EXAMINING PERFORMANCES OF RECYCLING PLASTIC NETWORK

Branislava Ratković [a,*], Milorad Vidović[a]

[a] University of Belgrade, Faculty of Transport and Traffic Engineering, Serbia

Abstract: *This paper examines performances of the logistics recycling system. We tested model that simultaneously determine collection points' locations with distance-dependent returns, location of intermediate consolidation points (transfer centers) and the route of the collection vehicle so as to maximize its profit from the collection of recyclables with different input parameters.*

Keywords: *logistics network, performance, recycling*

1. INTRODUCTION

Global plastics production has grown exponentially since the 1960s, reaching 311 million t produced in 2014, a twentyfold increase and it is expected to reach up to 1.2 billion t annually by 2050 (EU, 2016). Properties of plastic materials such as low cost, light weight and durability contributed to these numbers, but plastics materials are not inert and once in the environment it can persist for hundreds of years (EC, 2013). Almost 40% of plastics is used for packaging and in 2014, the EU generated about 25 million t of post-consumer plastic waste of which only 30% was recycled (http://ec.europa.eu/environment/waste/pdf/plastic_waste_factsheet.pdf).

In order to deal with packaging waste, especially plastics waste, European Union imposed several Directives aiming at reducing quantities as well recycling of different packaging waste streams such as Packaging Directive 94/62/EC and Framework Directive on waste 2008/98/EC. In Circular Economy Action Package (December 2015), European Commission proposed raising the recycling target for plastic packaging to 55%, and reducing landfilling to no more than 10% by 2030 (http://ec.europa.eu/environment/waste/plastic_waste.htm).

For achieving imposed recycling targets, it is necessary to establish logistics network structures. that will be convenient for end users (González-Torre and Adenso-Díaz, 2005, Garcés et al, 2002), because end users are responsible for separation of recyclables at their residence and carrying them to designated collection points (CPs). This paper presents extension of the research presented in paper Vidovic et al. (2016).

The location routing (LR) model for designing RN with profit proposed in Vidovic et al. (2016), has the following specificities. Location part of the model includes decisions of the positioning both CPs as a lower level of the network and transfer stations (TSs) at the higher level of the network. The revenue obtained from quantity of recyclables for specific CP is related with the proximity of the CP to the end users. So, we introduced distance dependent quantity of

* b.ratkovic@sf.bg.ac.rs

recyclables dropped off to CPs introducing collection rate as a function of distance. In this paper we examined recycling systems performance with different shape of function that correspond to collection rate *f(d).* Namely, we examined system's performance with different input parameter (collection rate function), that is we wanted to see if and how different shapes of collection function rate influences on system's performance.

From here, the paper is structured as follows. Description of the problem in Section 2. In Section 3 numerical results are presented, while Section 4 summarizes our findings and provides some thoughts regarding future research.

2. DESCRIPTION OF THE PROBLEM

Problem considered in this paper is the same as in Vidovic et al. (2016). That is, we considered a problem of designing of recycling plastic system in urban settlements (cities). Today's modern cities structures (block structure) gives an opportunity to address and formulate considered problem as LR problem, where vehicle routing part (VRP) of the LR problem is formulated as a multiple matching problem instead of classical VRP formulations. For mathematical formulation of the considered problem, reader is referred to Vidovic et al. (2016).

We will briefly describe the problem considered and solved in this paper. City blocks can be in a variety of sizes and shapes, characterized with buildings in which residents live and road network within. Term end user refers here to a building inside the specific city block (we aggregated residents to its residential building considering them as a single end user). Each end user is characterized by the volume of waste produced per day which corresponds to the total quantity generated in all households residing in a building. Potential locations of CP are characterized by its capacity and distances to all end users in each city block. Capacitated vehicle originating from transfer station (TS), performs a tour of visiting city blocks and collecting plastics located at CPs. The length of inner streets in city blocks may differ depending of the city block shape and size, but this length of the route through city block is always the same, regardless of the number of stops per CP. This fact enables us to route distance only from TS to city blocks, while route part when vehicle traverse city block is predetermined and included in routing costs. More importantly as stated this fact, gives us opportunity to formulate vehicle routing part of the LR problem as a multiple matching problem instead of classical VRP formulations. Also, we include idling time at each CP in costs calculation.

In order to model the influence of distance between end users and CPs on the collecting of recyclables, we assume that recyclables collection rate $f_d \in [0,1]$ is a known function of distance (figure 1.). This function models the influence of distance between end users and CPs, in way that collection rate is inversely proportional to distance (Berman et al., 2003). We define two characteristic distances *l* and *u* (l < u), between the end user and CP where *l* represents the lower and *u* upper bound of walking distance to CP for each end user (figure 1.). When the distance *d* from the end user to the closest CP is $0 \le d \le l$ then *f(d)=1*, while in case when $d \ge u$, *f(d)=0*. If the distance between the end user and CP is $l \le d \le u$.

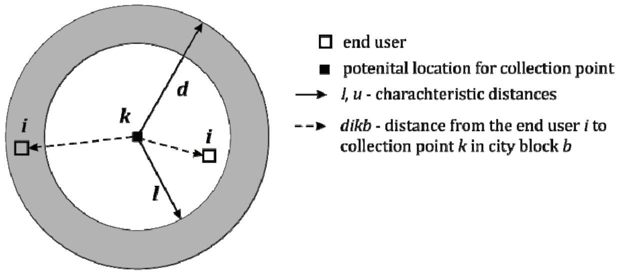


Figure 1. Characteristic distances between end user *i* and collection point *k*

In Vidovic et al. (2016) we assumed that the collection rate corresponds to linear function defined as $f(d) = \dfrac{u-d}{u-l}$. In this paper we examined system's performances with different shape of $f(d)$, that is we defined $f(d)$ as a step function. Different shapes of function f(d) are presented in figure 2, where step function is presented on the left side of the figure 2, while the linear function is presented on the right side of the figure 2.

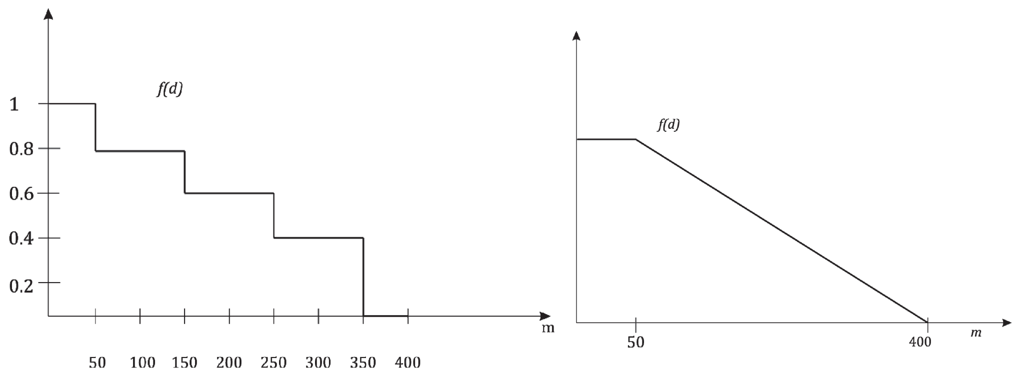


Figure 2. Different shapes of function *f(d)*

3. NUMERICAL EXAMPLE

Due to the complexity of proposed LR model, the instances that can be solved to optimality are typically of small size. So, we tested LR model only on the small instances of the problem, because we wanted to examine systems behavior with different input parameters. In this paper, as stated before, we changed the shape of the collection rate function *f(d)* from linear to step function. Input parameters for testing are presented in Table 1, while the results of the model are presented in table 2 and figures 3 and 4. Problem was developed using Python 2.7 programming language and solved by Cplex 12.6 software (IBM, 2012) on 64-bit PC Intel Core i7 machine with 2.8 gigahertz and 6 gigabyte RAM.

Table 1. Input parameters of the model

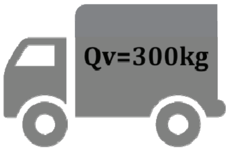
Input parameters	Small	
F_k(€/day)	0.5/0.8	
F_j(€/day)	0	
Costs per stop (€/per stop)	0.002	
revenue(€/kg)	0.12264	
Q_k(kg)	20	50
Q_r(kg)	300	600
l(m)	50	
u(m)	400	
Time horizon	7 days	
No. of city blocks	{4,5,6}	
No. of potential location for transfer points	2	
Number of residents in each city block	Beta (2,5) distribution in the range[48,200]	
Generated quantity of recyclables in (Q_{ib})	Uniform distribution (0.8;0.1)* P (P-% of plastics in municipal waste)	
Number of potential CPs	$(Q_{ib}/Q_k)+1$	
Distances between city blocks (m)	Randomly generated in the range [100,700]	
Distances between transfer points and city blocks (m)	Randomly generated in the range [1000,10000]	
Distances inside city blocks (m)	Randomly generated in range[400,1200]	
Distances between end users and potential locations for CPs	Beta (2,5) distribution in the range[15,400]	
Cost per km traveled (€/km)	0.0008 (inside the block x3)/	0.001(inside the block x3)
Number of end users in each city block (Randomly generated in the shown range)	[4,7]	

Table 2. Results of the numerical example

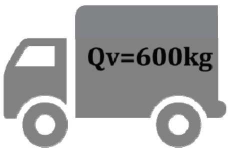
	No. of city blocks	Linear f(d)				Step f(d)			
Qv		300		600		300		600	
Qk		20	50	20	50	20	50	20	50
profit	4	35.84	39.55	36.31	40.26	35.84	38.76	36.31	39.47
	5	39.56	43.41	39.33	43.18	39.56	42.59	39.33	42.36
	6	50.81	55.48	50.08	54.75	50.81	54.66	50.08	53.92
collected recyclables (%)	4	94.65	98.78	95.98	98.78	94.65	98.80	95.98	98.80
	5	96.39	98.91	96.39	98.91	96.39	98.86	96.39	98.86
	6	96.84	99.13	96.84	99.13	96.84	99.10	96.84	99.10
Opened collection points (%)	4	95.24	47.62	100.00	47.62	95.24	52.38	100.00	52.38
	5	100.00	50.00	100.00	50.00	100.00	54.17	100.00	54.17
	6	96.67	46.67	100.00	46.67	100.00	53.33	100.00	53.33

As it can be seen from the table 2, In case of a container with the smaller capacity and a vehicle with the smaller capacity, obtained profit is the same for the different shapes of collection rate function. This can be explained with insufficient capacities of collection points as well vehicles, which detailed analysis of the results showed. In case of larger capacity of collection points and smaller capacity of vehicles, there are differences in obtained profit when it comes to describing collection rate as different functions. Profit decreases if the collection rate function is defined as step function instead of linear.

The same conclusion can be drawn for the all combinations of vehicle capacity and collection point's capacity (figures 3 and 4). Namely, when *f(d)* is defined as step function, larger quantities of recyclables are collected but in the same time larger number of collection points are opened, which results in slightly lower profit than in case of linear function rate. Since the routes are the same, that is transportation costs are the same in both cases of defining *f(d),* it can be concluded that obtained profit highly depends on the shape of the *f(d).* This fact suggests that detailed research on recycling behavior for certain region or city is needed for describing recycling attitude of end users correctly and in that way defining *f(d)* in proper and specific shape.

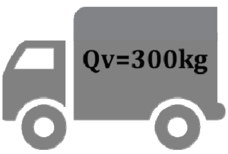


No. of city blocks	routes *Qk=20kg*	routes *Qk=50kg*	vehicle utilization *Qk=20kg*	vehicle utilization *Qk=50kg*
4	Yts1_1_4_3	Yts1_1_4_2	99.08%	97.43%
	Yts1_2	Yts1_3	31.71%	39.08%
5	Yts1_2_4_5	Yts1_2_4_5	80.52%	84.43%
	Yts1_1_3	Yts1_1_3	67.58%	67.55%
6	Yts1_1_4_2	Yts1_1_4_2	93.55%	97.43%
	Yts1_3_6_5	Yts1_3_6_5	94.55%	95.13%

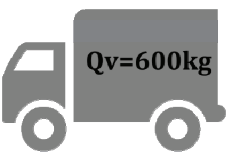


No. of city blocks	routes *Qk=20kg*	routes *Qk=50kg*	vehicle utilization *Qk=20kg*	vehicle utilization *Qk=50kg*
4	Yts1_1_3_4_2	Yts1_1_3_4_2	66.32%	68.25%
5	Yts1_1_3_4_5	Yts1_1_3_4_5	60.45%	58.19%
	Yts1_2	Yts1_2	15.54%	15.86%
6	Yts1_1_3_5	Yts1_1_3_5	41.53%	41.51%
	Yts2_2_4_6	Yts2_2_4_6	52.52%	54.77%

Figure 3. Vehicle utilization in case of linear function collection rate



No. of city blocks	routes *Qk=20kg*	routes *Qk=50kg*	vehicle utilization *Qk=20kg*	vehicle utilization *Qk=50kg*
4	Yts1_1_4_3	Yts1_1_4_2	91.71%	97.45%
	Yts1_2	Yts1_3	39.08%	39.08%
5	Yts1_2_4_5	Yts1_2_4_5	80.52%	98.59%
	Yts1_1_3	Yts1_1_3	39.08%	67.52%
6	Yts1_1_4_2	Yts1_1_4_2	93.55%	97.45%
	Yts1_3_6_5	Yts1_3_6_5	94.55%	95.04%



No. of city blocks	routes *Qk=20kg*	routes *Qk=50kg*	vehicle utilization *Qk=20kg*	vehicle utilization *Qk=50kg*
4	Yts1_1_3_4_2	Yts1_1_3_4_2	66.32%	68.27%
5	Yts1_1_3_4_5	Yts1_1_3_4_5	50.46%	60.10%
	Yts1_2	Yts1_2	15.86%	15.86%
6	Yts1_1_3_5	Yts1_1_3_5	41.53%	41.45%
	Yts2_2_4_6	Yts2_2_4_6	52.52%	54.80%

Figure 4. Vehicle utilization in case of step function collection rate

4. CONCLUSION

This paper examines recycling network performance for plastics waste. This research represents extension of research published in Vidovic et al. (2016), devoted to the collection rate function impact. We examined system's performance with different input parameters (collection rate function), that is we wanted to see if and how different shapes of collection function rate influences on system's performance. Although we tested model on small instances, results shows that different shapes of collection rate function strongly influences on obtained profit. Hence, in modeling and solving real and practical problem of collection plastics waste, it is crucial to define collection function rate as a function of socio-economic characteristic of the modeled region. Future research should be focused on precise estimation of plastic's wastes quantities in way that they are not modeled as deterministic parameters, then integrating plastic's waste flows with other recyclables, and modelling those systems, etc.

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