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How many urban recycling centers do we need and where? A continuum approximation approach

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Abstract

This article presents a methodology that uses the continuum approximation approach to formulate the logistical problem of determining the number and location of recycling centers to which individuals in a region can deliver solid wastes to be recycled. To solve the proposed problem a two-stage approach is proposed. First, we solve an optimization problem whose main decision variable is the density of recycling sites per unit area. This problem is solved assuming that local conditions are similar throughout the region of interest. So, this problem is solved for each point of a grid that divides the region under study, yielding an optimal solution that reflects an approximation of the local optimum density. In the second stage, the solution is refined by identifying specific locations in which recycling centers could be installed, in a manner consistent with the approximate solution obtained in the first stage. Finally, this proposed approach is tested in a case study using data from Santiago, Chile.

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Keywords: Recycling Centers Location; Waste Collection; Reverse Logistics; Continuum Approximation method; Logistics Network Design; Urban logistics.

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1. Introduction

Here introduce the paper, and put a nomenclature if necessary, in a box with the same font size as the rest of the paper. The paragraphs continue from here and are only separated by headings, subheadings, images and formulae. The section headings are arranged by numbers, bold and 10 pt. Here follows further instructions for authors.

In this paper we present a methodology that uses the continuum approximation approach (see for example, Daganzo, 2005) to determine the number and location of recycling centers (or distribution centers) to which individuals and/or households in a region can deliver solid wastes to be recycled and then applied to the case of Santiago, Chile.

We consider a company that operates recycling centers to which users can deliver their items to be recycled. Each of these recycling centers serves an area of influence, in which users in the region can deliver their waste items to be recycled. After these items are received in a center, they are classified and consolidated, and then transported to external recycling plants.

One of the key trade-off that occurs in choosing the number of recycling centers is between minimizing the cost per kilogram of recycled material and maximizing the quantity of material attracted. The proposed methodology explicitly recognizes that the demand attracted by each recycling center depends on the number of households in its area of influence and the distance of each of them to the center.

The logistics costs associated to this recycling system can be grouped into two categories:

i. Leasing, operation and maintenance costs associated with the process of preparation and delivery of products in each of the recycling centers. The leasing cost is related to the rental fee paid for occupying each square-meter of land during a time horizon. The operating cost includes the salary paid to each employee of the recycling center. The maintenance cost includes a fixed rate for each period. This rate consolidates the costs associated with cleaning, maintenance and care of the recycling center.

ii. Transportation costs associated with the movement of products from recycling centers to external recycling plants. Shipments are made in full truckloads, since vehicles are paid by distance regardless of the amount transported, and given the characteristics of the products which have extremely low inventory costs and do not lose their value. Accordingly every kilogram of material will be transported at a lower cost if we wait until filling the capacity of the vehicles.

Also, from a social perspective, it makes sense to consider as part of logistics costs the costs incurred by users on their trips to the recycling centers. This adds a third category:

iii. User costs associated with transportation of products from their homes to the recycling centers. This category consists mainly by the additional cost that may involve deliver waste to recycling centers. In this case, it is possible to differentiate in two user categories because some may travel to recycling centers in a private vehicle while others may simply walk to the nearest place. These differences strongly influence the cost incurred by users.

Furthermore, the recovery of recyclable material has a value associated to the recycling centers, thus we can consider income associated with each of the products recovered at recycling plants:

iv. Income (benefit) associated to received products in recycling plants. For each product recycled the company that owns the recycling centers is paid a fixed rate depending on the type of product. This income is a transfer from the recycling plant to the distribution centers. From a social standpoint, these values could represent the social or shadow prices of recycling these products.

These categories are added to obtain an objective function that includes the costs and revenues listed above. This objective function is used to find the density of distribution centers in the region that maximizes the benefit of the company in the private case, and the social benefit in the social case. The main decision variable in each case is the density (δ) of recycling centers around each point of the region of interest.

In this paper, we propose a methodology that uses continuum approximation (Daganzo, 2005) to determine the amount and location of recycling centers in a region. This type of problem has been studied and solved in the literature usually with integer programming methods in which you try to find the exact solution. Unfortunately, these solutions require a large amount of information about the instances to be solved and the computational requirements to find an optimal solution can be even today extremely time-consuming. A detailed review of integer programming models for localization issues can be found at Brandeau (1989) and Daskin (1995).