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Logistic Optimization Model Applied to a Mobile Energy Storage Network

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Extended Abstract

This paper presents a new optimization model to define a network of terminals that distribute charging batteries (powerbanks) for mobile devices. The model is applied to a Startup in Rio de Janeiro and is part of a more comprehensive study sponsored by ENEL enterprise that includes the logistics component presented here and another component for the study and development of batteries and charging terminals.

A mix integer programming model (MIP) is developed based on bicycle sharing network location models and combines strategic network location and sizing decisions (where to install and the capacity of the terminals) with operational decisions (allocation and reallocation of batteries at the terminals). The mathematical modeling uses as a reference the maximum coverage location model of bike-sharing systems presented by Frade and Ribeiro (2015) and innovates by including new aspects in the model: battery recharge time; different types of customer service; charging system settings and battery performance. Another new aspect of the model is related to the Objective Function (FO) which seeks to maximize the economic performance of the network obtained from the difference between the revenue generated by the leasing of batteries and the logistical costs of reallocating batteries, maintenance of terminals and depreciation of batteries in the system. The FO is given by equation 1.

$$\sum_{i\in J}\sum_{t\in T}(\mathrm{Dout}_{it}\times \mathrm{Y}_i \times \mathrm{Pm}) - \mathrm{Crb}\times\sum_{i\in J}\sum_{j\in J}\sum_{t\in T}\mathrm{R}_{ijt} - \mathrm{Cvrb}\times\sum_{i\in J}\sum_{j\in J}\sum_{t\in T}\mathrm{R}_{ijt}\times \mathrm{Dist}_{ij} \qquad (1)$$
$$- \mathrm{Cfmt}\times\sum_{i\in J}\mathrm{Y}_i - \mathrm{Cvmt}\times\sum_{i\in J}\mathrm{Si} - \mathrm{Cdb}\times\sum_{i\in J}\mathrm{B}_{i(t=1)}$$

Index i represents the set of candidate sites for installing terminals and index t represents the set of time intervals in which the T period is discretized. The binary variable Y_i indicates whether the terminal at point i is installed $(= 1)$ or not $(= 0)$. The revenue generated by users is calculated by multiplying the total number of leased battery in the network (Dout_{it}) by the parameter Pm (average revenue obtained for each leased battery). The cost of relocating batteries is represented by the fixed cost of reallocation (given by multiplying the fixed reallocation unit cost Crb by the total number of reallocations R_{ijt}) and the variable cost of reallocation (given by multiplying the unit cost of reallocation per km (Cvrb) by the total reallocations and their respective distances Dist_{ij}). The cost of maintaining the network is calculated according to the number of installed terminals (Y_i) and the capacity of the installed terminals (Si). The cost of depreciation of the batteries is calculated by multiplying the total number of batteries in the network

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(B_{it}) by the unit cost of depreciation in the period (Cdb). Similar models applied to battery charging networks have not been identified in the literature.

A case study is carried out with a Startup that has a network with 42 terminals installed in the cities of Rio de Janeiro and Niterói. Real data from the network containing 8,222 operations are used to simulate different demand scenarios using the Monte Carlo Method. Laboratory tests with lithium-ion batteries similar to those used in the network were carried out in 4 different voltage and electric current configurations to measure the degradation rate and the performance of the batteries in terms of charge and discharge time. These results are incorporated into the model as the parameters of the depreciation rate and the charging and discharging times of the batteries along the period.

The models are implemented simulating the operation of one day discretized in 48 periods of 30 minutes and using five different demand scenarios and the four different voltage and electrical current settings.

The results of the model indicates that the network performance using batteries in the fastest charging configuration (electrical voltage of 4.1 Volts and electrical current of 3.0 Ampere) tends to have a positive impact on their efficiency and profitability. The model's decisions are: optimal points for installing the terminals on the network; the capacity of each terminal installed; the number of batteries needed to supply the network; and the number of batteries to be reallocated between each point over the period. Among the locations selected for installation of the terminals, the following stand out: fitness center; public transport terminal; bar and restaurant; tourist spot; and university. The average capacity of the installed terminals varied from 3 to 10 battery slots. The average number of batteries for supplying the network was 76 batteries.

In addition to economic performance, the results related to the network sizing and operation are an important output to be evaluated. Perform new experiments varying the parameters of reallocation, maintenance and depreciation costs can be useful to identify more profitable configurations of the system. Regarding the stochastic characteristic of demand, it is suggested as a future perspective to use the Monte Carlo technique to generate a greater number of demand scenarios so that more experiments can be carried out, enabling a broader analysis of the network performance. The model can be used as a reference for other applications such as electric vehicle networks optimization.

Keywords: Logistic; Optimization Model; Batteries.

References

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