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PLANNING LOGISTICS NETWORK FOR RECYCLABLES COLLECTION

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Abstract: Rapid urbanization, intensified industrialization, rise of income, and a more sophisticated form of consumerism are leading to an increase in the amount and toxicity of waste all over the world. Whether reused, recycled, incinerated or put into landfill sites, the management of household and industrial waste yield financial and environmental costs. This paper presents a modeling approach that can be used for designing one part of recycling logistics network through defining optimal locations of collection points, and possible optimal scheduling of vehicles for collecting recyclables.

Keywords: Recycling, Collection, Location theory, Scheduling.

MSC: 90B06.

1. INTRODUCTION

Managing solid waste efficiently and affordably is one of the key challenges of the 21st century. Solid waste represents an enormous loss of resources be it in the form of materials or energy. In addition, waste management itself creates environmental damage. The increase in municipal waste generation in OECD countries was about 58% from 1980 to 2000, and 4.6% between 2000 and 2005 [9]. In 2030, the non-OECD area is expected to produce about 70% of the world's municipal waste, mainly due to rising incomes, rapid urbanization, and technical and economic development. During the past 10–20 years, high-income countries have been rediscovering the value of recycling as an integral part of their waste (and resource) management systems, and have invested heavily in both physical infrastructure and communication strategies to increase recycling rates. Their motivation is not primarily the commodity value of the recovered materials but the fact that the recycling market offers a competitive ‘sink’, as an alternative to increasingly expensive land-filling or incineration. Thus, recycling provide revenues through the sale of collected materials, ensures an adequate supply of raw materials for manufacturing recycled products and has important environmental benefits, including the conservation of energy, natural resources, and valuable landfill capacity.

However, recycling as one solution for the waste management problem requires appropriate logistics network structure and adequate realization of logistics activities. Typically, recycling encompasses collection of used products from generators at designated collection points, transport and sorting or testing operations at consolidation points (transfer points), then treatment options, i.e. recycling at recycling facility and finally environmentally sound disposal for any part, component or entire product which cannot be recovered. Hence, recycling creates a reverse flow of products comparing to (forward) logistics. A key element of recycling logistics system is the collection or acquisition of used product. Separating municipal waste into fractions like paper, glass, plastic, metal at the place where it is generated is one of the most efficient ways of collecting it, so it can later be recovered by recycling. To achieve this, it is essential to have an appropriate system of selective collection at source. The success of a program of selective collection lies mostly in citizens’ participation, which determines the type and the amount of materials to be collected. The generators want their waste collected with the minimum amount of inconvenience [2].Many studies demonstrated that the decision to participate in recycling activities is influenced by the provision of waste collection bins and easily accessible collection sites ([5], [1], [3]). Hence, an appropriate collection site can be selected by taking into consideration the geographic location, easy access and convenience for consumers, and the population distribution.

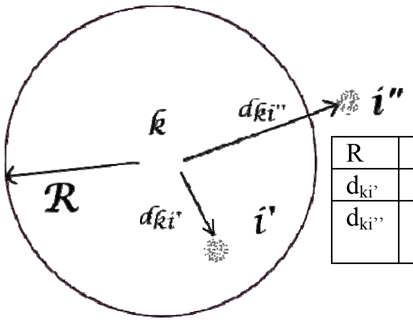
However, the success of recycling schemes is not just dependent on public participation; it is also dependent on careful planning, effective design and tailoring to local needs. Due to the large number of factors that must be taken into account when establishing a separate collection system (which may be economic, social, environmental or legal, among others), there is no single solution. The collection of municipal solid waste in general and the recyclables too is one of the most difficult operational problems faced by local authorities in any city. In recent years, due to a number of costs, health, and environmental concerns, many municipalities, particularly in industrialized nations, have been forced to assess their solid waste management and examine its cost effectiveness and environmental impacts, e.g. in terms of designing collection route [8]. Namely, the value of recyclables is relatively low, and realization of its logistics processes, particularly those related to its collection, introduces the relatively high costs. On the other hand, efficient and cost effective recycling in treatment facilities requires adequate supply with collected recyclables. For this reason, many authors have focused their research on how waste collection is influenced by design or logistic factors, such as collection staff, collection frequency, number of collection vehicles, distances to be walked by citizens, etc. ([6], [7], [5]).

From here, the main intention of our research is to propose a modeling approach which can be used for designing one part of recycling logistic network, locating collection points for recyclable materials depending on the distance from end users to collection points. After determining the optimal locations for collection points, we propose a model for truck scheduling for collecting used materials at collection points.

With this objective, the remaining part of the paper is organized as follows. Section two describes the problem analyzed, and the next section presents the mathematical formulation. The numerical results of the modeling approaches for the case of Belgrade city are shown in section four. Finally, some concluding remarks are made in section five.

2. PROBLEM DESCRIPTION

Before recyclable materials can be processed and recycled into new products, they must be collected. Most residential recycling involves curbside recyclables collection, drop-off programs, buy-back operations, and/or container deposit systems. Collection of recyclables from commercial establishments is usually separate from residential recyclables collection programs. Regardless of the type of collection system, convenience is the key to a successful recycling program. A convenient collection system will encourage generators to carefully sort recyclables by material type and to eliminate contaminants. The aim is to provide larger quantities of these products because they represent an input in the recycling process. So, in order to model the influence of distance between users and collection points of used products, we introduce the collection point's catchment area (Fig.1). The catchment area models the influence of distance between end users and collection points, in the sense that for all end users and collection points, collection service may exist only when end users are within the certain (reasonable) distance from a collection point k. Therefore, catchment area denotes the area within the circle of certain predefined radius from the drop-off location. This means that any arbitrary end user can be allocated to the collection point only if it is located within the collection point's catchment area.



R	Radius of the collection point *k*
$d_{ki'}$	Distance between collection point k and end user *i'*
$d_{ki''}$	Distance between collection point k and end user *i''*

Figure 1: Collection point's catchment area

Increasing reverse logistics flows introduce new issues in the areas of collection and vehicle routing. When comparing with distribution logistics, two main differences in area of vehicle routing can be noticed: low value of the goods (recyclables) and large degree of freedom in deciding the moment and method of collection. Collection of solid waste and recyclables typically represent the single largest percentage of municipal solid waste (MSW) management budgets—from 39 percent to 62 percent of total system costs in USA (Figure 2) [4]. Effective planning of solid waste recycling programs is currently a substantial challenge in many solid waste management systems. One such concern is how to effectively distribute collection vehicles and crews in a growing metropolitan region..Until recently, May 2009, Serbia did not have specific legislation and plans to manage waste management processes. Key factors that cause inefficient recyclables management in Serbia are lack of collection network, and inadequate treatment facilities. So, here we analyzed the problem how to find optimal location for collection points and scheduling plan for collecting the recyclables in Belgrade city, which still does not have an appropriate infrastructure for recyclables collection.

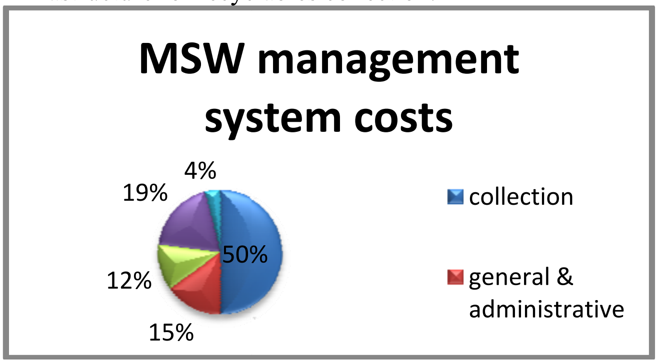


Figure 2: MSW management system costs (adapted from [7])

3. MATHEMATHICAL FORMULATION

The first phase of the recycling logistics network design refers to finding locations of collection points dependent on the radius of collection point catchment area (Fig. 3).

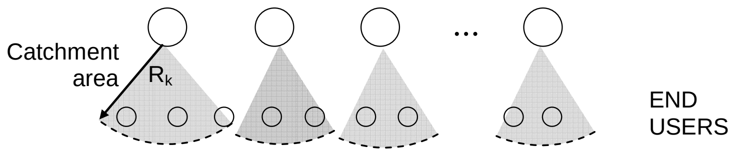


Figure 3: Collection points of recycling logistics network

Catchment area described in previous section was first introduced in [11], where authors located intermodal terminals by using p-hub location model. Mathematical formulation for locating collection points in recycling networks which includes catchment area present modified simple plant location problem with transport cost excluded. In previous section, we explained that success of a program of selective collection lies mostly in citizens' participation and decision to participate in recycling activities, which is influenced by the provision of waste collection bins and easily accessible collection sites. So, in this phase of designing recycling network, transportation cost are not included because we modeled the influence of distance between users and collection points on the collecting of used products. Hence, we propose the following mathematical formulation for locating collection points in recycling logistics network which includes catchment area:

Sets:

I set of end users
K set of collection points

Parameters:

G_k	capacity of collection point k
d_{ik}	road distance from an end user i to a collection point k
R_k	radius of the catchment area for collection point k
Fk	costs of opening collection points
Fd	costs of opening dummy node that prevent infeasibility in the solution procedure
q_i	quantity of recyclables at end user i

Variables

$$X_{ik} = \begin{Bmatrix} 1, if\ end\ user\ i\ is\ allocated\ to\ collection\ point\ k \\ 0, otherwise \end{Bmatrix}$$

$$Y_k = \begin{Bmatrix} 1, if\ collection\ point\ k\ is\ opened \\ 0, otherwise \end{Bmatrix}$$

$$Y_{D_k} = \begin{Bmatrix} 1, if\ dummy\ node\ k\ is\ opened \\ 0, otherwise \end{Bmatrix}$$

A dummy X_{iD_k} node was included to collect product flows from end user with a distance greater than R_k from any opened collection point k

$$X_{iD_k} = \begin{Bmatrix} 1, if\ end\ user\ i\ is\ alocated\ to\ dummy\ node\ k \\ 0, otherwise \end{Bmatrix}$$

$$\text{Min} \sum_k Y_k F_k + \sum_k Y_{D_k} F_D \qquad (1)$$

$$\sum_k X_{ik} + \sum_k X_{iD_k} = 1 \ldots \forall i, \qquad (2)$$

$$X_{ik} \le Y_k \ldots, \forall i, k \qquad (3)$$

$$X_{iD_k} \le Y_{D_k} \ldots, \forall i, k \qquad (4)$$

$$\sum_i X_{ik} q_i \le Y_k G_k \ldots \forall k \tag{5}$$

$$(d_{ik} - R\ )X_{ik} \le 0, \ldots \forall i,k \tag{6}$$

$$(d_{iD} - R\ )X_{iD_k} \le 0, \ldots \forall i,k \tag{7}$$

$$Y_k \in \{0,1\},\ X_{ik} \in \{0,1\} \tag{8}$$

$$Y_{D_k} \in \{0,1\}, X_{iD_k} \in \{0,1\} \tag{9}$$

The objective function (1) minimizes the cost of opening collection points. The first set of constraints (Equation 2) ensures that all used products currently located at end user are transferred to collection points (guaranteed that all products for recycling, currently at end users, are delivered to collection sites). Constraints 3 and 4 represent collection points opening constraints, stating that used products from the end user *i* can be transferred to collection point *k* only if it is opened. Constraint set 5 regards the capacity of collection point. The set of constraints 6 and 7 represents the catchment area of the collection point *k,* and allow allocation of end users to collection points only when the distance between end user and the collection point is within the predefined radius of the catchment area. Finally, last constraints define binary nature of variables.

As mentioned, collection costs of recyclables represent the single largest percent of MSW budgets. Collection costs are related to number of system requirements (i.e., how material is to be sorted, separate containers for glass, paper, and cans), frequency of collection, and level of community participation. By adjusting the variables that affect collection costs, local authorities can decrease the costs. Offering collection services less often can, in many cases, decreases costs and increase the amount of waste diverted from disposal [10]. Reduced frequency of collection lowers operating costs by improving operational productivity. With less frequent collection, end users set out more waste for each collection, making vehicle trips more productive [10]. Also, reducing collection frequency means fewer trucks, lower fuel usage and fewer air emissions, reduced traffic and safety impacts on community streets, etc. While decreasing frequency of collection, one way to recyclables collection get more productive is minimizing number of stops of vehicle while collecting as more recyclables as can.

So, after determining optimal locations of collection points in recycling network, it is necessary to define possible optimal scheduling plan of collecting recyclables in order to collect maximal possible quantity of recyclables with minimum number of stops per vehicle. We propose following mathematical formulation (10)-(19). The main idea of the proposed mathematical model was to ensure enough quantity of recyclables because they represent an input in recycling process.

Sets:

T set of planning horizons
K set of opened collection points

Parameters

Q_k capacity of collection point k

S_k^0 quantity of recyclables in collection point k at the beginning of the planning horizon

S_k^t quantity of recyclables in collection point k in day t

$MaxV$ maximal daily collected quantity

M big number in objective function

q_k daily generated quantity of recyclables at collection point k

Variables

X_k^t daily collected quantities of recyclables from collection point k in day t

$$p_k^t = \begin{cases} 1, if\ collection\ point\ k\ is\ served\ in\ day\ t \\ 0, otherwise \end{cases}$$

$$\text{Min } MaxV + M\sum_k \sum_t p_k^t \tag{10}$$

Subject to

$$p_k^t \geq \frac{1}{Q_k} X_k^t, \forall t \in T, \forall k \in K \tag{11}$$

$$z_k^1 = S_k^0 + q_k - X_k^1 \tag{12}$$

$$z_k^t = z_k^{t-1} + q_k - X_k^t \tag{13}$$

$$\sum_t X_k^t \geq MaxV, \forall t \tag{14}$$

$$X_k^0 = S_k^0 p_k^0 \tag{15}$$

$$X_k^t \geq z_k^{t-1} + k\left(p_k^t - 1\right), \forall t > 0 \tag{16}$$

$$X_k^t \leq z_k^{t-1} \tag{17}$$

$$X_k^t \leq kp_k^t \tag{18}$$

$$X_k^t \geq 0 \tag{19}$$

Objective function (10) minimizes number of stops of vehicles with maximal daily collected quantities of recyclables. As mentioned, recyclables represent an input in recycling process and big number M should be large enough so that a maximal daily collected material is more important than number of vehicle stops in collection process. Constraint (11) ensures that collection point is served in day t. Constraint (12) represents inventory level for collection point z_k^1, while constraint (13) represents the quantity of recyclables in collection point k in case where t>1. Constraints (14) represent collected recyclables in day t for every collection point. Constraints (15)-(19) define variableX_k^t.

4. NUMERICAL RESULTS

Proposed modeling approach was tested on New Belgrade municipality, part of Belgrade city. The first stage of designing the logistics network is related to the determination of number of locations for the collection of recyclables based on the distance from the end users to potential locations for the collection. Model 1 is solved using the IBM ILOG CPLEX 12.2 software, and the results for different values of radius catchment area are presented Table 1. The distances from the end users to potential locations for the collection are determined using the GIS software, while fixed costs of opening location were even for all possible locations, set to 150 euros. The waste quantities are estimated according to generated quantities in Belgrade (http://www.sepa.gov.rs/download/otpad.pdf).

Table **1**: The results obtained by solving the Model 1.

Local community "Stari aerodrome" (Municipality New Belgrade)	**Objective function value**	**Radius of collection point catchments area (m)**	**Number of opened collection points**
	4350	50	29
	2100	100	14
	1200	150	8

Among 49 potential collection points, the model determined 29, 14 and 8, respectively depending on the radius of catchment area. Results obtained by solving Model 1 can be used to demonstrate impact of the catchment area radius on the expected number of users served (and from there quantity of waste textiles collected) and the network configuration (number and structure of logistic nodes opened). After defining the optimal locations of collection points, we solved Model 2 in order to obtain truck schedule for each opened collection point. Capacity of the collection point is set to be 20 kg, and we don-t have limits in number of vehicles and their capacity, because the main goal was to get scheduling results, that is to see the systems' demands. Results obtained by solving Model 2 are given in Table 2, while the example of visits to collection points for R_k=100m and t=7 days, R_k=150m and t=7 days and R_k=50m and t=7 days is given in Tables 3, 4 and 5 respectively.

Table 2: The results obtained by solving the Model 2.

Radius of the cachment area	Planning horizon	no. of opened collection points	Objective function value	MaxV
R=50 m	7 days	29	5331.563	131.5626
	14 days		10396.59	196.5896
	21days		No results in acceptable time	No results in acceptable time
R=100 m	7 days	14	5840.388	140.3881
	14 days		11542.51	142.5109
	21days		17142.51	142.5109
R=150 m	7 days	8	5235.862	135.8623
	14 days		10435.86	135.8623
	21days		15535.86	135.8623

Table 3. The results obtained by solving the Model 2 (number of visits to collection points for $t=7$ days and $R_k=100m$).

Collection points	***Planning horizon***						
	0	1	2	3	4	5	6
1	■	■	■	■	■	■	■
5	■	■	■	■	■	■	■
9	■			■			
18	■	■		■		■	
20	■	■	■	■	■	■	■
24	■	■	■	■	■	■	■
29	■	■	■	■	■	■	■
35	■	■	■	■	■	■	■
38							
40		■			■		
41			■				■
42			■		■		
46		■		■		■	
47	■						
MaxV	90	140.3881	124.0196	135.8623	111.4495	123.1252	104.0196

Table 4. The results obtained by solving the Model 2 (number of visits to collection points for $t=7$ days and $R_k=150m$).

Collection points	***Planning horizon***						
	0	1	2	3	4	5	6
2	■	■	■	■	■	■	■
6	■	■	■	■	■	■	■
16	■	■	■	■	■	■	■
17	■	■	■	■	■	■	■
23	■	■	■	■	■	■	■
33	■	■	■	■	■	■	■
39		■			■		
49	■	■	■	■	■	■	■
MaxV	70	135.248	119.9409	119.9409	135.8623	119.9409	119.9409

Table 5. The results obtained by solving the Model 2 (number of visits to collection points for *t=7* days and R_k*=50m.)*

Collection points	*Planning horizon*						
	0	1	2	3	4	5	6
1			■				
2	■			■			
3	■						
5	■			■			
10	■			■			
11	■				■		
13							
14		■			■		
16		■		■		■	
17	■				■	■	
18			■			■	
19		■		■			
20		■			■	■	
21	■	■	■	■	■		■
24			■		■		
26		■		■		■	
28		■					
34		■			■		
35			■		■	■	
36	■			■			
37	■						
38							
39	■						
40	■						
41			■				
42							
45			■				
46			■	■			
47	■						
MaxV	120	131.5626	130.5012	128.4323	124.1866	90.22104	11.67566

As can be seen from Tables 3, 4, and 5, the number of visits to collection points increases with the increase in radius of the catchment area. Having in mind that with the increase in radius of the catchment area, the number of collection points decreases, this sounds reasonable. This is relatively small numerical example, with no limitations in number of vehicles, their capacity or other realistic limitations, it must be noticed that for the t=21 days and R_k=50 m, optimal solution for scheduling couldn't be obtained in acceptable time.

5. CONCLUSION

Managing recyclables, in terms of minimizing the costs associated with their separation and transport and maximizing any value that can be gained through their recovery, is becoming a goal of increasing interest being part of integrated supply chain management strategies. In this paper, we proposed modeling approaches that can be used for modeling recycling logistics network. First, in order to correctly model the influence of distance between users and collection points on optimal locations, we introduced collection point's catchment area. Additionally, for determining optimal scheduling plan for collection of recyclables, we proposed the second mathematical model.

The results obtained give some answers to the problem in sense of indicating complexity and importance of the problem. Yet, numerous other aspects of the problem so as the application of the proposed approach need future research: defining catchment area as a function of socio demographic and other relevant characteristics of potential users; aggregation concept to be applied for grouping users, analyzed as a waste sources with objective to make model tractable in real systems; introducing real limitations in vehicle scheduling like capacity constraints, working hours, possible routes, etc.

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