A GENERIC DECISION MODEL OF REFUELING POLICIES: CASE STUDY IN A BRAZILIAN MOTOR CARRIER

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Abstract

Fuel optimizers are decision models that are increasingly recognized as effective fuel management tools by truckload carriers. Using the latest price data of every truck stop, these models calculate the optimal fueling schedule for each route that indicates: (i) which truck stop(s) to use, and (ii) how much fuel to buy at the chosen truck stop(s) to minimize the refueling cost. However, the acquisition of this kind of software by small or medium companies of motor carriers in Brazil is not feasible due to high impact on fixed cost. Therefore, this study developed a generic model for fuel optimization based on linear programming using electronic spreadsheets. The model was presented using a case study as a reference and, in this case, the model provided a decrease of 2.3% in total fuel cost.

Keywords: Transportation, Fuel Costs, Linear Programming, Motors Carriers, Refueling Problem.

1. Introduction

Administration of transport is, undoubtedly, one of the biggest challenges of companies today. The process of logistics integration and the growing demand for products and services in a cost and time each moment lesser make firms to value their logistic system so that waste of resources and time are avoid. The transport cost in Brazil represents about 60% of logistics costs influencing the final product price and, consequently, the company’s competitiveness. Thus, the transportation has an important role in the logistical process, because its cost contributes for a significant share of expenditure of the companies and influences the level of service provided [1].

Academics works like Lima [2], Lopes [3] and Rittiner [4] corroborate that the fuel is the main cost of the motors carriers. Lima [2] showed that in 2004 the fuel cost represented 31.8% of the total cost and this values could achieve 41.8% when analyzed only long routes. In this same study, the author estimated that 55% of all diesel consumed in Brazil in 2004 were for cargo route transportation, equivalent to 21.7 billion liters and 32.7 billion BRL. According Rittiner [4], fuel is the main input for the motor carriers and represents on average 30% of total costs. Based on the representativeness of the fuel cost compared to the road transport cost and the impact of transportation in logistics costs, it is possible to estimate that, on average, the cost of fuel represents about 18% of logistics costs of a company that uses road transport as the main way of transport.

Given this scenario, where the fuel cost has a significant impact on the logistics costs and, consequently, on the competitiveness, this paper will develop an optimization model, based on linear programming model, aiming to reduce the fuel cost for the motors carriers.

2. Review of Fuel Optimizers

Fuel optimizers are decision models that reduce motor carriers fuel costs using information on prices at every gas station within a route. Thus, the optimal fueling schedule for each route is determined, including: (i) which truck stop(s) to use, and (ii) how much fuel to buy at the chosen truck stop(s) to minimize the cost of refueling. The basic concept of this model is to take advantage of such price variances across truck stops to reduce the cost of buying fuel. The model’s goal is to buy more gallons at truck stops where the fuel is cheap, and buy fewer gallons at truck stops where the fuel is expensive. This model typically work in conjunction with truck-routing software, so that users can first compute the optimal (shortest) route for a given origin-destination pair and then optimize the fueling operations along this route.

Research on vehicle refueling has been conducted by both the academic researchers and practitioners. According to Suzuki [5] most of the early works were conducted by practitioners in early 1990s during the software development phase. These products were designed in order to resolve the concern of many companies that fuel prices fluctuate, sometimes substantially, between a truck stop and the next truck stop in the same route. Suzuki [6] lists: (i) ProMiles, (ii) Expert Fuel, and (iii) Fuel & Route as the most famous fuel optimizer products. Basically, all these applications use mathematical programming models by selecting the optimal locations and quantities of truck stop previously given a route origin and destination. The following factors are the main required
inputs by these models:

- Vehicle tank capacity,
- Average fuel consumption rate for the role trip,
- Retail diesel price,
- Amount of fuel in tank at origin (starting fuel),
- Distance from truck stop i-1 (0 if i=1) to truck stop i,
- Minimum among of fuel to be maintained in the tank all time,
- Minimum gallons or liters to be maintained in tank at all times.

The majority of these commercial products allow their users to include some restrictions on the model that reflect your corporate policies and preferences so that the solutions become not only possible, but also practical in the point of view of implementation. Restrictions such as the removal of some truck stop on the models that do not meet the minimum specifications acceptable to the company. These specifications can be reference related quality aspect or related the minimum distance of the truck stop about the route defined. According to Huff [7], these applications may require significant adjustments of the optimal solution in order to achieve specific goals of each company, such as refueling only in truck stop that exist contract even if their prices are high.

Despite the proliferation of actual software products in the field, academic researchers did not study the type of vehicle refueling problem until recently. According with Suzuki [6], the first scholarly that considered the refueling problem with the focus on total fuel cost is Lin et al. [8]. They considered the fixed route vehicle refueling problem similar to that addressed by the commercial fuel optimizers, and developed a linear time greedy algorithm for finding optimal fueling policies. This algorithm developed by the authors based on in the special case of the capacity inventory lot size problem where there is a limit capacity inventory, the costs of preparation is zero, the costs of maintenance inventory is zero and production costs are linear. Lin [9] extended the work of Lin et al. [8] by developing an algorithm that jointly determine the optimal path (route) from origin to destination, and the optimal refueling decisions along the path, its denote that in this model the route is no more predetermined.

Other scholar works that investigated vehicle refueling problems include Khuller et al. [10] and Suzuki([5,6]). Khuller et al.[10] studied several models of vehicle routing problems related to shortest path and traveling-salesman problems and incorporated in these models the refueling cost and the restriction of capacity fuel tank with the goal of finding solutions to various optimization refueling problem. Base on interviews with motor carriers, fuel optimizer vendors and users, Suzuki [5] proposed a “generic” approach to the vehicle refueling problem by considering not only the fuel cost, but also several other costs of vehicle operation. Suzuki [6] added new restrictions on the commercial refueling problem aiming to reduce the fuel cost without confiscating the freedom to choose truck stops by the drives. The author expected to reduce the higher drive turnover rates with this proposed model.

Our review of literature indicates that the all the earlier studies have made important contributions to the vehicle refueling literature. However, no studiers have considered the use of these models in a practical situation showing that real savings.

3. Methodology

Aiming to develop, through a case study, a model that meets the characteristics of optimizing refueling policies, the work was divided into three stages. The first stage consisted of gathering information about the transport operation done by the company. At that point, we attempted to obtain information about the technical characteristics of vehicles, total distance, type of routes, number of vehicles, the truck stops and current costs charged in the gas stations. The second step was to adapt the model, using concepts of linear programming (LP), the characteristic of the transport operation of the company and the final stage consisted of implementing and testing the model using the solver application of Microsoft® Excel. Also was studied the necessary adjustments so that the model becomes applicable to others transport operations with similar characteristics to the proposed work. Furthermore, we evaluated the financial impact and the indirect benefits generated after applying the model on the route analyzed.

3.1. Description of Transport Operation

The problem analyzed were based on a road transport operation of auto-parts from southeast to northeast of Brazil with the objective of meet the demand of automotive industry in Camaçari city in the state of Bahia. This operation is complex because it involves the just in time supply at a distance of approximately 2,000 km between the place of loading and delivery of cargo.

In this transport operation they use 67 dedicated trucks with capacity of 30 tons each. To meet the system just in time of the client, it is necessary that the trucks work 24 hours a day, seven days a week and, with the aim of increasing the trucks occupancy, the company has developed a methodology of driver exchanges whose plans to replace the driver at certain points of the route so as not to leave any driver over eight hours driving, in other words, in this system the driver rests, but the vehicle remains the route.
The trucks always start from the southeast region, especially the region of the great Sao Paulo city, where are the main suppliers of auto parts, and will continue until the final destination that is Camaçari in the state of Bahia. To accomplish this journey, the company has the option to carry the loads of three different routes: The main one is the route that uses the BR381 (Fernão Dias) which goes to the city of Belo Horizonte and, from this point, goes from the BR116 highway, as shown in Figure 1.

The company chose to define the mandatory truck stops on the routes of this operation. At these points can be done drives exchanges, refueling, preventive maintenance, inspection of documents and the conference of the load. The letters A, B, C, D, E, F, G and H highlighted in green in Figure 1 represent the obligatory truck stop. The letter A refers to the main point of the operation, where is the company's headquarters and where it is done all the logistical planning. From this point, the vehicles follow to the point B to carry the load on suppliers through a logistics system called milk-run. The milk run system is a planning deliveries or collections, maintained by a transportation company, where for each day the company makes a collection of components from each supplier in predetermined amounts with the goal of delivering to the manufacturer [11]. After completion the collections in suppliers of ABC, trucks follow until the final destiny which is Camaçari, Bahia, illustrated by point H in Figure 1. Along the way the vehicles are passing some of the mandatory truck stops that are the points C, D, E, F and G. In all these points can be realized the refueling, change of drivers and cargo conference. Find below the location of each point described in Figure 1:

- **Point A:** Represents the motor carriers location,
- **Point B:** Represents the location of auto parts suppliers in the region of Sao Paulo city,
- **Point C:** Represents the truck stop at Atibaia (ATB), the northern city of São Paulo, on the margins of BR381 (Fernão Dias),
- **Point D:** Represents the truck stop in Belo Horizonte (BHZ),
- **Point E:** Represents the truck stop in the Governador Valadares (GVD) city in state of Minas Gerais,
- **Point F:** Represents the truck stop in the Vitoria da Conquista (VDC) city in state of Bahia,
- **Point G:** Represents the truck stop in the Feira de Santana (FES) city in the state of Bahia,
- **Point H:** Represents the location of the automobile industry, located in the city of Camaçari (CAM) in state of Bahia.

According to the company, the main cost of this operation is the fuel. On average, to complete the cycle of the main route each truck uses 2300 liters of diesel. Trucks are constantly supplied at the truck stops, mainly due to capacity limitation in the fuel tank. Each vehicle has two fuel tanks with a capacity of 225 liters each, totaling a
Analyzing the historic supply data of this operation, it was found that there is wide variation in retail diesel prices from the gas stations located in the truck stops and, due to storage capacity of fuel and long distances, it was observed that often the trucks were refueled in the points A, D, E, F and G. In all refueling process were asked to fill the tank completely and thus, the vehicle always left the gas station with the tank fully and went to the next point. One of the reasons to always completely fill the truck is to minimize the risk to have some truck stopped on the road for lack of fuel. This fact has become a constraint of the model to be presented in section 3.2. With parameter of this restriction, the company determined that the truck in this operation could not be less than 50 liters in the fuel tank.

After this stage of rising information about the transport operation, we elaborated a mathematical modeling to determine the ideal amount of fuel to be supplied at each truck stop in order to minimize the total cost so that the capacity refueling constraints must be met. In addition, other restrictions were considered, such as autonomy between the truck stops and minimum quantity in liters in the tank.

3.2 Model Formulation
The model is based on the basic concepts of refueling optimizers whose goal is to minimize the total cost of fuel in the transport operation. In this model, routes must be fixed and the truck stops need to be previously defined. Variables logistics of this operation and technical characteristics of vehicles are the input variables of the model. The amount of fuel to be supplied at each truck stop are the output figures.

Index:
- \( i \): index of stop points.

Variables:
- \( q_i \): quantity of fuel supplied at point \( i \) on the trip to the first destiny,
- \( q'_i \): quantity of fuel supplied at point \( i \) on the way back,
- \( v_i \): quantity of fuel on tank at the point \( i \) on the trip to the first destiny,
- \( v'_i \): quantity of fuel on tank at the point \( i \) on the way back,
- \( z \): fuel total costs.

Constants:
- \( c_i \): fuel price (R$/liters) at point \( i \),
- \( d_{i,i+1} \): distance from point \( i \) to the next point \( (i+1) \),
- \( k \): average consumption rate (km / l),
- \( Q \): fuel tank capacity (liters),
- \( S \): minimum acceptable quantity in the tank (safety characteristics).

Find below the graphical representation of the model:

![Graphical representation of a fixed route with N truck stops](image)

This model can be mathematical defined like:

\[
\text{Min } Z = \sum_{i=1}^{n} c_i q_i + \sum_{i=1}^{n} c_i q'_i \\
\]

\( n \) = quantity of truck-stops

Subject to:

Security restrict:

\[
v_i + q_i - (d_{i,i+1})/k \geq S \quad \forall \ 1 \leq i < (n-1)\\
v'_i + q'_i - (d_{i,i+1})/k \geq S \quad \forall \ 2 \leq i < n
\]

Fuel tank capacity restrict:
\[ v_i + q_i \leq Q \quad \forall i \in n \]  
\[ v'_i + q'_i \leq Q \quad \forall i \in n \]  

Restriction of non-negativity:

\[ q_i \geq 0 \]  
\[ q'_i \geq 0 \]  

Equation (1) is the objective function to be minimized and represents the total fuel cost considering the complete cycle route. The restrictions of the model are represented by equations (2) to (7). Equations (2) and (3) are the security restrictions of the model. The number (2) ensures that the vehicle will always have a minimum of S liters of fuel in the tank when it moves from origin to final destination. The constraint (3) guarantees this same minimum quantity S in the tank of the vehicle when the vehicle returns to the origin. The restrictions of a maximum capacity of fuel tanks are described in (4) and (5). Constraint (4) guarantees the maximum fuel when the vehicle moves from origin to destination and the equation (5) ensures the limit to the return of the vehicle. To complete the model is need to add the restrictions (6) and (7) of not negativity, that is, there is not negative refueling.

3.3 Computation development

Aiming to facilitate the use of the proposed model, we used the Solver tool, available in Microsoft® Excel application, in order to make the calculus of the model developed. Solver uses the simplex method with limits variables for solving linear and integer problems so they must be inserted all the sets of equations of mathematical programming model in cells of a worksheet.

To solve the model proposed were created a spreadsheet composed of two parts, the first for the input data and the second for the output data of the model. In the first part, the analyst must enter the data of possible points of support or truck-stops that can be done the refueling process, the points of origin and destination of the cargo, the distances between these truck stops, the maximum fuel capacity in liters, the cost per liter in every gas station and fuel consumption rate.

Table 1 shows the data about the route, distances and fuel costs in the truck stops of the manly route of transport illustrated in Figure 1 in section 3.1.

<table>
<thead>
<tr>
<th>i</th>
<th>Origin</th>
<th>j</th>
<th>Destination</th>
<th>Distance (km)</th>
<th>Fuel price (i)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>SAO</td>
<td>2</td>
<td>ATB</td>
<td>134</td>
<td>R$ 1.83</td>
</tr>
<tr>
<td>2</td>
<td>ATB</td>
<td>3</td>
<td>BHZ</td>
<td>560</td>
<td>R$ 2.11</td>
</tr>
<tr>
<td>3</td>
<td>BHZ</td>
<td>4</td>
<td>GVD</td>
<td>315</td>
<td>R$ 2.10</td>
</tr>
<tr>
<td>4</td>
<td>GVD</td>
<td>5</td>
<td>VDC</td>
<td>524</td>
<td>R$ 2.02</td>
</tr>
<tr>
<td>5</td>
<td>VDC</td>
<td>6</td>
<td>FES</td>
<td>398</td>
<td>R$ 1.98</td>
</tr>
<tr>
<td>6</td>
<td>FES</td>
<td>7</td>
<td>CAM</td>
<td>140</td>
<td>R$ 2.06</td>
</tr>
<tr>
<td>7</td>
<td>CAM</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

In the second part of the worksheet is the output information of the model. This information is presented after application Solver already parameterized with the characteristics of the model presented in section 3.2. Basically, the mainly output information of the model are: the truck stops that will be done the refueling, the optimal quantity of fuel to be supplied at these points and the total operation cost to fuel.
A new simulation should be done whenever there are changes in gas station prices in the transport operation. These updates can be done through annotations by drivers themselves during the route or making a download from specialized sites.

3.4 Adaptations of the model
The optimization model of refueling policies proposed in this paper can be applied to all the dedicated operations involving the movement of trucks on a fixed route. However, some modifications may be made in order to better adjust the model to the reality of the operation.

On some routes, mainly due to the different types of topography and road quality, there are significant differences in fuel consumption rate. In this case it is necessary to consider the average of fuel consumption rate (k) for each displacement between the truck stops. Thus, constraints (2) and (3) presented in section 4.2, would be as follows:

\[ v_i + q_i - \frac{(d_{i+1})}{k_i} \geq S \quad \forall \quad 1 \leq i < (n - 1) \quad (8) \]
\[ v_i + q'_i - \frac{(d_{i+1})}{k_i} \geq S \quad \forall \quad 2 \leq i < n \quad (9) \]

An important adaptation in the model is in the case of the vehicle go back to the origin by a different route from the main route, and, consequently, different fuel stations. In this case, you should consider returning as a step in the main route and dismiss all the variables on the return operation showed in model development.

Because the model parameters are described in spreadsheets and solved by the Solver tool, there is a great facility to perform simulations and to introduce new restrictions, so it is important to do some simulations comparing several scenarios of operation before validating the effective implementation of the model optimization.

4. Results and Discussions
The considered model was used to carry through the optimization of the refueling policies in the transports operations of auto parts analyzed. To verify the effectiveness of this model there were collected information about truck stops, amount of supplied fuel as well the fuel cost in each fuel station before the implementation of the model. Based on this information, it was observed that the vehicles always were supplied in A, D, E, F and G, as described in the section 3.1 and that the refueling was always completed, what means that the vehicle left the fuel station with the complete tank.

After this first analysis, the total cost of the fuel spent per each vehicle, before the application of the model, was compared with the total fuel cost per vehicle after the implementation. The Table 2 compares the refueling politics before and after the use of the model proposed.
Table 2: Comparisons between the current refueling politics and the proposal of the model

<table>
<thead>
<tr>
<th>Truck Stop</th>
<th>Current situation</th>
<th>Refueling quantity</th>
<th>Costs</th>
<th>After the use of proposed model</th>
<th>Refueling quantity</th>
<th>Costs</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td></td>
<td>386</td>
<td>R$ 700</td>
<td></td>
<td>500</td>
<td>R$ 915</td>
</tr>
<tr>
<td>B</td>
<td></td>
<td></td>
<td>-</td>
<td></td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>C</td>
<td></td>
<td></td>
<td>-</td>
<td></td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>D</td>
<td></td>
<td>561</td>
<td>R$ 1.177</td>
<td></td>
<td>121</td>
<td>R$ 254</td>
</tr>
<tr>
<td>E</td>
<td></td>
<td>466</td>
<td>R$ 942</td>
<td></td>
<td>582</td>
<td>R$ 1.176</td>
</tr>
<tr>
<td>F</td>
<td></td>
<td>512</td>
<td>R$ 1.014</td>
<td></td>
<td>442</td>
<td>R$ 876</td>
</tr>
<tr>
<td>G</td>
<td></td>
<td>377</td>
<td>R$ 693</td>
<td></td>
<td>656</td>
<td>R$ 1.206</td>
</tr>
<tr>
<td>H</td>
<td></td>
<td></td>
<td>-</td>
<td></td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td>2.302</td>
<td>R$ 4.532</td>
<td></td>
<td>2.301</td>
<td>R$ 4.427</td>
</tr>
</tbody>
</table>

When comparing the politics of refueling before the application of the optimization model with the new politic recommended in the model, significant differences in the amounts refueled can be observed in specific fuel station. In the station D, for example, a difference of 440 liters for trips was observed. Those differences, when multiplied for the cost of the fuel of each truck stop, had generated a fuel economy of 104 BRL (Brazilian Reals) per each vehicle in the analysis.

This value represents the reduction of 2.3% in the total cost of fuel and, based on the daily average amount of trips completed in the route analyzed (8 trips per day, 240 per month), we estimated that in one year the value saved with the application of the optimization model will be approximately 300,000 BRL.

5. Final Considerations

This paper approached the planning of the transport with regard to the refueling policies of trucks for motor carriers. A generic model of linear optimization was developed and applied in a case study. It was compared the current politics of refueling used for the company with the proposal for the model and a significant reduction of the fuel costs was observed in this comparison and, consequently, a reduction of the total cost of the transport. Moreover, it was verified that the model allows easily to be modified with the objective of better adjusting to the specific operation of transport of each company.

A limitation of the considered model is that it assumes that vehicle has a route predetermined before initiating the operation of transport, that is, for each change in the original route a new simulation is necessary as well the change of the original data. Therefore, an interesting extension of this paper is the addition of vehicle routing programs with the refueling problems, in such a way to map the previously highway and get, consequently, an optimization of the total fuel cost independent of the chosen route.

References