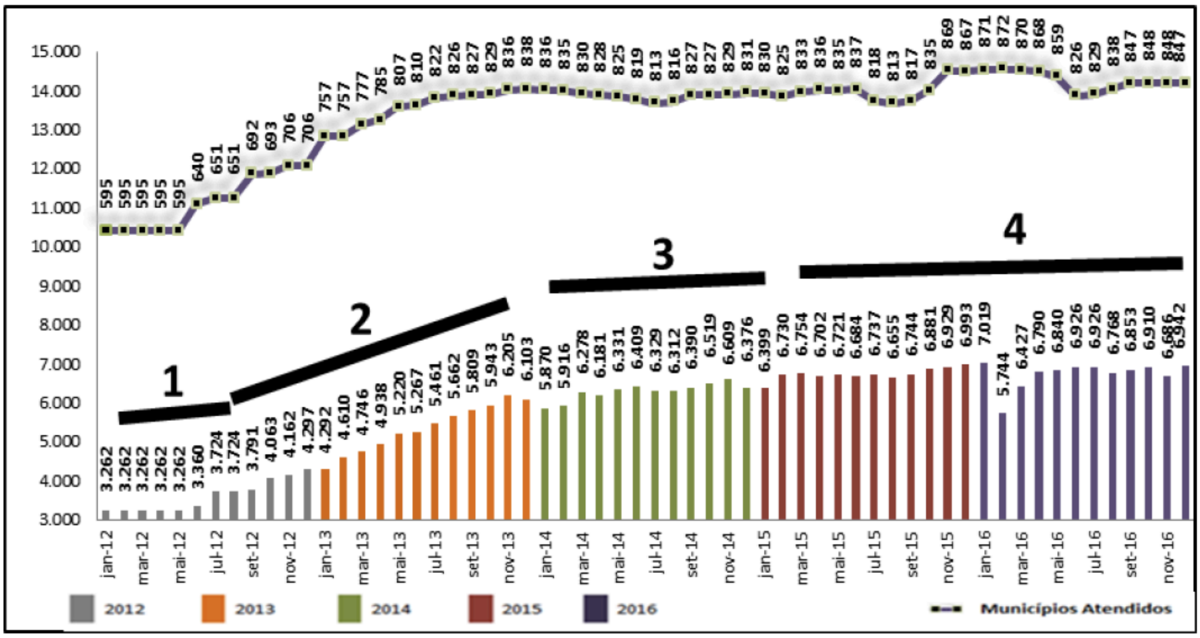
Figure 6 shows the visualization of the vehicles in GPIPABRASIL system, it is possible to visualize not only the vehicles but also supply and delivery points, rivers, weirs, streets, among others. Figure 7 shows the route visualization where can be selected the route dates and time, trucks and type of route. Figure 8 shows the details of the cisterns. Every point included in Figure 6 can be detailed, categorized and represented as in figure 8.

The water delivery is controlled by an ID card being given to registered drivers and there is an equipment installed on the trucks. Besides, trucks locations can also be monitored. The requirements for a good system operation are cisterns registration, card delivery, monitoring module vehicles installation, water delivery and card registration in every delivery (MARDER, 2019).

2.2.3. OCP past results

OCP serves about 4 million people per month, divided in around 900 municipalities in the northeastern semiarid, northern region of Minas Gerais and Espírito Santo states. The supply is based on the proportion of 20 liters of water per person per day and there are almost 7 thousand drivers in approximately 80 thousand supply points and collective cisterns

(MINISTÉRIO DA DEFESA, 2016). Figure 9 shows the number of municipalities and



drivers between 2012 and 2016 distributed in 4 phases.

Figure 9 - Number of municipalities (dotted lines) and drivers (colored lines) between 2012 and 2016

Font - Rocha, 2017

In phase 1 (from January to June 2012) there were 3724 drivers and 640 municipalities. In phase 2 (from July 2012 to November 2013), due to the worsening drought, there were 6205 drivers and 830 municipalities. Around 6300 drivers and 830 municipalities in phase 3 (from January to December 2014) and 6942 drivers and 847 municipalities in phase 4 (from January 2015 to December 2016).

On the past 6 years, OCP costs have increased as the drought worsens. In 2012, were invested R$ 450 million, R$ 700 million in 2013, R$ 850 million in 2014 and R$ 920 million in 2015. Moreover, investments were about R$ 1 billion in 2016 and 2017 (MINISTÉRIO DA DEFESA, 2016).

According to Lemos (2007) the expressive costs are because of two government response emphasis: first both the state and the federal governments spent significant resources in reservoirs and dams construction and second there is a substantially investment in post-disaster (LEMOS, 2007). Therefore, cost reduction throughout operations research application to identify the optimal delivery policy can allow an efficient optimized water distribution management.

2.3. Operations research

According to Hillier and Lieberman (1995) Operations Research (OR) is the application of problems that conduct and coordinate operations within an organization, using a research and a scientific method to investigate the problem of concern. Carter et al. (2017) defines OR as the use of quantitative methods to assist analysts and decision-makers in various systems areas. Although OR definitions can vary between authors, the field incorporate tools from many disciplines and can be applied in a rational way to solve problems (HILLIER et al., 1995; CARTER et al., 2017).

The system modeling principles involves building mathematical models and, as a model, it is hypothesized that is a sufficient precise representation of a situation and that the solutions can be valid for the real problem. Consequently, the mathematical construction is used to describe the most important features of the modeled entity (HILLIER et al., 1995; CARTER et al., 2017).

The model construction covers discovering an area that is in need of study, creating a model that embodies alternative courses of action, collecting data that characterize the system, formulating, testing, applying and implementing the model. Constant reevaluation is necessary and the aim of building a model is to understand the real system and predict its behavior to enable a better decision making. Algorithms are normally used to apply the mathematical models and can be measured by the computer time and quality of the solutions (CARTER et al., 2017).

2.3.1. Linear programming

Churchman et al. (1957) refers the linear programming tool to techniques for solving a general class of optimization problems dealing with interactions of variables subject to restraining conditions. By solving these problems, objectives are to be obtained in the best possible or optimal subject to certain restraining conditions that may arise from a variety of sources. These restrictions can include, for example, capacity limitations, minimum amounts required, production requirements, delivery requirements or limitations on the availability of the resources (CHURCHMAN et al., 1957).

Wagner (1969) emphasizes the industrial importance of linear programming models, that have been formulated and tested to aid in decision making at every major point of a stream. The models have been developed to schedule production, determine the net profitability, calculate the incremental costs, plan weekly minimum cost schedules, establishing the return on investment, route products, construct annual plants, among others ones (WAGNER, 1969).

According to Churchman et al. (1957), to reach an optimal programming decision, all combinations of operations and materials should be considered simultaneously. This results on complexity of application of linear programming models in the real world. Wagner (1969) states that the complexities to be found in real situations magnify the effort required to provide a scientific economic analysis of different decision consequences (WAGNER, 1969; CHURCHMAN et al., 1957).

Rardin (1998) enhance the importance of recognizing the major categories on the models because different classes of optimization models have different tractability. The recognition of this categories is illustrated in a standard form of the model proposed by Hillier and Lieberman (1995):

$$Maximize \qquad Z = c_1x_1 + c_2x_2 + \ldots + c_nx_n,$$

subject to the restrictions

$$a_{11}x_1 + a_{12}x_2 + \ldots + a_{1n}x_n \leq b_1$$
$$a_{21}x_1 + a_{22}x_2 + \ldots + a_{2n}x_n \leq b_2$$
$$\ldots$$
$$a_{m1}x_1 + a_{m2}x_2 + \ldots + a_{mn}x_n \leq b_m$$

and

$$x_1 \geq 0,\ x_2 \geq 0,\ \ldots,\ x_n \geq 0.$$

The aim is allocating the levels of the activities that achieve the best possible value of the overall measure of performance, where:

Z = overall measure of performance;

x_j = level of activity j (for j = 1,2,…,n);

c_j = increase in Z that result from each unit increase in the level of activity j;

b_i = amount of resource I that is available for allocation to activities (for I = 1,2,…,m);

a_{ij} = amount of resource I consumed by each unit of activity j.

The values of x_j are called the decision variables because the problem is based in terms of making decisions about the levels of activities. In the example, the function that is being maximized $c_1x_1 + c_2x_2 + \ldots + c_nx_n$, is called objective function and the restrictions are called constraints. The group of constraints related to b are called functional constraints and the other group of constraints (for example $x_j \geq 0$) are called non-negativity constraints.

The standard form can also be modeled in legitimate forms, such as:

1. Minimizing rather than maximizing the objective functions;
2. Functional constraints greater than or equal to inequalities;
3. Functional constraints equal to b values;
4. Deleting the non-negative constrains, meaning basically that the decision variables can assume any value.

Besides, any specification of the values for the levels of activities is called a solution. A feasible solution is when all the constraints are satisfied and an infeasible solution is when at least one constraint is not satisfied. Furthermore, a feasible region is a collection of all feasible solutions and an optimal solution is a feasible solution that has the most favorable value of the objective functions. Finally, the most favorable value is the largest value if the objective function is maximized and the smallest value if the objective function is minimized.

There are some important assumptions of linear programming, such as:

Proportionality: The contribution of each activity to the overall measure of performance (Z) is proportional to the level of activity (x_j) and represented by $c_j x_j$. The left side of each functional constraint is also proportional to the level of activity (x_j) and represented by $a_{ij} x_j$.

Additivity: Every function is a sum of the individual contributions of the respective activity;

Divisibility: The decision variables can have any values that satisfy the functional and non-negativity constraints, including non-integer values;

Certainty: The value assigned to each parameter is assumed as a known constant.

Hillier and Lieberman (1995) affirm that although adding too much detail and precision can make the model too unwieldy for useful analysis, a good model is when there is a high correlation between the model and what is happening in the real problem (HILLIER et al., 1995).

2.3.2. Integer programming

Wagner (1969) affirms that most industrial applications of large-scale programming models need planning decisions in complex situations and there are frequently circumstances that lead to integer valued variables, such as equipment utilization, setup costs, batch sizes or 'go-no-go' decisions.

According to Wagner (1969), the integer programming problem is based on the following model:

(1) $$optimize \sum_{j=1}^{n} c_j x_j \,,$$

subject to

(2) $$\sum_{j=1}^{n} a_{ij} x_j \le b_i \quad for\ i = 1,2, \ldots, m$$

(3) $$x_j \ge 0 \quad for\ j = 1,2, \ldots, n$$

(4) $$x_j\ integer - valued \quad for\ j = 1,2, \ldots, p(\le n)\,.$$

A pure integer programming is when p = n, so that every variable must be integer-valued, or else is called mixed integer programming. The sense of optimization in the objective function can be maximization or minimization and the integer programming problem should include equalities and/or inequalities.

In the example of traveling salesman problem it is possible to see the connection between combinatorial and integer programming problems and provide a bridge spanning some fundamental algorithmic concepts. The classical transportation problem is based on the following model:

$$(5) \qquad minimize \sum_{i=1}^{m} \sum_{j=1}^{n} c_{ij}x_{ij} ,$$

subject to

$$(6) \qquad \sum_{j=1}^{n} x_{ij} \leq S_i \qquad for\ i = 1,2, \ldots, m\ (supply)$$

$$(7) \qquad \sum_{i=1}^{m} x_{ij} \geq D_j \qquad for\ j = 1,2, \ldots, n\ (demand)$$

$$(8) \qquad x_{ij} \geq 0 \qquad for\ all\ i\ and\ j.$$

Scheduling, sequencing and routing problems are cases called combinatorial optimization problems and the aim is to find, from a set of alternatives, one alternative that optimizes the value of the objective function. The formulation of these integer programming problems are computational interest according to Wagner (1969) because there is a large number of constraints and variables.

Practical algorithms in integer programming must avoid explicitly enumerating all possibilities, must partially enumerate a manageable number of possibilities and must enumerate the rest implicitly. With these algorithms, it is easy to devise specific integer programming structures that require huge computational effort.

2.3.3. Vehicle Routing Problem

The Vehicle routing problem is one of the most studied combinatorial optimization problems and it consists basically on the determination of the optimal set of routes to be performed by vehicles to serve customers. The problem was introduced by Dantzig and Ramser in 1959 when they proposed a mathematical programming formulation to describe an application concerning the delivery of gasoline to service stations. Clarke and Wright proposed in 1964 an heuristic approach that improved Dantzig and Ramser approach and after that hundreds of models were proposed for finding approximate solutions of VRP (DANTZIG et al., 1959; CLARKE et al., 1964; TOTH et al., 2002).

The successful utilization of optimization techniques for the VRP is due to the power of current computer systems, integration of information systems into processes, development of rigorous mathematical models, real world applicability and practical relevance. Furthermore, the VRP is also often used for the development of new models and algorithmic techniques applied for the effective solution of combinatorial optimization problems (TOTH et al., 2014).

The problem consists of a distribution of goods in a time period of a set of customers by a set of vehicles. These vehicles are located in depots, operated by drivers and perform their movements using a road network. Considering this, the solution calls for a set of routes, performed by vehicles that starts and ends at its depots in such a way that (1) customer requirements are fulfilled, (2) operational constraints are satisfied and (3) transportation costs are minimized. Besides, some typical characteristics of the vehicles are: home depot, capacity, possible division into compartments, devices available for loading and unloading operations, transversed graphs and associated costs (TOTH et al., 2002).

Normally drivers must satisfy several constraints involving regulations and the routes must satisfy operational constraints, but the application of these constraints requires knowledge of the travel time and travel costs. Typical considered objectives are minimization of the global transportation cost, minimization of the number of vehicles used, balancing of the routes and minimization of penalties associated with partial service (TOTH et al., 2002).

Hassanzadeh et al. (2009) and Toth et al. (2002) gives an overview of the problem presenting the basic problems of VRP class and their interconnections (figure 10).

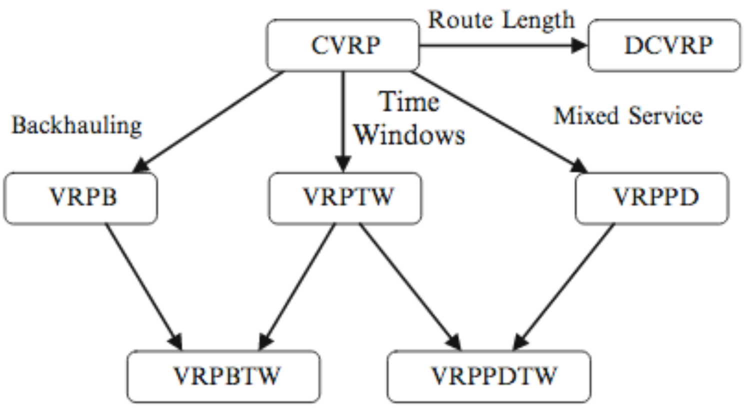


Figure 10 - Basic problems of VRP and their interconnections

Font - Toth et al., 2002

The CVRP stands for Capacitated VRP, where all the customers correspond to deliveries, the demands are deterministic and may not be split. It consists on finding circuits with minimum cost such that each circuit visits the depot vertex, each customer vertex is visited by exactly one circuit and the sum of the visited vertices demands does not exceed the vehicle capacity (TOTH et al., 2002).

VRPTW stands for VRP with time windows, VRPB stands for VRP with Backhauls and VRPPD stands for VRP with pick up and delivery. These problems are extensions of CVRP and on the first one, for each customer, the service starts within a time window and the vehicles stops for time instants. On the second, the customer set is split into two subsets: Linehaul customers and Backhaul customers, such that whenever a route serves both types of customers, all linehaul customers must be served before the backhaul customers. On the third one, each customer is associated with two quantities: the demand of homogeneous commodities to be delivered and picked up at a customer. In that case it is assumed that at each customer location the delivery is performed before the pickup (TOTH et al., 2002).

Furthermore, the other two basic problems are variations of the ones presented. VRPBTW stands for VRP with Backhauls and Time Windows and VRPPDTW for VRP with Pickup and Delivery and Time Windows (HASSANZADEH, 2009).

An example of VRP problem studied in this case and presented by Toth et al. (2002) is an integer linear programming formulation for Asymmetric Capacitated Vehicle Routing Problem ACVRP, using a two index vehicle flow formulation:

(9) $$minimize \sum_{i \in V} \sum_{j \in V} c_{ij} x_{ij}$$

subject to

(10) $$\sum_{i \in V} x_{ij} = 1 \quad \forall\, j \ \in \ V \,|\, \{0\},$$

(11) $$\sum_{j \in V} x_{ij} = 1 \quad \forall\, i \ \in \ V \,|\, \{0\},$$

(12) $$\sum_{i \in V} x_{i0} = K,$$

(13) $$\sum_{j \in V} x_{0j} = K,$$

(14) $$\sum_{i \notin S} \sum_{j \in S} x_{ij} \geq r(S) \quad \forall\, S \ \subseteq \ V \,|\, 0,\, S \neq \emptyset,$$

(15) $$x_{ij} \in \{0{,}1\} \quad \forall\, i, j \ \in \ V.$$

In this example, the variable x_{ij} takes value 1 if $(i, j) \in A$ belongs to the optimal solution and takes value 0 otherwise. The constraints (10) and (11) impose that exactly one arc enters and leaves each vertex associated with a customer and the constraints (12) and (13) are the degree requirements for the depot vertex. Besides, the constraint (14) impose connectivity between the solution and the vehicle capacity requirements.

Latest advances and new challenges of VRP involves complex variants of VRP, named as „rich" VRPs, and that are closer to practical distribution problems. These variants include multiple depots, multiple trips, multiple vehicle types and other operational issues. Golden et al. (2008) examines the recent developments in VRP by analyzing theoretical research and practical applications. Golden et al. (2008) studies and others (PILLAC et al., 2013; KUMAR et al., 2012; PSARAFTIS, 1995; LARSEN et al., 2008; LAHYANI et al., 2015; among others) show that new approaches for solving VRPs. These models have been developed and resulted in faster solution algorithms, accurate techniques and improvement of solving complex problems.

3. MODEL DEVELOPMENT

The purpose of this chapter is to describe the model development considering the following phases: (1) Defining the problem and gathering data; (2) Formulating the mathematical model; (3) Deriving solutions from the model; (4) Testing the model and (5) Application scenarios.

3.1. Defining the problem and gathering data

The problem aims to minimize Operação Carro Pipa costs by the application of vehicle routing problem. Concerning this, the purpose of the model development is to identify the optimal routing for water supply in the Northeast of Brazil, by analyzing different scenarios.

The costs in the Operação Carro Pipa are directly proporcional to the total distance routes performed by trucks that starts in a depot and ends in a delivery point. Therefore, it is possible to infer that the optimal solution can be obtained by the minimization of the total routes distance. Thereby, the aim is to find, from a set of alternatives, one alternative that minimizes the value of the objective function.

The constraints involved and defined by CENAD are:

- Each supply point has a maximal withdrawal limit;
- Each demand point has an exact requested quantity;
- Each delivery point can be served by just one supply location.

Therefore, is not possible to have a case where a demand point has deliveries made by two or more depot locations. Besides, considering that each demand and each supply capacity are accounted within integer values, it is possible to verify that this case is better solved through Integer Programming.

The relevant data was obtained through GPIPABRASIL computer based management information system. Using GPIPABRASIL, it was necessary to identify patterns that may lead to useful decisions and the following data was gathered:

- The number of delivery points and their respective requests (ANNEXURE A.1);
- The number of supply points and their respective capacities (ANNEXURE A.2);
- The distances between the supply and the delivery points (ANNEXURE A.3).

The tables presented in the ANNEXURES shows the results of the first scenario of Quixadá., with demand, capacities and distances. Second scenario, third scenario and results of each Northeast Brazilian states follow the same structure and wasn't presented in ANNEXURES due to it's extension.

3.2. Mathematical model

After cleaning the data, the problem was modeled using Integer Linear Programming. For each *I* delivery point and *J* demand point, the distances and deliveries where minimized through the following formulation:

(1) $$minimize \ \ Z = \sum_{i=1}^{M} \sum_{j=1}^{J} distances_{i,j} \cdot demand_j \cdot x_{i,j} \,,$$

subject to

(2) $$\sum_{j=1}^{J} demand_j \cdot x_{1,j} \leq capacity_1$$

$$\dots$$

$$\sum_{j=1}^{J} demand_j \cdot x_{M,j} \leq capacity_M$$

(3) $$\sum_{i=1}^{M} x_{i,1} = 1$$

$$\dots$$

$$\sum_{i=1}^{M} x_{i,J} = 1$$

(4) $$x_{ij} \in \{0,1\} \quad \forall \ i, j \ \in \ V$$

Where:

A. Z is the total distance of all deliveries in each case;

B. $distances_{i,j}$ is the distance between the supply point i and the demand point j;

C. $demand_j$ is the number of deliveries requested by the demand point j;

D. $x_{i,j}$ is the relation between the supply point i and the demand point j, that can have the values:

- 1, if the delivery is realized between two points;
- 0, otherwise.

E. $capacity_i$ is the capacity of the supply point i.

Considering that every summation in the last formulation can be represented as a matrix, the same problem can the formulated as:

(1) $$minimize \quad Z = f^{\intercal} \cdot x,$$

subject to

(2) $$A \cdot x \leq B,$$

(3) $$Aeq \cdot x = Beq,$$

(4) $$lb \leq x \leq ub,$$

(5) $$x(k) \in \mathbb{Z} \ \forall \ k \in \{1,2,3,...,I \cdot J\},$$

Where:

A. Z is the total distance of all deliveries in each case;

B. f is a column matrix, with i and j elements, where each element represents the association between the supply point and the delivery point;

C. $demand_j$ is the number of deliveries requested by the delivery point j;

D. x is a column vector, with $i \cdot j$ elements, where each element represents the association between the supply point and the delivery point point and can have the values:

- 1, if the delivery is realized between two points;
- 0, otherwise.

E. A is a matrix with i lines and $i \cdot j$ columns and the values can be:

- The necessary demand for the delivery point;
- 0, otherwise.

F. B is a column matrix, with i elements, where each element represents the maximal withdraw quantity of a supply point;

G. Aeq is a matrix with j rows and $i \cdot j$ columns and the values can be:

- 1, if the supply point in the row and in the column is the same;
- 0, otherwise.

H. Beq is a column matrix, with j elements, where each value is 1;

I. lb is a line matrix, with $i \cdot j$ elements, where each value is 0;

J. ub is a line matrix, with $i \cdot j$ elements, where each value is 1.

For each month, this method was applied comparing the system as it is and the optimal solution. With that, it was possible to calculate the possible monthly economy with the results implementation.

3.3. Deriving solutions from the model

After the mathematical model formulation, the next phase was procedure development for deriving solutions to the problem from this model. For that, it was firstly developed a MATLAB code and after the same algorithm was applied in R, Python and Julia languages.

Concerning this, for each month and location, the program read four *.txt* files:

- 'atual': Two data columns relation. The first has the number of each delivery point and the second has the respective supply point where the supply was realized;
- 'demanda': Two data columns relation. The first has the number of each delivery point and the second has the respective demand;
- 'oferta': Two data columns relation. The first has the number of each supply point and the second has the respective capacity;
- 'distancias': Matrix relation. The columns represent the delivery points and the lines represent the supply points, where each matrix element is the distance between delivery and supply points.

Besides, the two exit files are:

- ‘results’: Two data columns relation. The first has the number of each delivery point and the second has the respective supply point according to the optimal solution;

- ‘economy’: Relation between the total distance on the month and location without optimization and the total distance on the month and location with optimization.

The details of the code are shown in the Appendix B.

3.4.Testing the model

The model was firstly tested in a municipality called Quixadá, one of the largest municipalities in Ceará State, with a population of 85.371. Quixadá was used to test the model due to the rainfall characteristics and large number of people affected by drought. The city has 3 supply points and 229 delivery points, what proportionally represents a good sample of the Brazilian Northeast delivery necessities. Table 1 relates the municipality number of supply points, delivery points and number of deliveries.

Table 1 - Quixadá number of delivery points, deliveries and supply points

Number of delivery points	Number of deliveries	Number of supply points
229	671	3

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Quixadá application was important to test and improve the model validity. This preliminary application resulted in an average cost reduction of 8,08%, with an economy of 22% in the last application month, showing a possibility of around 6 million euros cost reduction in the city.

3.5. Application scenarios

For each month and location there is only one relation between a specific supply point and delivery demand. Due to the rainfall changes, there can be months where a specific location doesn’t need water supply, but the distances between supply and delivery points are invariable. Considering the decision making impact and for a better problem analysis, the model development was divided in 3 different scenarios.

The supply points can be divided in fountainheads, rivers and weirs. In the first scenario, the capacity of each river supply point was considered unlimited. In the second scenario, the capacities of both fountainheads and rivers were calculated as the average of last capacities and other CENAD requirements.

The third scenario is similar to the second one but with two more restrictions:

- In the locations where the Water Treatment Station (ETA’s) are not enough for demand fulfillment, both supply points rivers and weirs are considered;

- Rivers and weirs are considered in the formulation only in the locations where there was water withdrawal in the respective month.

These scenarios were applied for Piauí state.

3.5.1. First scenario

After testing the scenario in Quixadá, the model was applied separately in all Northeast states. Table 2 shows the summary of Ceará state information.

Table 2 - Ceará number of delivery points, deliveries and supply points on first scenario

Number of delivery points	Number of deliveries	Number of supply points
4.599	12.126	36

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The computational time in Ceará was considered very high and because of that, it was necessary to apply sparse matrix on the model. This necessity was identified due to the high quantity of null variables on A and Aeq matrixes.

For Piauí state, the model was applied to all 2017 months and from January until December 2017, table 3 shows the summary of Piauí delivery points, number of deliveries and supply points for each month.

Table 3 - Piauí number of delivery points, deliveries and supply points on first scenario

Year	Month	Number of delivery points	Number of deliveries	Number of supply points
2017	January	1.952	3.933	66
	Febraury	945	1.665	53
	March	1.827	3.384	53
	April	2.066	4.036	49
	May	3.195	7.033	62
	June	4.294	10.826	66
	July	5.110	13.953	61
	August	5.280	14.431	59
	September	5.794	16.087	60
	October	5.681	15.146	61
	November	5.696	14.979	64
	December	5.646	14.590	54

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It is possible to observe on table 3 the problem dynamics, in which the occurrence of rainfalls and drought characteristics may change delivery necessities and possible quantity of supply delivery points.

3.5.2. Second scenario - Piauí State

On this application, supply and delivery points data for each month were different from the first scenario and the capacities of fountainheads and rivers were calculated as the average of last capacities and other CENAD requirements. For example, if a water treatment station supplied two deliveries in one month, but in all other months the capacity was fifty, it was assumed that the real capacity if this supply station is fifty. Table 4 shows Piauí number of deliveries for each month.

Table 4 - Piauí number of deliveries on second scenario

Year	Month	Number of supply points
2017	January	66
	Febraury	51
	March	52
	April	47
	May	61
	June	64
	July	59
	August	58
	September	58
	October	58
	November	62
	December	52

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3.5.3. Third scenario - Piauí State

In this scenario was added two restrictions on the model:

1. In the locations where the ETA's are not enough for demand fulfillment, both supply points rivers and weirs are considered;
2. Rivers and weirs are considered in the formulation only in the locations where there was water withdrawal in the respective month.

The first restriction was added because the water quality of rivers and weirs is not as good as ETA's water quality, due to possible contaminations, so the locations that ETA's can cover were prioritized. Second restriction was a CENAD requirement for limiting rivers and weirs supply points. Table 5 shows Piauí number of deliveries for each month.

Table 5 - Piauí number of deliveries on third scenario

Year	Month	Number of supply points
2017	January	79
	Febraury	79
	March	79
	April	79
	May	79
	June	79
	July	81
	August	81
	September	81
	October	82
	November	81
	December	81

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On this scenario, the number of supply points were considered the same of first and second scenario although the number of supply points changed due to the restrictions related to rivers and weirs.

4. RESULTS

In this section, we analyze the results for each scenario, based on the optimal solution algorithm presented on APPENDIX B and present a data visualization with the results of the specific Northeast Brazilian states. The model application determines how much water must be send from the sources to the delivery points to minimize the cost and will be presented a summary of the results together with their respective analyzes.

The structure of this chapter consider the following phases: (1) First scenario; (2) Second scenario; (3) Third scenario and (4) Data visualization. The second and third scenario were applied for the state of Piauí.

4.1. First scenario

For Quixadá municipality, it was calculated the total actual distance without the model application, the optimized distance after model application with the absolute and relative economies (table 6).

Table 6 - Summary of Quixadá first scenario results

Total actual distance (km)	Total optimized distance (km)	Absolute economy (km)	Relative economy
22.162	16.136	6.027	27%

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The relative economy of 27% represents a high cost reduction proportion and justify the necessity of a deep study and model application for the whole ‘Operação Carro-Pipa’ development. A detailed presentation with the supply and the respective delivery points is specified on APPENDIX A.

Table 7 shows the same summary results of table 6 but for the Ceará state.

Table 7 - Summary of Ceará first scenario results

Total actual distance (km)	Total optimized distance (km)	Absolute economy (km)	Relative economy
1.085.602	1.018.335	67.267	6,2%

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Although Quixadá is a Ceará municipality, the relative economy for the whole state is considerably lower. The reasons for these results can be a disorderly Quixadá delivery routing, trucks covering not specified routes, delivery delays, water scarcity, among others. Nevertheless, the relative economy of 6.2% represents a direct cost reduction of around 5 million euros in 'Operação Carro-Pipa', due to the characteristic of Ceará of being the more burdensome state in the Brazilian Northeast.

Table 8 shows the results for Piauí state, considering 12 months application.

Table 8 - Summary of Piauí first scenario results from January until December 2017

Year	Month	Total actual distance (km)	Total optimized distance (km)	Absolute economy (km)	Relative economy
2017	January	2.756	2.605	151	5,5%
	Febraury	1.147	1.101	46	4,0%
	March	2.453	2.375	77	3,1%
	April	2.963	2.890	73	2,5%
	May	5.078	4.923	155	3,1%
	June	7.772	7.407	366	4,7%
	July	10.641	9.828	813	7,6%
	August	11.159	10.318	841	7,5%
	September	12.492	11.546	946	7,6%
	October	11.159	10.981	950	8,0%

Year	Month	Total actual distance (km)	Total optimized distance (km)	Absolute economy (km)	Relative economy
	November	10.882	8.462	2.420	22,2%
	December	10.451	8.240	2.211	21,2%
Total		88.953	80.676	9049	8,1%

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The results are obtained with higher accuracy when analyzing each month and relative economies are considerably high, specially from November 2017 to December 2017. Beside other reasons, one explanation for these values can be water scarcity during the period. The number of deliveries presented on table 3 increased during these months but CENAD managers reported that this happens every year. However, optimization results presents the possibility of around 2.000 km reduction and relative economy range between 2.5% and 22.2%, with an average of 8.1%.

4.2.Second scenario

This second scenario, due to its complexity, was applied only to the state of Piauí. Table 9 shows the summary of second scenario Piauí results on 2017.

Table 9 - Summary of Piauí second scenario results on 2017

Year	Month	Total actual distance (km)	Total optimized distance (km)	Absolute economy (km)	Relative economy
2017	January	2.756	2.171	585	21,2%
	Febraury	1.147	876	271	23,6%
	March	2.453	1.826	627	25,6%
	April	2.963	2.472	491	16,6%

Year	Month	Total actual distance (km)	Total optimized distance (km)	Absolute economy (km)	Relative economy
	May	5.078	4.203	875	17,2%
	June	7.772	6.959	814	10,5%
	July	10.641	9.649	992	9,3%
	August	11.159	10.194	964	8,6%
	September	12.492	6.905	5.587	44,7%
	October	11.159	10.268	1.663	13,9%
	November	10.882	8.033	2.849	26,2%
	December	10.451	7.984	2.467	23,6%
Total		89.725	71.542	18.183	20,3%

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The total relative economy on second scenario was 20.3% comparing to first scenario result of 12.1%. This economy on this second scenario application presents better results comparing to first, demonstrating that a greater versatility in choosing water delivery points provides more optimized routes.

4.3.Third scenario

Once again, this third scenario was applied only to Piauí state. Table 10 presents Piauí the results summary and its application horizon within twelve months of 2017.

Table 10 - Summary of Piauí third scenario results on 2017

Year	Month	Total actual distance (km)	Total optimized distance (km)	Absolute economy (km)	Relative economy
2017	January	2.756	2.229	556	19,1%

Year	Month	Total actual distance (km)	Total optimized distance (km)	Absolute economy (km)	Relative economy
	Febraury	1.147	945	201	17,5%
	March	2.453	1.945	508	20,7%
	April	2.963	2.634	329	11,1%
	May	5.078	4.401	678	13,3%
	June	7.772	7.372	400	5,1%
	July	10.641	11.419	-777	-7,3%
	August	11.159	12.751	-1.592	-14,3%
	September	12.492	18.204	-5.712	-45,7%
	October	11.159	15.648	-3.718	-31,2%
	November	10.882	9.125	1.758	16,2%
	December	10.451	8.846	1.605	15,4%
Total		89.725	95.519	-5.794	-6,5%

Font - Author

The total developed economy on this scenario was negative, mainly due to the results between July and October. However the negative results, that happened because optimized distances were higher than actual ones, were expected. The proposal on this scenario is to reduce rivers and weirs supply points to the minimum amount demand necessary payment and preventing these deliveries increase the routing distance.

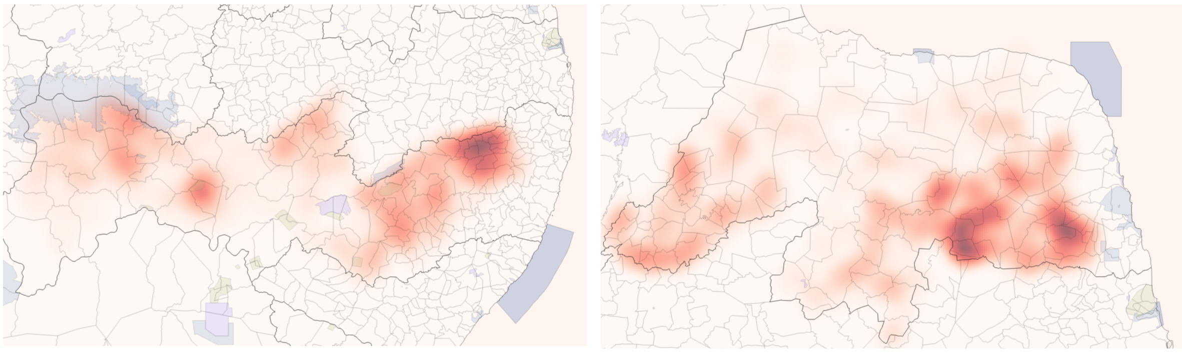
Besides, large increase in demand for supply points that are closer to rivers or weirs than ETA's is another influence factor. Because of that, the weighting of delivery volume to these locations and the increase on delivery distance showed a notable impact on overall Piauí routing results. Considering that, this scenario shows that additional restrictions related to rivers and weirs results in obstacles for routing optimization. It can be considered, consequently, higher flexibility of these supply points or more ETA's constructions Nevertheless, results for the other 8 months have a relative economy average of 13,8%, that presents a better application than first scenario.

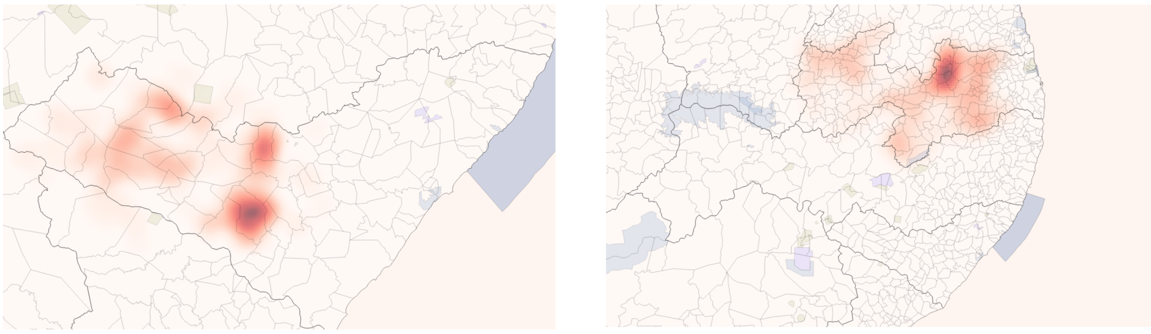
Second scenario have the higher economy and although third scenario has a lower total economy, the average of the first months economy (13.8%) is better than on first scenario. Besides, third scenario has a higher social impact because delivering more water with a better quality is socially better for the population. Regarding this, it is important to consider not only water delivery in the best possible conditions, but also higher flexibility of supply points with the purpose of routes minimization.

4.4.Data visualization

In order to visualize the results obtained, the software QGIS was used. QGIS is a free and open source cross platform desktop geographic information system application for visualization of geospatial data, allowing the user to edit and analyze information by composing and exporting graphical maps.

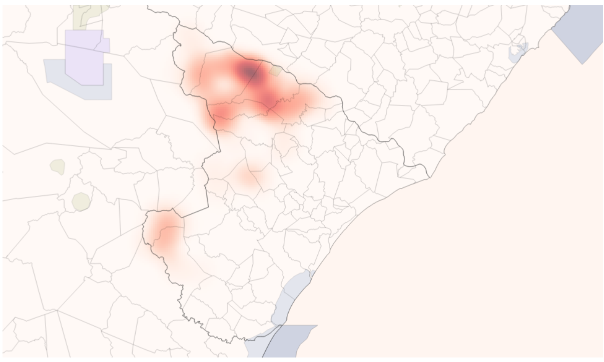
Considering that, and regarding CENAD requirements, heat maps of delivery points results were generated due to the quality visualization of dense point data that heat maps can provide. Figure 12 shows the delivery points results of (a) Alagoas, (b) Paraíba and (c) Sergipe states.





(12a) Delivery point optimization results of Alagoas

(12b) Delivery point optimization results of Paraíba



(12c) Delivery point optimization results of Sergipe

Figure 12 - Alagoas, Paraíba and Sergipe delivery points optimization results visualization

Font - Garcia et al.

Both Alagoas and Sergipe states concentrate delivery points most in rural populations, that are characterized as the driest regions. The three states presented on figure 12 are part of the referred Polygon das Secas (Drought Polygon) and more than 10 million people have been affected by drought during the last 5 years in this region. The extreme conditions caused by deficient rainfall and drying conditions reduce water availability.

(13a) Delivery point optimization results of Pernambuco

(13b) Delivery point optimization results of Rio Grande do Norte

Figure 13 - Pernambuco and Rio Grande do Norte delivery points optimization results visualization

Font - Garcia et al.

Figure 13 shows that Pernambuco and Rio Grande do Norte have higher water delivery necessities comparing to Alagoas and Sergipe. Paraíba is located between the two states presented on figure 13 and constitute together one of the driest regions in the country.

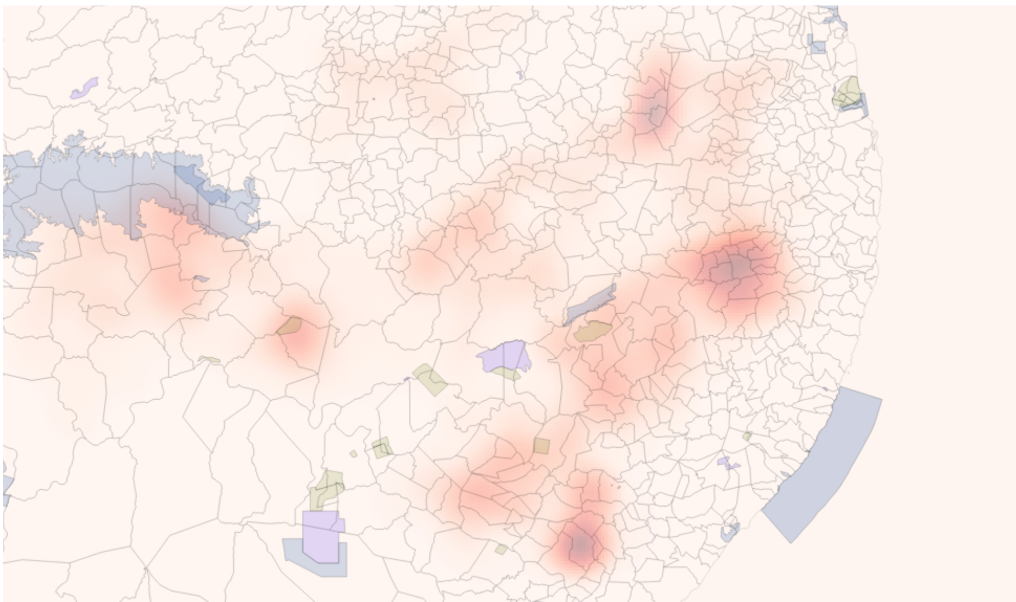


Figure 14 - The Brazilian Northeast delivery points optimization results visualization

Font - Garcia et al.

Water delivery requested in all states follow drought severity maps in the Brazilian Northeast described in figure 14 and one of the reasons, is that most part of the rural locations still lack proper sanitation infrastructure and are subject of water scarcity. Optimization results visualization prove that a large relative economy can be obtained through vehicle routing problem development and operations research application, the Brazilian Northeast is still suffering from extreme climate events and a larger operations research study can not only reduce governmental costs but also prevent millions of people from water scarcity.

Development of viability studies for new ETA's constructions is a long term decision that can turn this vehicle routing problem in future risk management. Delivery points optimization results present that regions affected by land degradation and desertification have a strongly impact on water scarcity, besides the negative consequences on energy security, substance agriculture, biodiversity and Amazonia risk of fires.

5. CONCLUSION

This thesis presents a model which analyzes the water supply routing under an emergency situation in the Northeast of Brazil. The monthly economy with the model implementation was obtained for the Brazilian states involved on Operação Carro Pipa and made a data visualization with the results.

One of the biggest advantages of the model, presented in Model development chapter, is to be able to adapt to different scenarios with new restrictions and the use of sparse matrix to structure the data. The biggest municipality Ceara was used to test the model and the economy of 22% represented a cost reduction possibility of around 60 million euros on 2017 if it that were extrapolated to the whole Northeast of Brazil.

The first scenario represented a cost reduction of 12,1% for the Piauí state but second scenario have the highest economy comparing with the others. The results on the third scenario were not positive due to the restrictions addition of minimum water deliver from rivers and weirs, however, this scenario has a higher social impact because it delivers more water in the best treatment conditions to the populations. Comparing these scenarios a good policy would be a mix between the second and the third scenario restrictions because it is important to consider not only water delivery in the best possible conditions, but also higher flexibility of supply points with the purpose of routing minimization.

The model was applied in Matlab, Julia, Python and R languages and the software QGIS was used for visualization of the geospatial delivery points results. The visualization shows that water delivery requests in the the Northeast of Brazil follow the same dissipation of drought severity maps and optimization results shows that although there is a large relative economy through vehicle routing problem application, the Brazilian Northeast is still suffering from extreme climate events and a larger operations research study can reduce governmental costs and prevent water scarcity.

Model application contributes to minimize the routing distance, water delivery fulfillment, reduce costs, build resilience beyond drought hazards, prevent adaptations, prepare to risk management. Nevertheless operational research in Operação Carro Pipa application needs to continue because droughts have caused serious agricultural losses and human suffering and that illustrates just a few of the hardships that are part of a much larger problem.

As future work, a the model development of a scenario including both second and third scenarios aiming to find the best policy implementation that allows a future risk management application. Besides, development of viability studies about water treatment stations construction is important to guarantee good water quality distribution and reduce costs.

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APPENDICES

APPENDIX A - Simulation results

The following table present the simulation results for first scenario of Quixadá., with delivery points (DP) and it's respective supply point (SP). Second scenario, third scenario and results of each Northeast Brazilian states follow the same structure.

Table 11 - First scenario results of Quixadá

DP	SP	DP	SP	DP	SP
2655	2703	18390	100	47087	2703
18309	2715	18393	100	47088	100
18310	2715	18409	100	47120	2715
18316	2715	18411	2703	47233	2715
18318	2715	18412	2715	57191	100
18319	2703	18416	100	57197	2703
18322	2703	18420	100	72542	2715
18324	2715	18421	100	72544	100
18332	100	18424	100	72942	2715
18338	2703	18425	100	72946	2703
18345	100	18432	2715	73159	2715
18347	2715	18433	2715	73160	100
18349	2715	18435	2715	73165	100
18354	100	18438	100	88318	2703
18355	2715	18442	2703	88322	100
18359	100	18444	100	88328	100
18363	100	18453	2715	88357	100
18365	2715	24347	2703	88370	100
18366	2715	37319	100	88389	100
18367	2715	37331	100	88566	2703

DP	SP	DP	SP	DP	SP
18368	2715	37340	2703	88641	100
18372	2715	46732	2703	88649	2703
18374	2715	46997	2715	88655	100
18376	2715	47056	2703	88656	100
18386	2715	47083	100	88657	100
18388	100	47084	100	88659	2715
88661	100	88980	2715	127346	100
88690	100	88993	100	127347	2715
88691	2715	89004	2715	127352	100
88699	100	89024	100	127356	2715
88705	2715	89027	2715	127364	2703
88707	2715	89032	100	127365	2715
88724	100	89056	100	127366	2715
88740	100	89066	2703	127367	2715
88747	100	90591	100	127451	100
88756	100	90777	100	127533	100
88758	100	92942	2715	128423	100
88761	100	93721	2715	128622	2703
88763	100	93723	100	128625	2703
88767	100	93726	100	129325	100
88769	2715	111097	2715	129737	2715
88788	100	111759	100	129738	2703
88812	2703	112789	100	129739	2715
88814	2703	114017	2715	129755	2715
88816	2715	114021	2715	129818	2715
88818	2715	114022	2715	129849	100
88858	2715	114025	2715	130739	2703
88859	2715	114044	2715	130808	100
88862	100	114074	100	132099	100

DP	SP	DP	SP	DP	SP
88865	2715	114253	2715	134732	2703
88868	100	114254	100	138690	100
88904	2715	116363	100	138691	100
88913	2715	116366	100	138695	2715
88927	100	118723	100	138699	2703
88950	100	118724	100	138702	100
88958	2715	118725	100	138703	100
88965	2715	127344	100	139479	100
139480	100	147210	100	151164	2715
140091	2715	147222	2703	151165	2703
143447	100	147223	100	154369	2703
146664	100	147225	100	154758	2715
146696	2715	147227	100	154780	100
146954	100	147878	100	156828	2715
146958	2715	148419	100	156971	100
146959	2715	148420	2715	156977	2715
146978	100	149276	100	156984	100
146984	2715	149284	100	156985	100
147005	2703	149287	100	157030	100
147014	2715	150086	100	157157	100
147016	100	150091	100	190349	2715
147020	100	150560	100	399350	100
147050	100	150564	2703	399452	100
147051	100	150565	2715	465969	100
147053	100	150608	100	466262	100
147204	2715	150609	100	467441	2703
147205	2715	150610	2703		
147207	2703	151113	100		

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APPENDIX B - Used code

B.1 - Python code

```
from pulp import *
ofertatxt = open('../dados/quixada_oferta.txt','r')
demandatxt = open('../dados/quixada_demanda.txt','r')
distanciastxt = open('../dados/quixada_distancias.txt','r')

mOferta = list(map(int,ofertatxt.read().split()))
mDemanda = list(map(int,demandatxt.read().split()))

mDistancias = list(distanciastxt.read().split())
for i in range(len(mDistancias)):
    mDistancias[i] = int(round(float(mDistancias[i].replace('.','').replace(',','.'))))

cont = 0
ldemanda = []
Distancias =[]

for i in range(len(mDemanda)):
    for j in range(len(mOferta)):
        ldemanda.append(mDistancias[cont])
        cont += 1
    Distancias.append(ldemanda)
    ldemanda = []
ofertatxt.close()
demandatxt.close()
distanciastxt.close()

prob = LpProblem("mainPulp",LpMinimize)

Varx = LpVariable.dicts("Varx",[(i,j) for i in range(len(mDemanda))
                              for j in range(len(mOferta))],0,None,LpInteger)

prob += lpSum(Distancias[i][j] * Varx[(i,j)] for i in range(len(mDemanda))
              for j in range(len(mOferta)))

for i in range(len(mDemanda)):
    prob += lpSum(Varx[(i,j)] for j in range(len(mOferta))) == mDemanda[i]
for i in range(len(mOferta)):
    prob += lpSum(Varx[(j,i)] for j in range(len(mDemanda))) <= mOferta[i]

prob.solve()

for i in prob.variables():
    if i.varValue > 0:
        print(i.name,' carros = ',i.varValue)
```

B.2 - Julia code

```
using JuMP, DelimitedFiles, GLPK

oferta = readdlm("../dados/exemplo_oferta.txt");
demanda = readdlm("../dados/exemplo_demanda.txt");
Distancias = readdlm("../dados/exemplo_distancias.txt");

noferta = size(oferta,1)
ndemanda = size(demanda,1);

LpModel = Model(with_optimizer(GLPK.Optimizer))

@variable(LpModel, x[1:ndemanda*noferta] >= 0)

@objective(LpModel, Min,sum(Distancias[i,j]*x[j+(i-1)*noferta]
                            for i in 1:ndemanda for j in 1:noferta));

for i in 1:ndemanda
    @constraint(LpModel, sum(x[j+(i-1)*noferta] for j in 1:noferta) == demanda[i])
end
for j in 1:noferta
    @constraint(LpModel, sum(x[j+(i-1)*noferta] for i in 1:ndemanda) <= oferta[j])
end

LpModel

@time begin
status = JuMP.optimize!(LpModel)
end
@show JuMP.has_values(LpModel)
@show JuMP.termination_status(LpModel)
@show JuMP.primal_status(LpModel) == MOI.FEASIBLE_POINT;

println("Objective value: ", JuMP.objective_value(LpModel))

[println("destino: ",i,", origem: ",j,", carros: ",JuMP.value.(x)[j+(i-1)*noferta])
  for i in 1:ndemanda for j in 1:noferta if JuMP.value.(x)[j+(i-1)*noferta] >0];
```

B.3 - R code

```
library(Rglpk)
library(readxl)
library(Matrix)
library(optimbase)
library(tibble)

distancias <- read.delim("../dados/exemplo_distancias.txt", header=FALSE)
oferta <- read.delim("../dados/exemplo_oferta.txt", header=FALSE)
demanda <- read.delim("../dados/exemplo_demanda.txt", header=FALSE)

n_ofer <- nrow(oferta)
n_dema <- nrow(demanda)

funcao_f <- matrix(nrow = 1 , ncol =  n_ofer*n_dema)
for (i in 1:n_dema){
  for (j in 1:n_ofer){
    funcao_f[(j+(i-1)*n_ofer)] <- distancias[i,j]
  }
}
funcao_f[is.na(funcao_f)] <- 0
obj <- funcao_f

funcao_A <- matrix(nrow = n_ofer, ncol = n_dema*n_ofer)
for (i in 1:n_ofer){
  for (j in 1:n_dema){
    funcao_A[i,i+(j-1)*n_ofer] <- 1
  }
}
funcao_A[is.na(funcao_A)] <- 0

funcao_Aeq <- matrix(nrow = n_dema, ncol = n_dema*n_ofer)
for (i in 1:n_dema){
    for (j in 1:n_ofer){
        funcao_Aeq[i,j+(i-1)*n_ofer] <- 1
    }
}
funcao_Aeq[is.na(funcao_Aeq)] <- 0
funcao_A_Aeq <- rbind(funcao_A, funcao_Aeq)
mat <- funcao_A_Aeq
funcao_b <- matrix(nrow = 36, ncol = 1)
funcao_b <- oferta
funcao_b_final <- t(funcao_b)
funcao_b_final[is.na(funcao_b_final)] <- 0

funcao_beq <- matrix(nrow = n_dema, ncol = 1)
for (i in 1:n_dema){
    funcao_beq[i,1] <- as.matrix(demanda[i,1])
}
funcao_beq_final <- t(funcao_beq)
funcao_beq_final[is.na(funcao_beq_final)] <- 0
```

```
funcao_b_beq <- cbind(funcao_b_final, funcao_beq_final)
rhs <- funcao_b_beq

funcao_lb <- matrix(nrow = 1, ncol = n_dema*n_ofer)
```

B.4 - Matlab code


```
function otimizar_rota_v4

%Matriz de distâncias total e os identificadores gerais de demanda e oferta
distanciasparcial = dlmread('distancias.txt');
for i = 1:(size(distanciasparcial,1)-1)
    total_demanda_name(i,1) = int32(distanciasparcial(i+1,1));
end
for i = 1:(size(distanciasparcial,2)-1)
    total_oferta_name(i,1) = int32(distanciasparcial(1,i));
end
for i = 1:(size(distanciasparcial,1)-1)
    for j = 1:(size(distanciasparcial,2)-1)
        total_distancias(i,j)= double(distanciasparcial(i+1,j+1));
    end
end

%Matriz de demanda e seu identificador
demandaparcial = dlmread('demanda.txt');
n_demanda = size(demandaparcial,1);
for i = 1:n_demanda
    demanda_name(i,1) = int32(demandaparcial(i,1));
    demanda(i,1) = double(demandaparcial(i,2));
end

%Matriz de oferta e seu identificador
ofertaparcial = dlmread('oferta.txt');
n_oferta = size(ofertaparcial,1);
for i = 1:n_oferta
    oferta_name(i,1) = int32(ofertaparcial(i,1));
    oferta(i,1) = double(ofertaparcial(i,2));
end

%Matriz de distâncias do caso específico
for i = 1:n_demanda
    for j = 1:n_oferta
        distancias(i,j) = total_distancias(find(total_demanda_name == demanda_name(i,↙
1)),find(total_oferta_name == oferta_name(j,1)));
    end
end

%f
for i = 1:n_demanda
    for j = 1:n_oferta
        f(j+(i-1)*n_oferta,1)=distancias(i,j)*demanda(i,1);
    end
end

%intcon
intcon = [1:n_oferta*n_demanda];

%A
for i = 1:n_oferta
    for j = 1:n_demanda
        A(i,i+(j-1)*n_oferta)=demanda(j,1);
```

```
    end
end

%b
for i = 1:n_oferta
    b(i,1) = oferta(i,1);
end

%Aeq
for i = 1:n_demanda
    i
    for j = 1:n_oferta
        Aeq(i,j+(i-1)*n_oferta)=1;
    end
end

%beq
for i = 1:n_demanda
    beq(i,1) = 1;
end

%lb
for i = 1:n_oferta*n_demanda
    lb(i) = 0;
end

%ub
for i = 1:n_oferta*n_demanda
    ub(i) = 1;
end

%Resultado
%[x,fval,exitflag,output] = intlinprog(f,intcon,A,b,Aeq,beq,lb,ub);

options = optimoptions('intlinprog','AbsoluteGapTolerance',0.1,'ConstraintTolerance',↙
1e-3,'IntegerTolerance',1e-3,'MaxTime',26600,'RelativeGapTolerance',1e-2);
%[x,fval]=intlinprog(f,intcon,[],[],Aeq,beq,lb,[],options)
teste=1
%Resultado
[x,fval,exitflag,output] = intlinprog(f,intcon,A,b,Aeq,beq,lb,ub,options);

for i = 1:n_demanda
    for j = 1:n_oferta
        resultadoparc(i,j) = round(x(j+(i-1)*n_oferta,1));
    end
end

resultado = demanda_name;
for i = 1:n_demanda
    resultado(i,2) = oferta_name(find(resultadoparc(i,:)==1));
end

resultadotxt = fopen('resultado.txt','w');
fprintf(resultadotxt,'%s\t%s\r\n','PA','MAN');
for i = 1:n_demanda
```

```
    fprintf(resultadotxt,'%u\t%u\r\n',resultado(i,1),resultado(i,2));
end
fclose(resultadotxt);

soma_otimizado=0;
for i = 1:n_demanda
    soma_otimizado = soma_otimizado + (demanda(i,1)*distancias(i,find↙
(oferta_name==resultado(i,2))))/1000;
end

soma_otimizado

%Matriz de situação atual
atualparcial = dlmread('atual.txt');
n_atual = size(atualparcial,1);

soma_atual=0;
for i = 1:n_atual
    soma_atual = soma_atual + (atualparcial(i,3)*distanciasparcial(find↙
(total_demanda_name==int32(atualparcial(i,1))),find(total_oferta_name==int32↙
(atualparcial(i,2)))))/1000;
end

economiaperc = 100*(1-(soma_otimizado/soma_atual));

soma_atual = int32(soma_atual);
soma_otimizado = int32(soma_otimizado);

economiatxt = fopen('economia.txt','w');
fprintf(resultadotxt,'ATUAL (km): %d\r\n', soma_atual);
fprintf(resultadotxt,'OTIMIZADO (km): %d\r\n', soma_otimizado);
fprintf(resultadotxt,'ECONOMIA: %.2f%%\r\n', economiaperc);
fclose(economiatxt);

end
```

ANNEXES

ANNEXURE A - Obtained data

The following tables present the obtained for first scenario of Quixadá., with demand, capacities and distances. Second scenario, third scenario and results of each Northeast Brazilian states follow the same structure.

A.1 - First scenario demand of Quixadá

Table 12 - First scenario demand of Quixadá

DP	Demand	DP	Demand	DP	Demand
2655	2	18388	4	47083	4
18309	3	18390	2	47084	2
18310	1	18393	6	47087	1
18316	1	18409	2	47088	4
18318	2	18411	1	47120	1
18319	2	18412	2	47233	2
18322	2	18416	5	57191	1
18324	3	18420	4	57197	1
18332	4	18421	2	72542	2
18338	6	18424	5	72544	1
18345	4	18425	1	72942	2
18347	3	18432	3	72946	3
18349	2	18433	1	73159	5
18354	3	18435	3	73160	1
18355	1	18438	5	73165	2
18359	1	18442	2	88318	5
18363	1	18444	4	88322	1
18365	2	18453	6	88328	5

DP	Demand	DP	Demand	DP	Demand
18366	1	24347	4	88357	1
18367	1	37319	1	88370	3
18368	2	37331	1	88389	3
18372	2	37340	6	88566	4
18374	1	46732	1	88641	1
18376	3	46997	1	88649	1
18386	7	47056	5	88655	9
88656	12	88950	1	118724	6
88657	2	88958	2	118725	3
88659	2	88965	2	127344	5
88661	1	88980	2	127346	5
88690	1	88993	1	127347	1
88691	5	89004	2	127352	1
88699	1	89024	1	127356	2
88705	5	89027	1	127364	5
88707	1	89032	1	127365	4
88724	2	89056	2	127366	2
88740	3	89066	5	127367	3
88747	2	90591	2	127451	3
88756	4	90777	1	127533	3
88758	5	92942	1	128423	4
88761	3	93721	1	128622	8
88763	2	93723	1	128625	5
88767	2	93726	2	129325	6
88769	1	111097	1	129737	3
88788	1	111759	1	129738	1
88812	4	112789	3	129739	1
88814	2	114017	2	129755	2
88816	3	114021	10	129818	5

DP	Demand	DP	Demand	DP	Demand
88818	5	114022	4	129849	1
88858	1	114025	2	130739	1
88859	3	114044	1	130808	1
88862	1	114074	4	132099	1
88865	1	114253	1	134732	2
88868	1	114254	2	138690	4
88904	1	116363	1	138691	3
88913	3	116366	3	138695	5
88927	1	118723	3	138699	2
138702	5	147205	3	151113	1
138703	5	147207	2	151164	2
139479	1	147210	12	151165	3
139480	4	147222	5	154369	1
140091	3	147223	4	154758	4
143447	1	147225	4	154780	2
146664	4	147227	8	156828	2
146696	7	147878	4	156971	1
146954	2	148419	4	156977	12
146958	4	148420	2	156984	2
146959	1	149276	1	156985	7
146978	4	149284	2	157030	2
146984	2	149287	7	157157	1
147005	4	150086	1	190349	1
147014	1	150091	2	399350	4
147016	7	150560	3	399452	2
147020	7	150564	1	465969	12
147050	15	150565	3	466262	1
147051	4	150608	1	467441	1
147053	2	150609	5		

DP	Demand	DP	Demand	DP	Demand
147204	3	150610	3		

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A.2 - First scenario capacities of Quixadá

Table 13 - First scenario capacities of Quixadá

SP	Capacities
100	ilimited
2703	101
2715	204

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A.3 - First scenario distances of Quixadá

Table 14 - First scenario distances of Quixadá

DP	SP			DP	SP		
	100	2703	2715		100	2703	2715
2655	43.277	14.061	29.550	18393	18.137	14.395	29.143
18309	54.804	25.461	9.752	18409	19.892	13.375	29.735
18310	49.511	20.168	4.459	18411	38.276	12.268	27.756
18316	55.355	26.013	10.303	18412	42.260	11.370	19.733
18318	51.892	22.566	23.806	18416	49.512	36.461	40.304
18319	36.766	6.284	21.773	18420	64.471	54.917	58.760
18322	39.838	10.621	26.110	18421	40.322	30.943	40.786
18324	48.591	19.375	29.539	18424	48.223	38.844	48.686
18332	25.914	14.362	30.722	18425	59.910	48.574	51.445
18338	43.920	14.704	30.192	18432	43.616	18.200	19.926
18345	47.412	34.115	42.506	18433	41.620	16.203	21.815
18347	37.198	12.088	21.931	18435	49.258	18.368	26.731
18349	38.677	13.260	21.278	18438	21.394	11.873	28.233
18354	53.864	44.485	53.040	18442	38.977	12.969	28.458
18355	54.914	37.309	41.151	18444	51.267	39.931	43.774
18359	34.897	24.285	34.128	18453	43.251	22.223	27.536
18363	69.747	58.753	62.027	24347	42.926	13.709	29.134
18365	42.316	16.899	22.383	37319	18.232	13.551	28.299
18366	43.866	18.450	21.001	37331	37.104	17.049	26.892
18367	44.240	18.824	21.557	37340	38.357	9.141	24.629
18368	45.594	26.394	30.237	46732	76.794	26.575	46.260
18372	52.885	25.212	26.452	46997	47.781	26.413	27.653
18374	42.896	13.571	12.939	47056	34.384	8.687	20.619
18376	44.010	14.685	14.053	47083	46.399	37.019	46.862
18386	39.049	8.159	16.521	47084	40.552	22.207	28.662

DP	SP			DP	SP		
	100	2703	2715		100	2703	2715
47120	49.458	20.241	30.406	88707	48.608	17.718	26.081
47233	49.200	28.633	30.284	88724	14.033	41.712	54.589
57191	52.027	39.344	43.187	88740	23.509	15.149	31.509
57197	33.314	10.078	26.151	88747	49.911	41.150	50.992
72542	42.390	13.065	14.305	88756	9.144	26.087	40.834
72544	24.804	20.145	33.022	88758	9.811	26.372	41.502
72942	42.891	17.474	21.819	88761	10.122	25.461	41.691
72946	36.380	5.490	19.185	88763	9.751	25.925	41.442
73159	49.960	20.744	30.908	88767	3.313	27.674	42.422
73160	40.830	26.428	35.824	88769	49.036	18.146	26.508
73165	69.829	58.835	60.529	88788	44.072	30.775	40.171
88318	34.829	4.347	19.835	88812	34.894	9.477	21.409
88322	41.245	31.865	41.708	88814	35.273	9.856	21.236
88328	42.913	33.534	43.377	88816	43.473	18.210	21.450
88357	43.693	29.292	36.757	88818	46.480	15.590	23.953
88370	53.686	44.307	52.135	88858	48.294	19.078	28.528
88389	51.269	39.933	43.776	88859	52.122	34.517	38.360
88566	35.846	5.364	20.853	88862	27.127	16.829	29.706
88641	18.072	15.195	31.555	88865	56.045	26.720	11.469
88649	36.802	6.320	21.808	88868	30.952	10.764	27.124
88655	9.421	26.289	41.112	88904	36.375	7.050	13.374
88656	9.346	26.238	41.037	88913	42.794	21.766	27.079
88657	14.461	22.929	37.677	88927	35.252	19.474	29.317
88659	46.483	17.158	17.614	88950	17.555	26.320	39.197
88661	15.768	24.236	38.983	88958	48.262	17.371	25.734
88690	20.185	11.598	26.346	88965	52.473	23.131	7.421
88691	40.399	11.057	5.608	88980	52.209	22.867	6.474
88699	24.684	7.606	22.354	88993	49.327	33.773	37.615

DP	SP			DP	SP		
	100	2703	2715		100	2703	2715
89024	46.802	33.504	39.764	127347	48.442	20.012	21.253
89027	48.006	19.159	20.399	127352	52.242	38.525	42.367
89032	46.597	37.218	44.653	127356	39.139	8.249	16.612
89056	7.261	33.456	48.203	127364	44.443	15.227	30.716
89066	94.401	70.321	87.104	127365	39.146	14.037	23.879
90591	16.644	27.230	40.107	127366	39.220	14.427	24.270
90777	69.934	58.940	61.765	127367	44.552	13.662	22.024
92942	38.786	8.108	13.082	127451	14.702	29.172	42.049
93721	51.009	21.684	22.924	127533	47.819	39.057	48.900
93723	39.586	18.824	34.313	128423	38.342	19.657	35.146
93726	28.095	6.883	23.243	128622	42.791	13.575	27.491
111097	51.445	22.103	6.393	128625	86.822	28.389	54.489
111759	13.072	20.166	34.914	129325	10.209	40.416	53.293
112789	24.662	7.628	22.376	129737	40.608	9.717	18.080
114017	48.056	18.713	6.677	129738	42.434	13.218	28.706
114021	46.375	15.545	23.907	129739	49.120	18.230	26.592
114022	49.660	20.443	30.608	129755	36.173	6.830	10.117
114025	44.224	13.334	21.696	129818	44.948	23.920	28.349
114044	49.095	18.205	26.567	129849	27.314	12.961	29.321
114074	36.965	32.256	42.099	130739	39.583	10.367	25.856
114253	43.819	19.254	21.988	130808	14.140	42.285	55.162
114254	14.372	22.623	38.983	132099	5.413	36.401	51.149
116363	14.715	29.159	42.036	134732	35.848	6.933	18.865
116366	14.702	29.172	42.049	138690	13.030	33.843	46.720
118723	40.194	30.815	40.657	138691	4.443	26.545	41.293
118724	41.220	31.840	41.683	138695	50.540	21.324	31.488
118725	50.232	40.852	50.695	138699	42.048	12.832	28.320
127344	9.410	26.353	41.100	138702	25.782	11.316	27.676

DP	SP			DP	SP		
	100	2703	2715		100	2703	2715
139479	51.290	39.954	43.796	149276	18.715	26.366	39.243
139480	5.829	32.024	46.771	149284	15.649	35.525	48.402
140091	46.053	15.163	23.526	149287	12.923	36.335	49.212
143447	47.672	38.293	44.880	150086	27.777	10.332	23.400
146664	47.058	35.304	43.695	150091	59.829	45.098	46.782
146696	38.822	15.580	25.422	150560	45.251	35.872	45.715
146954	46.534	37.155	46.998	150564	30.480	3.184	19.544
146958	45.130	15.914	25.892	150565	35.530	6.188	10.205
146959	44.968	15.752	25.530	150608	51.255	39.919	43.762
146978	10.732	36.927	51.674	150609	55.027	42.934	46.777
146984	39.244	14.403	24.246	150610	39.261	10.045	25.533
147005	34.728	9.248	24.736	151113	38.050	32.711	42.554
147014	40.857	9.967	18.330	151164	46.341	15.451	23.813
147016	34.531	19.874	29.717	151165	46.447	17.231	32.720
147020	31.529	21.231	33.795	154369	36.363	5.881	19.624
147050	8.830	35.024	49.772	154758	54.226	24.901	13.402
147051	11.052	37.247	51.994	154780	23.048	7.940	22.687
147053	47.769	39.008	48.850	156828	53.463	24.138	8.886
147204	37.686	6.796	15.143	156971	51.915	42.536	46.901
147205	40.924	10.034	18.396	156977	34.540	5.197	11.463
147207	35.945	8.031	23.519	156984	15.748	38.427	51.304
147210	35.145	20.488	30.330	156985	7.253	29.267	44.015
147222	76.688	39.319	70.296	157030	14.715	29.159	42.036
147223	38.345	19.652	35.140	157157	51.953	41.180	45.022
147225	39.484	20.762	36.251	190349	51.399	20.509	28.872
147227	39.484	20.762	36.251	399350	19.658	15.916	30.664
147878	45.344	28.762	61.482	399452	23.223	9.067	23.815

DP	SP			DP	SP		
	100	2703	2715		100	2703	2715
148419	48.830	35.209	39.052	465969	19.872	51.295	83.253
148420	45.158	15.942	25.340	466262	25.115	11.155	27.515
467441	36.462	8.925	24.413				

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