

A Methodology for Integration of CO₂ Emissions on the Single-Facility Location Problem

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Abstract

The Single-Facility Location Problem (SFLP) is one of the most important problems in Logistics and Supply Chain Management. Its significance is crucial for transportation routes and capacity planning, selection of suppliers, and international expansion of enterprises. Concerns regarding the emission of pollutants by transportation vehicles have led to the development of green technologies and sustainable practices. Within this context we present a model to dynamically integrate an emission factor of CO₂ emissions in the SFLP. This model is proposed in order to consider the pollutant risk factor within the location decision process. Experiments performed on standard FLP instances present a difference in the final location of the facility if the CO₂ factor is considered. This is an important insight to estimate the generation of CO₂ for this kind of decisions and the pollution risks in specific regions.

Keywords

Facility Location Problem, CO₂, Green Logistics, Heuristic Optimization

1. Introduction

Facilities, customers and suppliers are important elements of the Supply Chain. Within the Logistic Network, facilities (distribution or manufacturing centers) must be efficiently connected to their customers in order to achieve a fast and controlled product flow. The location of these facilities involves finding the best location from a set of potential locations to minimize the associated distributing costs (Yang et al., 2007).

The Single-Facility Location Problem (SFLP), also known as the Weber's Problem (WP), consists on determining the location of a single facility which minimizes the sum of weighted Euclidean distances to n demand points (Chen et al. 1992). WP is one of the most important problems of optimal location of interconnected points (i.e., demand or service points) (Zabudskii and Veremchuk, 2016).

In recent years, concerns regarding climate change have led to modelling environmental objectives within the formulation of distribution problems (Harris et al., 2009). Thus, it is now strategically important to design efficient and environmentally-friendly distribution networks that depend of the locations of the main distribution centers. Within this context, Green Logistics has become an important aspect of the Supply Chain as it consists of the management practices and strategies developed to reduce the environmental impact of the distribution activities of products (e.g., materials and waste management, packaging and transport). It also focuses on the development of sustainable production and distribution strategies considering the associated environmental and social factors (Guirong et al. 2012; Sbihi and Eglese, 2009). Particularly for the manufacturing and transportation industry, Green Logistics has become very important to reduce the emission of pollutants (i.e., CO₂ emissions).

As presented by Kakouei et al. (2012), there is a relationship between transportation and air pollutants such as CO₂, CO, NO_x and SO₂. Particularly, on-road vehicle emissions constitute the major source of atmospheric CO₂ in urban areas, contributing to approximately 10% of the total global atmospheric CO₂ emissions. Due to this fact, it is important to improve transportation planning to reduce the emission of air pollutants.

Research as described by Harris et al. (2011) has considered financial costs and CO₂ emissions to determine optimal locations for facilities. However, as presented, sometimes the solution with the minimum cost also generates the highest CO₂ emissions. Thus, the environmental goals do not necessarily match the financial goals.

Hence, in this work we extend on the field of Green Logistics with the following specific contributions:

- a) Development of a CO₂ metric based on current environmental data. This metric considers the type of vehicle considered to service the transportation routes from customers to the distribution center.
- b) Integration of the CO₂ metric on the SFLP as an environmental emission factor.

Experiments performed on FLP instances showed that optimization of the facility location depends on the emission factor. Also, the metric can be used to dynamically estimate the magnitude of CO₂ emissions considering a specific location. Thus, this metric can be used for simulation and / or assessment of planning scenarios for facility location.

2. Development of the CO₂ Metric

The proposed metric for CO₂ emission is based on the *kgCO₂/km* emission factor described by Hill et al. (2013) from the UK agencies of the Department of Environment, Food and Rural Affairs (DEFRA) and the Department of Energy and Climate Change. This metric represents the kilograms/grams of CO₂ emitted per kilometer.

The emission factor was estimated for different vehicles and fuel types. Table 1 presents an overview of the source data from Hill et al. (2013) regarding these considerations. Average and standard deviation values were estimated from this information.

Table 1. Direct emissions of *gCO₂/km* from different vehicles.

		Fuel Type		
		Diesel	Petrol	(Diesel+Petrol)
Direct Emissions from Passenger Cars				
Market Segment	Example Model			
A. Mini	Smart Fortwo	87.00	131.34	130.73
B. Super Mini	VW Polo	109.13	145.31	142.33
C. Lower Medium	Ford Focus	118.86	172.68	160.92
D. Upper Medium	Toyota Avensis	126.68	198.16	177.43
E. Executive	BMW 5-Series	139.46	232.77	201.83
F. Luxury Saloon	Bentley Continental GT	176.06	299.16	274.21
G. Specialist Sports	Mercedes SLK	134.99	218.80	214.35
H. Dual Purpose	Land Rover Discovery	174.43	246.18	227.30
I. Multi Purpose	Renault Space	145.80	195.99	182.21
Direct Emissions from Vans				
Up to 1.305 tonne	-	152.30	193.00	-
1.305 to 1.740 tonne	-	225.30	211.20	-
Over 1.740 tonne	-	266.90	255.70	-
Average (\bar{X}) =		183.89		
Standard Deviation (S) =		51.82		

By obtaining the average and standard deviation data of the $kgCO_2/km$ emission factor, a confidence interval can be defined to estimate the minimum and maximum values for CO_2 emissions. Then, the following expression is considered to estimate the interval for CO_2 emissions:

$$E_{CO_2} = \bar{X} \pm ZS \quad (1)$$

For a confidence level of 0.99 the variable Z is defined as equal to 2.326. This leads to the following interval for E_{CO_2} : [63.356, 304.423].

In order to dynamically model the general practical uncertainty of the emission, Z can be extended to be defined as a random number between -2.326 and +2.326 which is expressed as *random* (-2.326, +2.326). Then, the CO_2 metric is defined by the following expression:

$$E_{CO_2} = 183.89 + random(-2.326, +2.326) \times (51.82) \quad (2)$$

In order to assess the emission pattern generated by the CO_2 metric a sample of $N=500$ pairs of emission values was generated with Eq. (2). As presented in Figure 1 the E_{CO_2} values generated by Eq. (2) are uniformly distributed over the range [63.356, 304.423].

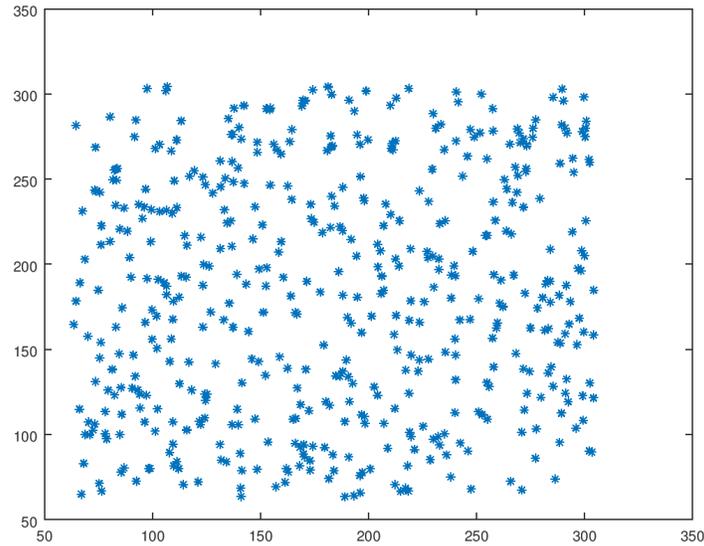


Figure 1. Uniform distribution of E_{CO_2} values.

3. Integrated Facility Location Model

As discussed earlier, the SFLP consists of minimizing the weighted distances from the potential location of the facility to the customers. This is expressed by the following objective function:

$$\min f = \sum_{i=1}^n w_i d_{ij} \quad (3)$$

In Eq. (3) w_i is the weight associated to each customer, and d_{ij} is the distance between the location of the facility at j and the customer located at i . In contrast to most of the facility location models, the implication of the CO_2 metric will be assessed on the spherical model of the Earth surface. This leads to the following expression for d_{ij} (Dhar and Rao, 1982):

$$d_{ij} = E_{CO_2} \times r \times \theta_{ij} \quad (4)$$

Where r is the radius of the spherical Earth ($r = 6371\text{km}$) and θ_{ij} is the angle between the vectors that define the points at i and j from the center of the sphere. This angle is computed as:

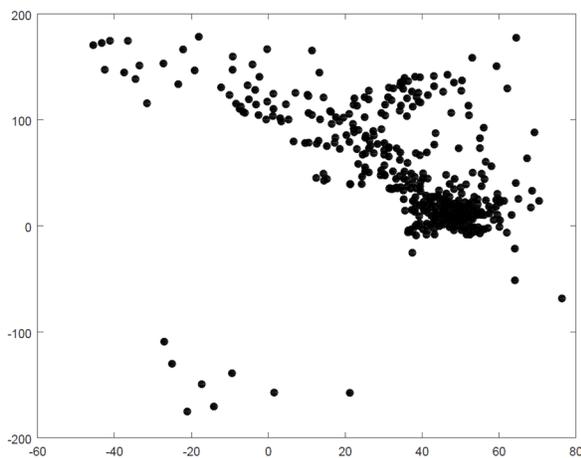
$$\theta_{ij} = \text{Arccos}[\cos \theta_i \cos \theta_j \cos(\theta_i - \theta_j) + \sin \theta_i \sin \theta_j] \quad (5)$$

Because $r = 6371$ kilometers, the distance d_{ij} is computed in km. We set w_i as equal to 1.0.

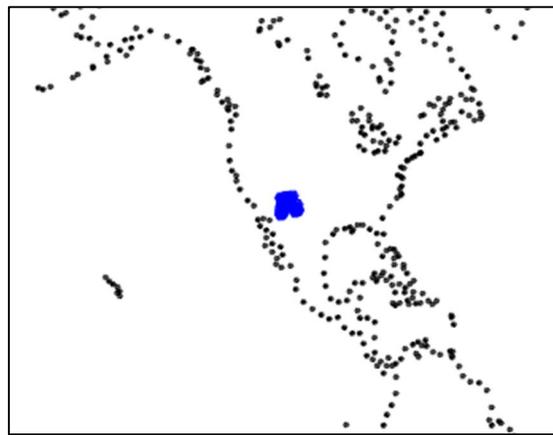
4. Assessment of the Model

In order to assess the implications of the CO₂ metric on the SFLP, five instances of the Travelling Salesman Problem (TSP) from the TSPLIB database (Reinelt, 2013) were converted to adjust to geodetic points. Conversion of XY coordinates to latitude/longitude coordinates on the geodetic region of the United States of America was performed with Octave programming. Figure 2 presents an example of this conversion.

a) Original TSP data on XY Coordinates



b) Converted data into Latitude/Longitude Coordinates



c) Converted data (zoom-in)

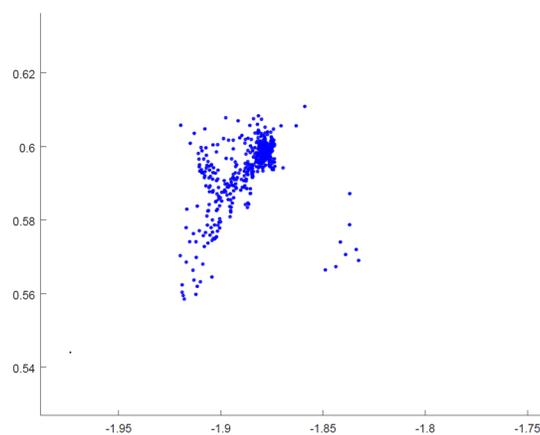


Figure 2. Example of converted TSP instance (*gr431.tsp*) for assessment of the model.

On this converted data the SFLP was solved by means of a Genetic Algorithm for two cases: (1) with and (2) without the E_{CO_2} factor. The results are presented in Table 2.

Table 2. Facility location (latitude/longitude) considering the E_{CO_2} metric

TSP Instance	Customers (n)	Facility Location (Lat/Lon)	
		Without E_{CO_2}	With E_{CO_2}
gr431.tsp	431	34.17, -107.87	34.12, -107.83
pr144.tsp	144	33.54, -107.57	33.69, -107.48
kroB100.tsp	100	33.65, -107.70	33.78, -107.75
fl417.tsp	417	33.37, -107.58	33.28, -107.82
ali535	535	34.19, -107.42	34.21, -107.48

5. Conclusions and Future Work

In this work we proposed a methodology and metric to integrate pollutant emissions within the SFLP. The metric uniformly generates emission values within a confidence interval estimated from DEFRA data. Thus, dynamic practical variation of the CO_2 emission can be modelled with the proposed metric. Also, the methodology and metric proposed to integrate CO_2 emissions on the SFLP showed that there is a difference in the facility location when this factor is considered.

Due to these observations, it is important to highlight the pollutant reduction within logistic planning (particularly if Green Logistics is expected to be achieved). Hence, the future work is to be focused on:

- to extend on the modelling of CO_2 emissions for more distance metrics and surface models;
- to analyze the suitability of the model for other distribution contexts;
- to implement the CO_2 metric on other distribution planning problems (e.g., vehicle routing problems).

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Biography

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