Energy Management Through Optimal Logistics Planning. Case Study of a Power Electrical Distribution Company in Southern Chile

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Abstract. Climate change is a real fact. The increase in temperatures, the change in rain cycles, the generation of more extreme seasons and natural disasters at a global and local level, are examples of its effects. In the electricity environment, the interruption of supply caused by extreme weather events is increasingly frequent; while electricity distribution companies in Chile are required by law to maintain the electric service constantly, guaranteeing the service quality and the quality of life of their customers. The adequate fulfillment of this legal mandate, require attend opportunely the client’s energy supply, before any eventuality. Consequently, electric companies must assign repair units to guarantee this objective. However, this process involves the assignment and displacement of these units in vehicles. This allocation, without efficient planning, involve an excessive consumption of resources such as fuel and other inputs that affect the environment. This leads to having to review the logistics processes and establish mechanisms to promote sustainable development, looking for tools that provide data to support and improve the evaluation process of alternatives for friendly building and architectural structures, which help to improve the environment and mitigate visual pollution, as well as the use of less polluting alternative energies (wind or solar energy, for example) that allow the direct supply of electrical energy. Therefore, this study seeks to present mechanisms to determine an optimal allocation of repair units to minimize the amount of contamination in the operational process and, in turn, establish a reference value, which can be used as a complementary element in the evaluation of the use of new non-polluting electrical technologies.

1. Introduction
Climate change is an undeniable reality. All over the world phenomena are reported attesting more extreme temperatures, intense storms, less rainfall, among other. Many articles searching to identify the effects of climate change on the carbon cycle [1], [2] and finding models that make possible to establish future rainfall behavior [3].

Chile has been classified as highly vulnerable to climate change, according to the criteria of the United Nations Framework Convention on Climate Change. In this sense, it is estimated that an increase in the frequency and intensity of extreme hydrometeorological events would put the built
public infrastructure at risk, with effects on land-sea-air connectivity, potable water provision, environmental services and associated economic activities, among others [4].

This leads to the thought that in the electric energy environment, the interruption of supply due to climate conditions is becoming worse. The Superintendency of Electricity and Fuels (SEC – Superintendencia de Energía y Combustibles) of Chile indicates that there has been an increase in hours without electricity as a result of power cuts, being La Araucanía the most affected. This is a major problem for the electric energy distribution companies, because they are compelled to compensate users for any unauthorized interruption or suspension of service [5].

The above makes necessary for them to take special care to maintain their distribution lines operational and comply in a timely manner with their clients’ supply requirements in the event of any contingency. Consequently, power companies must assign repair units to guarantee that this is the case. This process involves deciding upon the assignment and movement of vehicles from these units. But decision-making based on tacit knowledge and without any clear procedure is inadvisable [6]. In this case, an erroneous decision gives rise to inefficient movements involving excess consumption of resources such as fuel and other consumables that affect the environment. For this reason, companies should seek mechanisms that will improve their decision-making, promoting sustainable development of their processes.

In this sense, a review of the logistical process of assigning work teams makes it possible to know their current performance behavior, and also establish the bases for a mathematical model adjusted to their needs that will provide efficient solutions. An example of this is the work of Soysal, Bloemhof-Ruwaard, and Bektas (2015), who developed a vehicle routing model with two time-dependent echelons (Two-Echelon Capacitated Vehicle Routing Problem - 2E-CVRP) which considered the type of vehicle, distance travelled, speed, load, different time zones and emissions, thus achieving an environmentally-friendly solution [7]. Similarly, Jabali, Van Woensel, and de Kok (2012) proposed a framework to model CO2 emissions in a time-dependent vehicle routing context, in particular, as the amount of CO2 emissions correlates with the speed of the vehicle, the model establishes speed limits as part of the optimization process [8]. In turn, the work of Esmaili and Sahraeian (2017) presents the problem of generating routes for limited capacity vehicles that are delivering perishable goods for the first time, taking into account both client satisfaction and environmental problems. Specifically, they establish a restriction on the maximum permissible emissions of CO2 for the transport on each route. The model sensitivity reveals that less restrictive policies regarding carbon emissions lead to more total emissions but a lower total cost of trips and client waiting times [9].

Thus, an efficient solution to vehicle assignment makes it possible to recognize regarding the minimum resource consumption that needs to be used, and the lower cost. These data can be used as a basis to assess non-conventional energy options or construction structure alternatives. That is to say, if an assessment is made of the use of clean energies, and their process cost is lower than the assignment cost for the use of maintenance brigades, then clean energy becomes a convenient development decision for the company. The same can be applied to the assessment of construction alternatives

Therefore, the aim of this study is to present mechanisms to determine the optimal assignment of repair units guarantying minimum pollution levels during operations and, in addition, to have a complement when assessing alternative renewable energy options or alternative construction structures.

2. Methodology

2.1. Overview

The electricity market in Chile is made up of three areas: generation, transmission and distribution [10].

In the distribution area, companies operate under a licensing public distribution system, and are obliged to provide service and maintain regulated rates for the supply of regulated clients [11]. In this sense, in 2017 a new Technical Quality of Service Regulation for Distribution Systems (Norma
Técnica de Calidad de Servicio para Sistemas de Distribución) [12] was established, which describes the characteristics of the distribution of electric energy, including requirements, obligations, rights and duties established for companies and their clients. Among these are the establishment of time limits for the reinstatement of electric supply during abnormal operating circumstances, where its noncompliance gives rise to sanctions and costs for the companies.

Therefore, maintaining adequate supply is crucial and has become more complicated because of the increase in electric distribution lines, the addition of new clients and contingencies from climate change. This latter factor, in the south of Chile, has caused periods of drought with a high risk of fire, and periods of extreme rainfall and wind, giving rise to fallen trees, road cuts and landslides, among others.

According to the May 2019 report of SEC, 7.8 billion pesos were expended during 2018 by way of compensation for lack of service to 3757 clients [13].

Even so, this companies must respond to random contingencies that interrupt the appropriate flow of electricity supply. At the same time, it must be permanently assessing improvement plans for its facilities and physical distribution structures.

2.2. Mathematical model for route assignment
In operations research, there is extensive literature concerning models that represent real situations associated with the establishment of routes. Among these is the Traveling Salesman Problem (TSP) and its variants that can include time windows (TSPTW), multiple salesmen (mTSP), with draft limits (TSPDL), among other conditions. There is also the Vehicle Routing Problem (VRP) and its variants, such as time windows (VRPTW), heterogeneous fleet (HFVRP), and with pickups and deliveries (VRPPD).

The classic TSP consists of finding the shortest route through all cities, so that no city is visited twice and the salesman returns to the original point at the end of the run [14]. Instead, VRP is a model that seeks to determine the route a vehicle should follow to deliver products to the clients to satisfy their demand with the lowest transportation cost.

For the study of routes’ assignment, TSP will be used. The TSP is considered an HP-hard problem for discrete optimization techniques [15]. Many algorithmic methods have been analyzed to meet the challenge of finding the fastest algorithm in terms of execution time [16]. The mathematical structure of the model considers: the distance between city $i$ and city $j$, and the number of cities (clients) to be visited [17]. The target function is unique and seeks to minimize the distance traveled [18]. The restrictions associated with the model guarantee that each city is included exactly once in the cycle [19], and it specifies that the route there and back will be different. The decision variable $X_{ij}$ is a non negative integer [20], the value of which is 1 if the salesman travels from $i$ to $j$, and 0 in any other case [21].

2.3. Linear programming
A linear programming model has solely linear equations. The classical solution for this type of model is through the Simplex Method. This method was used by Dantzig, Fulkerson and Johnson in 1954 to solve the TSP problem [22]; [23].

In problems where all equations are linear, the application of the Simplex Method will guarantee the optimal solution.

Although exact methods guarantee an optimal solution to problems, they are not necessarily the most efficient in terms of processing time [24]. Therefore, exist alternative tools that allow faster answers, but non necessarily optimal.

Among these are: Bee Colony Optimization (BCO) [25], Ant Colony Optimization (ACO) [26], Tabu Search (TS) [27], [28], [17], Discrete Symbiotic Organisms Search [29].
2.4. Carbon footprint quantification

Over the past few years, the determination of the greenhouse gas (GHG) emissions of the productive matrix has become a matter of concern for developing economies [30], due to the loss of competitiveness vis-à-vis countries that are deeply committed to reducing emissions [31]. This has been influenced by inclusion of the carbon footprint on the GHGs in the discussion on economic policies at global level.

Various methodologies and protocols have been developed to account for GHG emissions, notably Publicly Available Specification (PAS) 2050, GHG Protocol Product Standard (GHG Protocol), and ISO 14067 Carbon Footprint of Products (ISO 14067) [32]. To date, no consensus has been reached regarding one sole methodology to calculate emissions, because the adoption of one or another will depend on the availability of data and the uncertainty affecting the key variables [33]. Even in the past few years, attention has been focused on calculating the indirect carbon emissions that are produced in the logistics chain [34].

The GHG protocol has contributed a comprehensive analysis for any type of organization [35]. This protocol considers: direct GHG emissions, indirect GHG emissions associated with electricity, and other indirect emissions (not associated with electricity). This permits compare the improvements that can be achieved within the organization and with regard to market competition.

The quantification of GHG emissions in land transport can be obtained on the basis of two variables, independently: either by the amount of fuel consumed or considering the distance traveled by the vehicle. In the latter case, the emissions calculation is obtained by the sum total of the product between the distance traveled by each vehicle and the emission factor (amount of CO2 emitted in kg per unit of distance traveled) for each type of vehicle [36], [37].

3. Results and discussion

The distance to be traveled by 14 repair units on a specific day, obtained as solution to the TSP model via linear programming and manual assignment, is shown in Table 1.

| Repair unit | Number of points assigned | Total journey (km) with linear programming | Total journey (km) with manual assignment |
|-------------|--------------------------|------------------------------------------|-----------------------------------------|
| 1           | 3                        | 70.70                                    | 101.90                                  |
| 2           | 4                        | 75.60                                    | 87.60                                   |
| 3           | 4                        | 97.10                                    | 108.50                                  |
| 4           | 4                        | 55.10                                    | 56.80                                   |
| 5           | 4                        | 180.10                                   | 192.90                                  |
| 6           | 4                        | 91.60                                    | 128.70                                  |
| 7           | 5                        | 96.30                                    | 158.70                                  |
| 8           | 6                        | 140.30                                   | 220.74                                  |
| 9           | 7                        | 194.80                                   | 252.90                                  |
| 10          | 7                        | 146.97                                   | 185.07                                  |
| 11          | 7                        | 141.51                                   | 141.51                                  |
| 12          | 7                        | 123.00                                   | 155.20                                  |
| 13          | 8                        | 168.40                                   | 173.00                                  |
| 14          | 8                        | 177.40                                   | 259.80                                  |

| Total distance traveled | 1 758.88 km. | 2 223.32 km. |

In this case, the use of linear programming to determine efficient assignment makes it possible to generate a saving of 464.44 km.

The difference the distance saved, for each repair unit, is shown in Graph 1.
Considering a working year of 312 days, 144 905.28 km are saved. With regard to carbon footprint, considering the saving obtained in Table 1 and an emission factor of 0.2508 (kg CO$_2$/km), a reduction of 116.48 kg CO$_2$ per day is obtained. The comparison of carbon footprint in each unit, considering linear programming and manual assignment, is shown in Graph 2.

In annual terms this amounts to 36 642.24 kg CO$_2$ and is equivalent to carbon footprint produced by 407 flights from Temuco to Santiago (Chile).

Moreover, the 144 905.28 km saving can be translated into a saving of 18 113.16 liters of fuel, or 15 982 dollars per year.

Withal, the minimum possible distance traveled is 548 770.56 km per year, and therefore the minimum fuel consumption will be 68 596.32 liters, with a financial outlay of 60 526.16 dollars. This value represents a benchmark regarding the costs that can be generated. In other words, for the proposed scenario, there is no better way of assigning the repair units that would generate a lower cost than that mentioned.
This becomes relevant when understanding that this value can be used as a reference point for the assignment cost of repair units within the energy distribution process. Thus, the information provided can be used as a complement when assessing alternative renewable energy options or alternative construction structures.

4. Conclusions
The result of the study established that TSP model to assign repair units, solved by means of linear programming, makes it possible to arrive at an optimal solution regarding the route the units should follow.

The optimal logistics planning achieved through the TSP model is expedient to minimize the distance traveled and the pollution resulting from fuel consumption. It also leads to a reduction in greenhouse gas emissions.

The reduction of greenhouse gas emissions was quantified through the GHG protocol used to account for carbon footprint, which reached a value of 36,642.24 kg CO₂ per year.

This study shows that the result of applying the TSP model makes it possible to establish the minimum distance to be traveled, and its valuation in financial and energy terms. In turn, this result can be used as a reference point when assessing renewable energy options or alternative construction structures.

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