ISSN: 2288-2766 © 2016 ICMA. http://www.icma.or.kr

doi: http://dx.doi.org/10.20482/jemm.2016.4.1.1

Study of Optimization of Ground Vehicles Routes Aiming to Reduce Operational Costs and to Contribute to a Sustainable Development with the Reduction of Carbon Dioxide in the Atmosphere

[1] A. Clecio, [2] F. Thomaz, [2] Daniela Hereid

[1, First Author & Corresponding Author] Departamento de Computação, Brazil. E-mail: cleciothomaz@flf.edu.br

[*2,] Faculdade Lourenço Filho, Ceará, Brazil. E-mail: daniela.hereid@flf.edu.br

Received: November 15, 2015. Revised: February 01, 2016. Accepted: March 17, 2016.

Abstract

The purpose of this paper is to discuss the methodology of optimizing delivery route scheduling using a capacity integer linear programming problem model developed to a previous case study. The methodology suggests a two-stage decision: the first, automatic, where the manager will obtain guidance generated by the solution of the linear programming model, later they could use post-optimization techniques to fine tune to the best operational solution. This study has the goal to reduce the size of service companies' ground transportation fleets, aiming not only to reduce costs and increase competitive advantages but also to lower levels of air pollution and its consequences, traffic and, therefore, the levels of carbon dioxide, allowing for a reduction in environmental disasters.

Keywords*:* Logistics Management, Mathematical Programming, Cluster, Sustainable Development.

1. Introduction

Logistics management is part of all levels of planning and execution - strategic, operational and tactical – so, it is an integrating function, which coordinates all logistics activities, as well as integrates logistics activities with other functions including marketing, sales manufacturing, finance, and information technology.

Transport is a major task of logistics service and it is also the biggest proportion of total logistics cost. Therefore, transport improvement is a key to let the company be competitive in the market. Route management takes the theory of optimizing route efficiencies and combines that with the real-time fleet tracking and turn-by-turn driver direction to ensure that vehicles actually use those routes that minimize the distance, the amount of fuel used, or the amount of time required to fulfill their duties. In this study we have focused specifically in the route management matters. We wish not only optimize the logistic system, but also contribute to the sustainability of the environment.

Sustainable development as a strategy to harmonization between companies and the environment in which they operate has been highlighted worldwide. The Rio Declaration states that "human beings . . . are entitled to a healthy and productive life in harmony with nature." (1992). Since air pollution damages both human health and the environment, air quality implicates both environmental and health concerns.

The growth of air pollution in big cities it is encouraged research since the main sources of emission are constantly present in our society: plants and ground vehicles, while the latter has become the main source of emission since the second half of the 20th century. The accumulation of carbon dioxide, one of the gases derived from burning fossil fuels, causes changes in the atmosphere through greenhouse effect, and its consequences in human health, specifically in the respiratory system, have been studied.

Ground transportation is broadly used in Brazil: 63% of all shipments and 97% of all passengers use ground transportation, which causes an indisputable increase in air pollution. Given their height, children are the ones most affected since their exposure to air pollutants is higher than that of the adults when these pollutants are released close to the ground as is with vehicles gas exhaust (OMS, 1986). It is worth mentioning that 15% of the total population in the city of São Paulo, for example, is made of children and elders, the group most susceptible to the harmful effects of pollution (Miraglia, 2002). Such consequences can be seen in the increase on the number of visits to ERs, hospitals and mortality rates in the capital (Salduva, Pereira, Marly & Braga, 2007).

In children, air pollution can result in significant absenteeism in school, reduction in peak flow rates, and an increase in usage of medicine by children with asthma. In normal persons - adults, children, and elderly - air pollution can cause changes in the immunologic system (Atkinson, Anderson, Sunyer, Ayres, Vonk, et al, 2001).

According to the final report in "1º Inventário Nacional de Emissões Atmosféricas por Veículos Automotores Rodoviários", it is estimated that, in 2020, ground transportation will emit around 60% more CO_2 than in 2009, getting close to 270 million of tons of CO_2, 36% of which will be from trucks, 13% from buses, 40% from automobiles, and 3% from motorcycles (2011).

Given the above, there is a need to the companies play the important social role and make changes. In this sense, this multidisciplinary study was done to analytically integrate the economic aspects with the ones from the environmental system. An important company from the state of Ceara was adopted as prototype to the application of a mathematical model that will make possible to generate competitive advantage by reducing operational costs, and to contribute socio-environmentally to the reduction on the pollutants emissions in the atmosphere.

2. Methodology

Most existing decision support tools in client support logistic systems are inefficient in total cost optimization processes in transportation logistics, especially in reducing the number of ground vehicles and the related reduction in carbon dioxide in the air. Furthermore, most logistics managers always believe the main goal is to meet the commercial requirements, i.e. deliver the goods at any cost. There is a need for studies on the economic feasibility that can measure how much this delivery costs.

This methodology aims to:

Redefine, in an optimized way, new groups of cities to be supplied in each route (clustering techniques - classification);

Optimize minimal cost routes (shortest path) within each cluster;

Develop an optimal fleet design necessary to cover all client cities (set covering problem), vertex covering through a integer programming model with limited capacity (supply and demand) on the vertices of the road graph;

Develop an interactive and parameterized computational environment to simulate new scenarios (Decision Support System).

A mathematical linear programming and model were developed in this paper to allow clustering points of higher proximity in terms of distance; meeting each vehicle's supply constraints; meeting each consumer center's demand constraints; and balancing the number of visits of each vehicle in each cluster. The clustering problem will not be detailed, as well the mathematical programming, since the main objective here is to show to the community involved in business administration research, the importance of the use of operation research in the managers life and how it can be useful.

The optimization module aims to present a new methodology to the process of logistic management, based on a mathematical model and targeting the reduction of costs and pollutant gases in the environment.

Here is a C_ILPP (Capacity Integer Linear Programming Problem) model that is developed in the first decision stage:

$$\text{Min } \sum_{i=1}^{n}\sum_{j=1}^{n} d_{ij}\, x_{ij} + \sum_{j=1}^{n} y_j$$

subject to:

$$\sum_{j=1}^{n} x_{ij} = 1; \quad i = 1, \dots, n$$

$\sum_{i=1}^{n} x_{ij} \leq \text{int}\left[\frac{n}{kk}\right] + 1; \; j = 1, \dots, n \quad (\text{balancing})$

$$\sum_{j=1}^{n} \alpha_i \, x_{ij} \leq \beta_j y_j; \; i = 1, \dots, n \quad (\text{Supply and Demand Capacity})$$

$$\sum_{j=1}^{n} y_j = kk; \; j = 1, \dots, n \quad (\text{total number of vehicles})$$

$n = \text{total number of deliveries}$

$kk = \text{number of vehicles} \quad (\text{parameter})$

$\text{int}\left[\frac{n}{kk}\right] + 1 = \text{biggest quocient} + 1 \text{ integer upper limit of number of visits}$

$\propto i$ e βj are parameters of supply capacity i e demand j respectively

xij e yj are decision variables $\in 0,1$

The application of these mathematical programming techniques according to the above model allowed great reductions in operational costs, in the number of vehicles, and, at the same time, contributed to the improvement on life quality by reducing traffic and atmosphere pollutants. Thus, these techniques were used at a company in the Ceara state, Brazil. This company has 46 vehicles for a week worth of deliveries as will be seen in the next section.

3. Expected Results and Discussion

The current scenario of the prototype company, whose total demand is 135142,90kg, and 46 vehicles and supplying 234000kg of vehicle capacity, allowed the C_ILPP model previously discussed to be executed for 195 locations in Ceara during the week from the 2nd to the 6th of August, 2011.

The geospatial view of the problem can be better interpreted in the figure below, where the above modules fit.

From the data provided by the aforementioned company, two simulations were made using the optimization software developed here; first with 46 vehicles the company already used, and the second simulation with 30 vehicles (number suggested by the mathematical modelling).

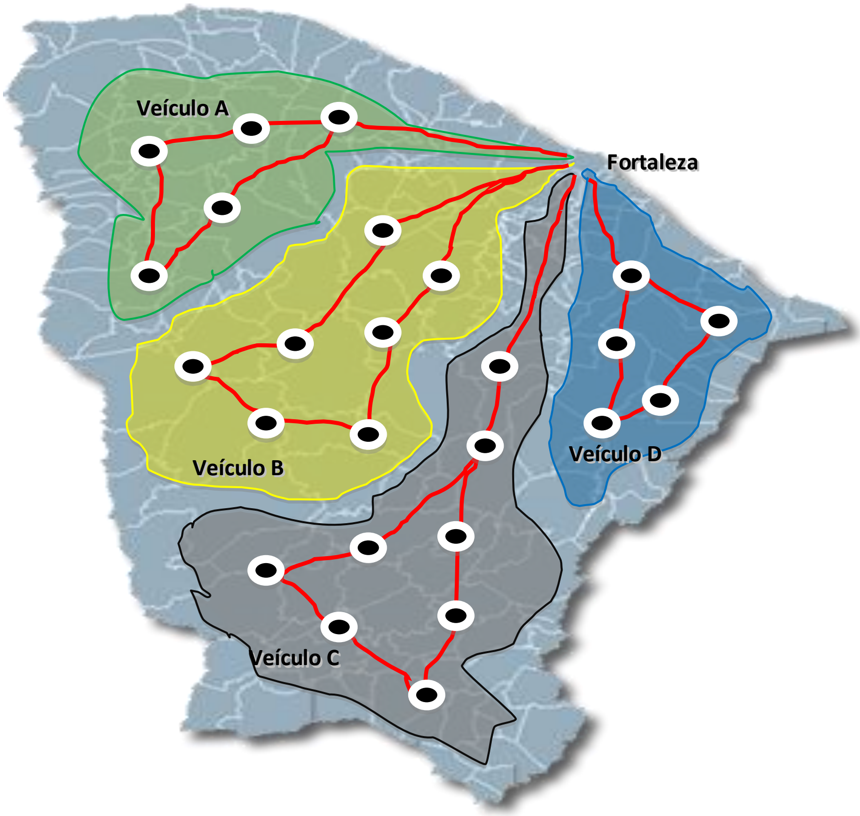

Figure 1: Route Clustering in Ceara

The results will be presented and discussed in the following tables where two aspects will be assessed: Financial and Ecological Economics.

The adopted economic indicators represent:

ICT = load/km average index = Load T/Total distance

CKr = average cost/km = R$ 11.47

R/Km = average index of revenue/km = Revenue T/Total distance

Contribution margin/km = Revenue - Costs (transportation, maintenance, drivers, etc)

Table 1 shows the results of optimized delivery of goods from August 2 to 6 for both simulations, with a reduction of 8846.69km, i.e. 33.9%.

Table 1: Financial Economics Statistics of the Simulations

No. Vehicles	Locations	Path T (km)	Load T (Kg)	Revenue T(R$)
46	195	26042.49	135142.90	1.788803.52
30	195	17195.80	135142.90	1.788803.51
Difference		8846.69		

Table 2 shows, after the optimization, an increase in the transported load index even with the reduction of 34.7% of vehicles, as well as an increase on the revenue/km and contribution margin.

Table 2: Financial Economics Indicators for the selected prototype.

No. Vehicles	ICT(Kg/Km)	CKr (R$)	R/Km(R$)	Margin(R$)	Econ.(R$/Km)
46	5.048	11.47	68.68	57.21	
30	7.850	11.47	104.02	92.55	38.00 Profit

Focusing on the Ecological Economics matters we took the recommendation of the scientific paper “Metodologia Simplificada de Cálculo das Emissões de Gases do Efeito Estufa de Frotas de Veículos no Brasil” (Jr & Linke, 2011), which says that the estimated CO2 emissions for diesel trucks should preferably be made with European data, since the technology used in Brazil is similar to the one used in Europe and yet Brazil does not have data on the emission factors. So, the data presented in the table 3 that have been used as reference in this study and it is from the IPCC Guidelines for National Greenhouse Gas Inventories.

Table 3: Estimated Emission Factors for European Diesel Light – Duty Vehicles

CO2 Emissions	
Total kg/km	0.280
g/kg of diesel	3140
g/MJ	74

Table 4: Company Information

	No. Vehicles	Average Distance per year (km)	CO2 Emissions Factor (kgCO2/km)
Prototype Company	16	22000	0.280

In this paper, the following equation (Jr & Linke, 2011) for greenhouse gas emission is being used:

E = F x FEi x kma

Where,

F = number of vehicles;

FEi = gas emission factor;

Kma = average distance per year

From the data presented in the tables 3 and 4 and the aforementioned equation, the weekly reduction of 16 vehicles from the company allows for a yearly reduction of 98.56 tons of CO_2 in the atmosphere.

E= 4weeks x16 vehicles x 22000 km/year x 0.280 = 394240kgCO_2 = 394.24 ton. of Carbon Dioxide/year

With this information and based on the value of carbon credit in the international market, estimated according to the Kyoto Protocol in 10.00US$/ton, we can deduce that the ecological economy with the optimization in reducing 16 vehicles will be approximately: 394.24 x 10.00US$/year = 3942.40US$/year. This is how much the company can apply to receive.

4. Conclusion

In order to reach a sustainable development, it is necessary to examine the social, economic, ecological, and cultural dimensions - in a multidisciplinary vision - so as to analyze all variables and spectrum of perspectives involved in the huge challenge of equitably meeting material and immaterial needs of the society.

So, the results in this case study shows that optimization projects have brought not only immediate financial benefits that allow high quality and speed, but also huge benefits to the society with the reduction in usage of natural resources, fuel, reduction of pollutants emission and the level of noise, and also the reduction of many vehicles from the streets, minimizing the possibilities of an accident and reducing the traffic lines.

The environmental and climate impacts caused, mainly, by the use of a wide range of ground transportation vehicles can be gradually reduced with a higher demand for projects that apply optimization as a basis for decisions, promoting a greater contribution to society as a whole.

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