ASSESSING THE EFFICIENCY OF SOLID WASTE COLLECTION SERVICES IN BRAZIL

R.G. SOUZA, M.P.E. LINS AND R.A.B. VALLE

Department of Production Engineering, Federal University of Rio de Janeiro - Cidade Universitaria, Centro de Tecnologia, Sala F-105 - CEP 21941-972, Brazil

SUMMARY: Different contexts of cities and operational environment lead to different scenarios of public waste collection services, which may reflect on variations of their relative efficiencies. In this paper, we make a comparison of the relative efficiency of waste collection services in Brazilian state capitals and cities with more than 500 thousand inhabitants. The complexity of the problem is explored in a conceptual map, which reveals relevant inputs and outputs variables. We determine the relative efficiencies of the cities' waste collection systems using Data Envelopment Analysis (DEA) Models, VRS input oriented and then investigate their association with cities' population range, as well as juridical nature of waste management entities. Results indicate that there are few efficient systems, amongst them Londrina and Sorocaba stand out. Public companies were the most efficient ones, as well as systems of cities with population from 500 to 750 thousand inhabitants.

1. INTRODUCTION

UN-HABITAT (2010) recognizes that waste collection services are a fundamental service which is directly associated to health and urban quality of life. Besides that, their efficiency is determined by variations in cities' context, as well as of the operational conditions. In Brazil, the expectations provoked by the recent National Policy of Solid Waste (established in 2010) can only be realized if waste management operational processes have their efficiency enhanced.

Assessing waste collection services' relative efficiencies, by using Data Envelopment Analysis (DEA), can bring relevant information to their managers, such as:

- in which aspects are these services actually inefficient;
- what is the relative importance of these aspects to the systems' efficiencies;
- what systems are the most relatively efficient and can be a reference to processes improvement;
- what can be improved in inefficient systems; and
- what are the efficient resources quantities to the actual production

There are still few experiences on applying DEA to waste management systems. Some recent

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cases are the assessment of: waste incinerators (Chen et al., 2010), reduction on industrial waste and air pollutants generation (Honma & Hu, 2009), and operational environment of waste management (Simoes et al., 2010). There is no published research regarding the assessment of waste collection services, and neither an application of DEA to waste management systems in Brazil.

This research compares the relative efficiency of waste collection services in Brazilian state capitals and cities with more than 500 thousand inhabitants. Then we analyse the possible association of efficiencies with cities' population range, and with the juridical nature of their waste management entities.

2. RESEARCH METHODOLOGY

This research was executed following these steps: problem structuring; data collection; formulation of DEA Models; execution of DEA Models; comparison and discussion. The softwares DEA Frontier and IDEAL (2010) were used to execute the Models.

2.1 Problem structuring by conceptual mapping

For the problem structuring we applied the technique known as conceptual mapping. Conceptual maps not only allow for eliciting and structuring the complexity of variables involved in a problem, but also for perceiving the problem's overall context. In quantitative methods we usually work with a specific set of aspects that are isolated from the problem's reality.

The conceptual map generated in this research represents definitions from the bibliography, about efficiency measurement on solid waste management (Den Boer et al., 2007; Gallardo et al., 2010; Larsen et al., 2010; Monteiro et al., 2001; Slack, 2002; UN-HABITAT, 2010; Vilhena, 2010). The map reveals that the aforementioned service's efficiency can be measured through a sort of social (like motivation, capacity and opportunity to population, work conditions, security level), economic (revenues and costs), environmental (like odour, noises and visual impacts, traffic provoked, occurrence of infectious diseases, adequacy of waste disposal) and operational indicators (efficiency, quality and productivity measures).

Knowledge of the complexity of variables leads to the selection of a small group of them, which we could use to formulate DEA Models. The criteria for this selection were, mainly, the availability of trusted quantitative data, but also, the representation of a specific subsystem of inputs and outputs within the waste management systems' complexity.

2.2 Data collection

The main database for this research was the Brazilian National System of Sanitation Information (Brasil, 2007), with data from the year of 2007. The scope of the research was the set of state capitals and Brazilian cities over 500 thousand inhabitants. Missing data was handled as follows: three cities were excluded from the sample and the remaining was supplied by the Brazilian Public Sanitation and Special Waste Organizations Association (Associacao Brasileira de Empresas de Limpeza Publica e Residuos Especiais, 2008) report. We executed the DEA Models considering 41 municipal waste collection systems (from now on called DMUs, or Decision Making Units, using DEA designation).

Waste generated quantities, as considered in the DEA Models, were calculated as following: we obtained the waste generation per capita through the ratio of the total waste collected and the total population supplied by waste collection services. This ratio was then applied to the total population.

Table 1. Inputs and Outputs of the DEA Models.

Inputs	Outputs
1. Total expenses with waste collection services (thousand R$/month)	1. Total of waste collected (ton/day)
2. Number of workers involved with waste management 3. Number of waste collection trucks 4. Total of waste generated (ton/day)	2. Population supplied by waste collection services (thousand inhabitants)

The variables considered for the DEA Models are informed in Table 1. It is important to report that these variables were scaled to 103, in order to facilitate the computational implementation, obtaining weights with similar order of magnitude, and favour the definition of weight restrictions.

2.3 Weight restrictions and DEA Models

We do not intend to present a theoretical explanation on formulating, executing and interpreting DEA models. For a better comprehension of DEA methodology, please refer to Thanassoulis et al. in Fried et al. (2008). We will focus on the particularities of the Models formulated in this research.

All Models were VRS input-oriented, what means that it is intended to obtain the same actual productivity of the DMUs, but with a minor use of inputs. The targets for inefficient DMUs were all projected on the Pareto-efficient regions of DEA frontier. The weight restrictions used are presented in Table 2.

These restrictions are based on Brazilian references on waste management (Monteiro et al., 2001; Vilhena, 2010). For example, R1 indicates that there are, usually, 2 to 5 workers per truck, considering that operating trucks must be 85% of total flee. R4 denotes the waste quantity that can be collected by each operating truck. They must be at least 4 tons times two turns per day, and in maximum 8 tons per three turns/day. R5 indicates that waste generated must be higher or equal to the waste collected amount. R6 represents the waste generation per capita that can be considered acceptable (0.1 to 1.5 kg/person.day), according to the literature. The other restrictions represent reasonable values to the relation of expenses and other inputs.

Firstly we ran a DEA Model without weight restrictions. Then, using the restrictions, we formulated and executed three DEA Models:

- Model 1: adopting all 41 DMUs, with absolute values for inputs and outputs;
- Model 2: adopting absolute values, but excluding the megacities (Sao Paulo and Rio de Janeiro);
- Model 3: adopting all 41 DMUs, but using per capita values.

We excluded the megacities in Model 2 in order to get a more homogeneous dataset, as their outputs values are outstanding, and they may behave as outliers on the DEA frontier, “stretching” it far from the other DMUs. In the case of per capita values in Model 3, we must explain that we are implicitly running a CRS model followed by a VRS.

Table 2. DEA Models inputs and outputs weights restrictions.

Restriction	Weights ratio	Minimum value	Maximum value
R1	Workers/Trucks	1.7	5.25
R2	Expenses/Workers	0.1	6.0
R3	Expenses/Waste generated	0.1	6.0
R4	Waste collected/Trucks	6.8	20.4
R5	Waste generated/Waste collected	1.0	1.18
R6	Waste collected/Population supplied	0.1	1.5

3. RESULTS AND DISCUSSION

Relative efficiencies were analyzed using an unrestricted and three weights-restricted DEA Models.

3.1 Unrestricted Model

The Unrestricted Model presented a large number of efficient DMUs: 31 out of 41 analyzed.

Besides, this Model allowed some variables to assume null weights (Table 3), what means that there are slacks between the value of the DMU input or output and its projected target on the efficient frontier. This way, DMUs that present an efficiency index equal to one (100%) in this Model are not Pareto-efficient, considering all dimensions of the frontier.

3.2 Weight-Restricted Models

Weight-restricted Models were programmed according to the definitions mentioned in 2.3.

One of the consequences of adopting restrictions was a better distribution of virtual weights – the relative importance of inputs and outputs for the efficiency, calculated by multiplying variables weights and respective values. Table 4 exhibits some virtual weights values for Model 1. In this Table, we verify that some variables (like the expenses in Palmas and the waste generated in Nova Iguacu) still have high virtual weights values. By the other hand, if we applied more severe restrictions, we would get less DMUs on the efficient frontier, while relaxing restrictions would yield even higher weight values.

3.2.1 DMUs Efficiency

Differently from the Unrestricted Model, there are few efficient DMUs in the Restricted Models: in Model 1, they are 7 out of 41 analyzed; in Model 2, 8 efficient DMUs; and in Model 3, only 2 DMUs. Two of the DMUs, Londrina and Sorocaba, were the only efficient in all DEA Models.

In general, the restricted Models presented a good coherence of results, in spite of their formulations particularities (Item 2.3). Figure 1 presents the relative efficiencies of the most efficient DMUs in the three Models. Figure 2 presents the efficiencies of the less efficient DMUs.

Greatest variations on efficiency values can be explained by the modifications on the efficient frontier, especially in Model 3. In the case of Sao Paulo, it occurred because, in Model 3, its population size was not determinant to its per capita outputs values. The same occurred to Palmas, which in Models 1 and 2 had some of the lowest inputs values, as it is the smaller city considered in this study (a state capital). Both the greatest values for outputs and the lowest values for inputs are relevant on determining the efficient frontier.

Table 3. Relative efficiency and variables weights of DMUS in the Unrestricted Model.

DMU	Efficiency (h)	Inputs Weights on the Efficient frontier			
		Expenses	Workers	Trucks	Waste Generated
Palmas	1.00	0.00000	0.00232	0.00000	0.00064
Fortaleza	1.00	0.00006	0.00000	0.00213	0.00000
Brasilia	1.00	0.00000	0.00001	0.00024	0.00017
Belo Horizonte	1.00	0.00006	0.00000	0.00207	0.00000
Porto Alegre	1.00	0.00014	0.00000	0.00495	0.00000
Goiania	0.993	0.00000	0.00000	0.00000	0.00083

Table 4. Relative efficiency and variables weights of DMUS in the Unrestricted Model.

DMU	Virtual Weights on the Efficient frontier					
	Inputs				Outputs	
	Expenses	Workers	Trucks	Waste Generated	Waste Collected	Population Supplied
Sao Paulo	35.7%	7.2%	0.3%	56.9%	54.9%	47.0%
Palmas	75.1%	15.1%	0.1%	9.6%	8.2%	6.0%
Porto Alegre	17.7%	18.7%	0.2%	63.4%	63.4%	61.2%
Sao Goncalo	27.7%	6.1%	0.3%	65.9%	65.9%	64.8%
Sorocaba	32.2%	7.1%	0.1%	60.5%	51.5%	48.6%
Londrina	22.0%	9.5%	0.2%	68.3%	68.3%	58.1%
Nova Iguacu	23.4%	4.6%	0.2%	71.8%	71.8%	36.9%

3.2.2 Validation of the Results

In some cases, it was possible to validate the results, based on technical references. Porto Alegre, one of the most efficient DMUs, has a waste management system that is a top reference for Brazilian cities, due to many aspects (Costa et al., 2006; Simonetto and Borenstein, 2007).

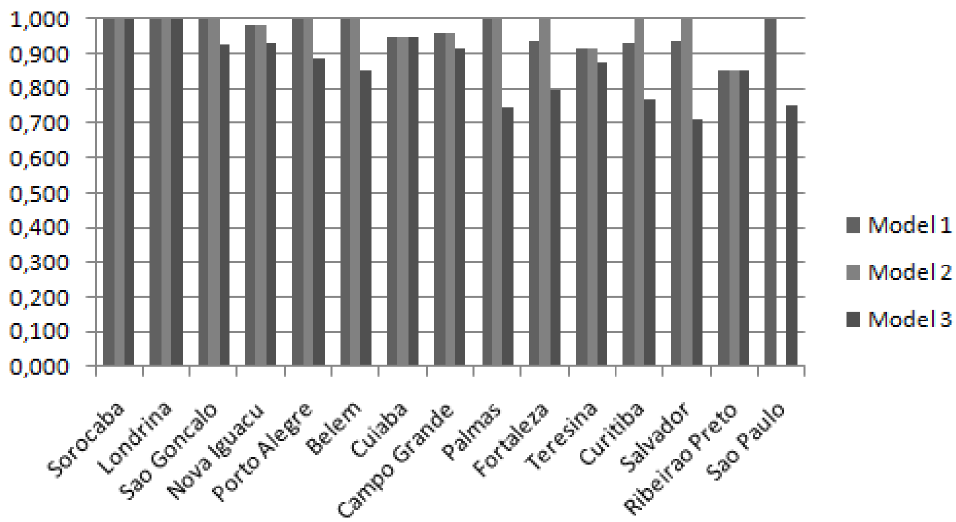

Figure 1. Relative efficiencies of most efficient DMUs in the three Models.

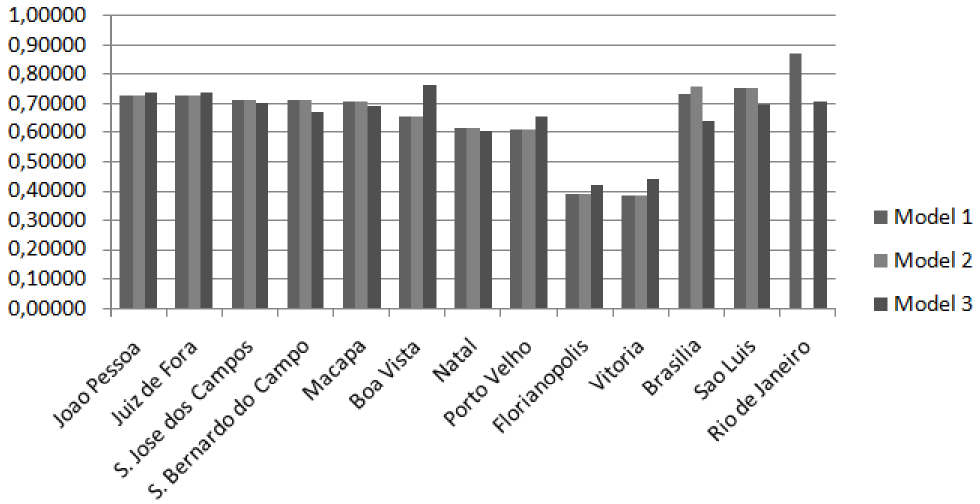

Figure 2. Relative efficiencies of less efficient DMUs in the three Models.

In particular, we assume that the efficiency in selective collection reflects on the whole waste collection service's efficiency. Porto Alegre is one of the few systems in Brazil with 100% of selective collection services supply. From 2008 to 2010, Porto Alegre was able to lower its selective collection unitary cost from US$ 159.41/ton to US$ 81/ton, while keeping the 100% population supply (CEMPRE, 2010).

Londrina was one of the top benchmarks of this study. In 2008, it had 85% of its population supplied by the selective collection services, at a relatively very low unitary cost (US$ 21.76 per ton, compared to US$ 159.41/ton in Porto Alegre and US$ 587/ton in Santos). As an efficiency indicator, in 2010 Londrina could expand its selective collection to 90% of population, while lowering the unitary cost to US$ 7.2/ton (CEMPRE, 2010).

3.2.3 Analysis by Population Size and Juridical Nature of Waste Management Entities

Concerning the population size of municipalities, greater average efficiencies of waste collection services occurred most in two population ranges: between 500 and 750 thousand inhabitants; and between 1 and 2 million inhabitants (Figure 3).

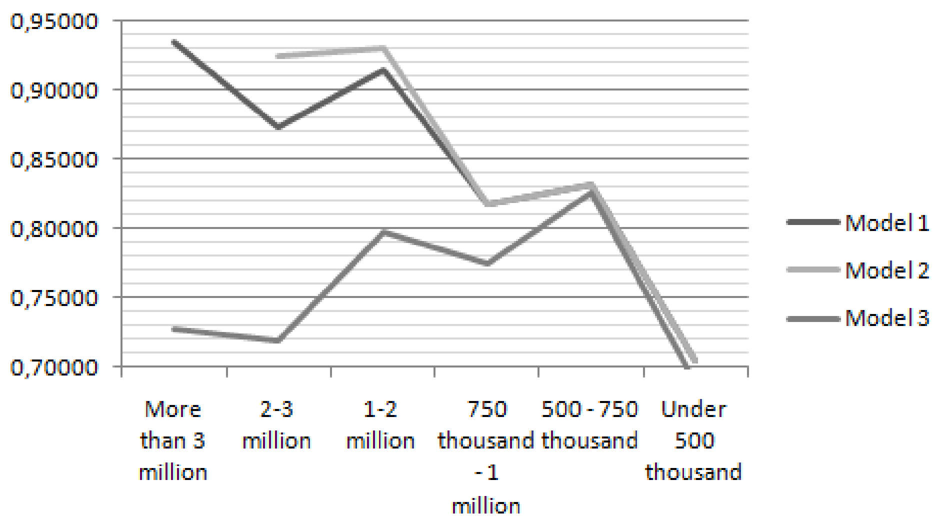

Figure 3. Average efficiencies of DMUs, according to their population size.

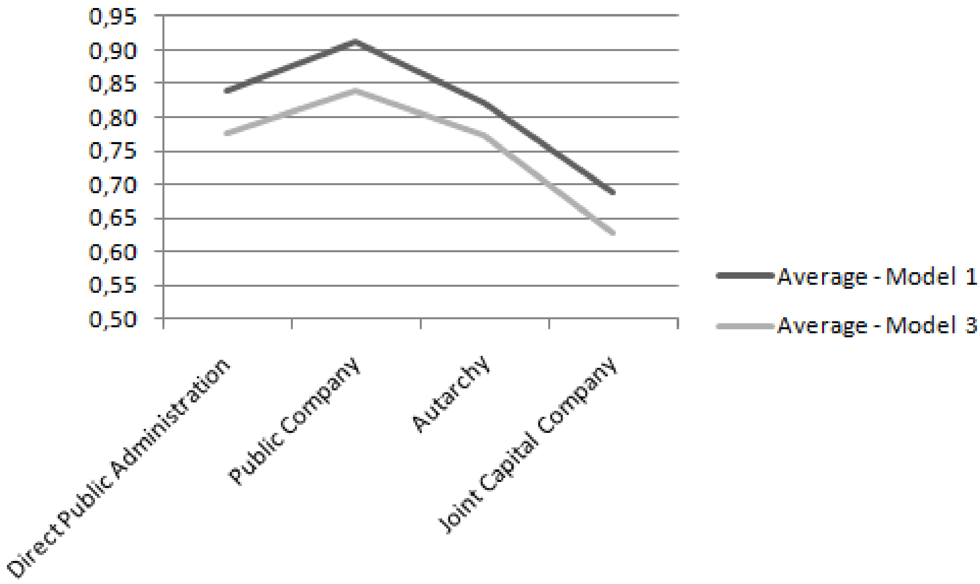

Figure 4. Average efficiencies according to the juridical nature of entities.

The first range can be considered the most consistently efficient, regarding all the three Models. The second range (1-2 million) was much more efficient in Models 1 and 2 than in Model 3, what can be explained by the population size and outputs values scale, as discussed in Item 3.2.1.

According to the juridical nature of waste management responsible entities (not only waste collection but the full set of processes from acconditioning to final disposal), we observe a good coherence of results in the Models, considering public companies as the most efficient ones. On the other side, joint capital companies with public administration were the least efficient entities (Figure 4).

4. CONCLUSIONS

In summary, the main conclusions of this research are:

- Restrictions used allowed a few number of efficient DMUs, but relaxed restrictions would allow excessive weights for some of the inputs and outputs;
- The classic DEA model, without restrictions, presented a large quantity of efficient DMUs, but allowed some of their inputs and outputs to assume null weights. Restricted models presented a short number of efficient DMUs, but did not present slacks to the efficient frontier;
- As a megacity, Sao Paulo was an outlier of Model 1, due to its outputs scale in comparison to other municipalities. The same holds for the inputs of Palmas, the smallest city;
- Londrina and Sorocaba were the only systems considered efficient in all models, and so they are the most interesting benchmarks for waste collection systems in Brazil;
- There is good coherence in the results of Models 1, 2 and 3, both for most efficient and less efficient DMUs;
- Observing the population size of municipalities, those in the range between 500 and 750 thousand inhabitants presented high consistent average efficiencies, considering the three

restricted Models. Those in the range between 1 and 2 million inhabitants presented the highest average efficiency in Model 1 and 2, and the second in Model 3, although displaying a large gap between these efficiencies, due to the outputs scale.

- Observing the juridical nature of municipal waste management entities, public companies were the most efficient, and joint capital companies the least efficient, in the three Models;
- Results in this paper are only related to the specific waste collection subsystem characterized by the set of inputs and outputs adopted. Changing the scope of the waste management subsystem would probably provoke variations on these results.

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