MODELLING PRODUCTION COSTS FOR PACKAGING WASTE
AND APPLICATION TO DETERMINE SOURCES OF SAVINGS

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ABSTRACT

The cost of municipal solid waste (MSW) management is rising quickly, especially after the development of collection of packaging waste in France after 1992. The main objective of the study, realized jointly by the CEMAGREF and ONYX, is to provide technical and economical evaluation of collection options of household waste (packaging, magazines-newspapers) for recycling, in order to identify the levers of actions for the decision makers and help them to choose the most appropriate technological system according to local situations. This model must answer to the need to understand the mechanisms governing the evolution of these costs. The stream of packaging waste will be divided into distinct solid waste activities: collection, transport, sorting, linked together by different waste flows. The interest of this study is on the one hand, to identify and evaluate the collection parameters, and on the other hand, to evaluate the organization system options for collecting packaging waste. Thus, this tool allows to simulate the economical influence of different packaging waste management options.

Keywords : Municipal solid waste; Packaging waste; Collection; economic costs; simulation.

INTRODUCTION

The control of costs is a main concern for the elected officials in charge of the supply of a service of quality at an acceptable cost by their fellow-citizens. However, in the particular context of waste management, costs are growing fast in particular because of the financial impacts of the collection's diversification, and environmental constraints of the treatment units. The search for savings thus becomes a legitimate concern which goes hand in hand with a questioning on the waste flows collection organization scenarios, in particular constraints imposed to the provider of waste services by the communities or the State (labour legislation) and on the level of service offered to the citizens. How, consequently, can we measure the impact of

2 ONYX is Veolia Environnement Waste Management division : http://www.onyx-environnement.com
3 Packaging waste designate now the whole packaging (plastics, glass, aluminium, metal, cardboard) and magazines-newspapers
these variables on the cost and define the influence of each operational lever in a
given territorial context? The present study proposes to examine these various
questions for the stream of packaging and newspaper-magazines waste by means of
designing and realizing a costs simulator which is based on the modelling of each
technical module of the integrated waste management: pre-collection, collection,
transport, sorting. This paper will be limited to the modelling of collection, often
presented like carrying savings.

BACKGROUND

The study of the collection service and of the costs linked is a topic which has been
approached many times. The work presented here belongs to the family of methods
which seek to represent the course of collection in a physical model. Among these,
one can quote the method of Stevens (1980) which assigns a crew to a vehicle, thus
limiting the possibility to rationalize the use of the vehicles. R. Tchobanoglous (1993)
gives a version which is based on the calculation of the various working times but
reference to a unit time of emptying of the containers, which requires to obtain sharp
data. A. Le Bozec (1994) proposed a method of calculation of the collection costs
taking account of the territorial constraints, but it requires also a link vehicle-crew
which does not take place any more with the legislative evolution over the working
time. Everett (1998) built a technical collection model which uses in particular the rate
of presentation of the bins and their rate of filling. However these rates are correlated
with seasonal or random factors and the model requires a vehicle equipped with an
embarked data processing to evaluate them. These various works show that it is
necessary to take better into account the territory and organization constraints which
the collection operators are confronted.

METHOD and DATA COLLECTION

Method

The construction of the collection model takes into account:
- the influence of the types of housing through a load waste indicator of waste
  presented to collection by year,
- the influence of the various technical levers, often imposed by the local
  communities,
- the impact of legal constraints on the collectors (legal limitation of work time,
  flexibility of employment of vehicles and staff),
- the economical evaluation with the real and updatable data on unit costs given
  by a private operator (ONYX group).

The indicator that we adopted to discriminate the various types of housing is the
kilometric load, CK, which represents the annual tonnage collected divided by the
length of the road to collected, independently of the frequency (Table1). This
kilometric load is calculated by the following formula on a given territory:

\[
CK = \frac{\text{Annual collected tonnage}}{\text{Total length of collection circuit}}
\]
Table 1: performance indices of collection

<table>
<thead>
<tr>
<th>Data necessary to calculate the indices</th>
<th>Symbol</th>
<th>Performance indices</th>
<th>Symbol</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Daily collected quantity (metric ton)</td>
<td>$Q_i$</td>
<td>Collection efficiency: $R_c$</td>
<td>$R_c = \frac{Q_i}{T_c}$</td>
<td>t/h</td>
</tr>
<tr>
<td>Daily collection time (h)</td>
<td>$T_c$</td>
<td>Kilometric load: $C_K$</td>
<td>$C_K = 52 \times c \times \frac{Q_i}{D_c}$</td>
<td>t/km</td>
</tr>
<tr>
<td>Daily collection distance (km)</td>
<td>$D_c$</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Collection frequency (week$^{-1}$)</td>
<td>$c$</td>
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</table>

The collection efficiency ($R_c$) is a function of the waste flow, the kilometric load, the size of the crew appointed to the vehicle, the type of bin, the type of vehicle. The kilometric load ($C_K$) is a function of the waste flow, the population density, the collection frequency, the type of collection (curbside or bring system), the bin capacity.

It is possible to link the collection performances, and in particular the collection efficiency $R_c$, with the indicator $C_K$. These curves of efficiency $R_c = f(C_K)$ are obtained on a type of housing for a given organization of collection. A terrain survey is necessary to define the function which links the type of housing, defined by $C_K$, with a collection performance represented by $R_c$ for a flow and a given collection organization. The example below (Figure 1) shows the evolution of the curbside collection efficiency of packaging waste collected in bags once per week (C1), on various types of housing.

Figure 1: Efficiency curves examples

Curbside, packaging waste, C1, bag

Data collection

The technical data were provided by ONYX which has a library of data resulting from collection follow-ups in various configurations of housing and collection organizations within the scope of its contracts. The recorded data relate to the various phases of course of the collection (Figure 2) on a daily circuit. These data are times, distances and quantities of collected waste.

The economic data relating to the time costs of the personnel are indexed on the values published by the French National Trade Union of the Activity of Waste
(SNAD). The data relating to the possession of the means of collection (containers, vehicles) and real productive annual times of the staff and the vehicles, taking account of the absences and maintenance, are extracted from the accountancy of ONYX.

MODEL DEVELOPMENT

The originality of the simulation model developed is to take into account both the territory constraints through kilometric loads of various flows (packaging, glass, newspaper, residual waste) and the organization constraints imposed to the operator. In particular, the legal work time limitation of personnel leads to break the link vehicle-crew. Thus, the organization of production means (crew, vehicle) becomes more complex and has a great influence on the collection production costs.

The five following steps of cost modelling are described below:
- territorial zoning of the community in territories where collection is homogeneous, then in sectors,
- technical modelling of the collection of a waste flow on one sector,
- waste flow collected aggregation on the various territories,
- estimation of needs in equipment and crew,
- direct costs calculation (for each waste flow) and associated direct costs calculation (for the community).

Zoning of the local authority

In order to use the collection efficiency curves, we have to cut the community into territorial units, named territories, where the collection organization is homogeneous. Each variation of a collection organization criterion determines a new territory. A territory is thus defined by a specific collection organization of a waste flow on a type of housing (urban, rural...).

For the needs of modelling, the territory itself is then cut out in sectors. A sector is the zone of collection served by a crew for one working day per shift with only one vehicle. The sectors of a same territory correspond to identical organizations of collection of a given flow waste. The sum of different territories represents the collection service of all flow waste on the whole local authority.

The calculation of the average number of trips \( N_t \) carried out by the vehicle to collect \( Q_{js} \) in the course of the day on a sector depends on the assumption on the mean filling rate of the truck \( (\tau_b)^4 \), so the equation is:

\[
N_t = \frac{Q_{js}}{\tau_b \times CU}
\]

But, this number of trips average \( N_t \) is limited by the comparison between the time of collection of the sector, \( T_{js} \), and the maximum daily working time of the crew, \( T_{mje} \).

This vehicle can thus collect each week the following quantity:

\[
Q_s = \frac{Q_a}{52} = (N_t \times \tau_b \times CU) \times c \times np \times ns
\]

\( \tau_b \): filling rate of the truck (0.90).

\( ^5 \) The trip is defined as the collection carried out by a crew between two emptying of the vehicle per shift.
With:
- Qs : quantity collected each week for a waste flow on a territory,
- c : collection frequency,
- ns : number of sectors on this territory,
- np : number of shift per day,
- CU : payload (t) of the vehicle full for a given flow of waste,
- Nt : number of trips per shift and per day,
- Qa : annual quantity of the waste flow collected on a given territory.

**Technical modelling of the collection : time and distance**

Collection costs depend on the two technical data which are the working times and the distance covered. Thus the problem is to model the collection over the theoretical day of work of the crew in a fine way according to the productivity of the crew and the characteristics of the territory (waste flow, CK) and to extend it to the week and year temporal periods. The same logic of analysis and modelling is applied for the two factors of production (personnel and vehicle), in particular to define times and various replacements (vacation, maintenance and breakdowns) according to various scales of time (day, week, year).

**Estimation of distances and time of collection of a flow on a sector (day period)**

The terminology which will be employed in the study to define the phases of a standard circuit is defined in figure 2. A collection circuit is decomposed into a phase of collection, subscripted c, and a phase of transport, subscripted h. Calculation is led over one theoretical day and centred on the vehicle collecting a flow of waste on a given sector (subscripted s).
Curbside collection

- Distance covered by the vehicle
  - Daily quantity to collect: \( Q_j = \frac{Q_a}{52 \times c} \)
  - Collection distance: \( D_{cj} = \frac{Q_j \times c \times 52}{CK} \)
  - Haul distance: \( D_{hj} = 2 \times Nt \times Dm \)
  - Daily distance: \( D_j = D_{cj} + D_{hj} \)

- Crew and vehicle working time
  - Collection Time: \( T_{cj} = \frac{Q_j}{Rc} \)
  - Haul Time: \( T_{hj} = 2 \times Nt \times \frac{Dm}{Vh} \)
  - Immobilization time: \( T_{ij} = T_f + Nt \times Tw \)
  - Daily time: \( T_j = T_{cj} + T_{hj} + T_{ij} \)

With:
- \( Q_a \): annual quantity
- \( c \): collection frequency
- \( Dm \): haul average distance to the recovery facility
- \( T_f \): Fixed time estimated
- \( Tw \): truck emptying waiting time

Drop-off collection

The modelling of the drop-off collection is identical and considers the assumption that speeds of way between containers are the same ones as speeds of transport, that is to say: \( V = Vc = Vh \). Collection time is thus given by:
- on the one hand, the sum of times spent to empty the containers
- on the other hand, the sum of times of haul between containers,

\[
T_{cj} = (N_{rj} \times T_{cr}) + \frac{D_{cj}}{V}
\]

With:
- \( N_{r} \): number of containers collected,
- \( T_{cr} \): time to empty a container,
- \( D_{c} \): collection distance.

Extension of the times and distances calculation at the week and year temporal periods

The calculation, previously carried out over one day for the collection of a flow on a sector, must be extended to the other temporal periods, the week and the year. Extension to the week is obtained by multiplication of the number of days of collection over the week, that is to say the collection frequency on the sector, then by 52 weeks for the year. In the event of seasonal variations, the model will be applied over periods having homogeneous characteristics of population, tonnage, frequency, that is to say an summer period and a sedentary period. It results from it that the crews working time to collect a flow over the week is: \( T_{se,j} = c \times T_j \).
These various times must be compatible with maxima employment times over the day and the week for the vehicles (Tmj\text{e}, Tms\text{e}) and the staff (Tmj\text{v}, Tms\text{v}), according to the number of days worked by the crew over the week, the number of days of use of the vehicles over the week and the legal limitation of crew work time per day.

**Extension on the whole local authority**

Consequently, crews (\text{e}) and vehicles (\text{v}) are lead to:
- on the one hand, work daily and weekly over different durations,
- on the other hand, be allocated at different flow waste collections over the week.

Then it is necessary to proceed by separated summation of times of crew work and vehicle use. Moreover, the zoning of the community into territories, then in sectors, leads to realize the territorial aggregation to define the total crew time to collect various flows of waste each week in three stages:

- Aggregation of \( ns \) sectors in a territory to collect one flow of waste: \( T_{s,e} = \sum_{s=1}^{ns} T_{s,e,s} \)
- Aggregation of \( nt \) territories of the community to collect one waste flow, over \( np \) shifts per day: \( T_{v,E} = \sum_{t=1}^{nt} \sum_{p=1}^{np} \sum_{s=1}^{ns} T_{v,e,s} \)
- Aggregation of the whole \( nf \) flows of waste collected on the community (\text{E}):
  \[ T_{E,E,f} = \sum_{n=1}^{nf} \sum_{t=1}^{nt} \sum_{p=1}^{np} \sum_{s=1}^{ns} T_{E,e,s} \]

The formulas are applicable in the same way for the calculation of distances covered and times of use of the vehicles, by replacing the index \( e \) by \( v \).

Crew annual time of work is then de:
\[ T_{e,E,f} = 52 \times T_{e,E,f} \]
Vehicle annual time of use:
\[ T_{v,E,f} = 52 \times T_{v,E,f} \]

Annual distance covered:
\[ D_{v,E,f} = 52 \times D_{v,E,f} \]

For the vehicles, the results aggregation to the whole flows of waste can thus be made only if the vehicles are interchangeable (an even number of compartments and loading methods) between various flows considered. If not, sums can be made only among the interchangeable vehicle.

**Estimation of vehicles and labour requirements**

The distances covered by the vehicles, the crew working times and the time of use of the vehicles allow us to estimate the needs in vehicles and crews to collect various flows of the community over the year, by confrontation with real annual productive times of the production means.

For the vehicles, the sum of unavailabilities (visits, maintenance, breakdowns) are fixed at 5 weeks per annum. The annual productive time of a vehicle or time of real use is equal to:
\[ T_{ma,v} = (4935^6 \times np)/2 \text{ in hours.} \]

The real annual crew working time is:
\[ T_{ma,e} = 1505 \text{ hours like annual productive crew working time, deducted of the paid holidays and various absences.} \]

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\(^6\) 4935 \text{ h/y} : \text{maximum time of use of a vehicle per year}
\(^7\) 7 \text{ h/d x 215 d worked (French legislation limits the weekly work to 35h)}
Crew needs
The crews are able indifferently to collect various wastes so, the total time of work on the whole flows of waste of the community gives the number of crews.

\[ N_{e,E,f} = \frac{T_{a_e,E,f}}{T_{ma_e}} \]

Vehicle needs
According to constraints imposed to the operator by the community, an estimation of the needs in vehicles is subjected to different rules of calculation.

- Case of the vehicles dedicated to a community or a waste flow (either reserved for a community, or incompatible between several flows) : the calculation of the number of vehicles to ensure the service is done for each type of vehicle.

\[ N_{V,E,f} = \frac{52}{47} \times \frac{\sum_{n=1}^{n_{fi}} \sum_{r=1}^{n_{s}} \sum_{s} (c_{s} \times n_{s})}{n_{p} \times n_{j}} \]

With : 
- \( n_{j} \) : number of days of collection,
- \( n_{fi} \) : waste flows of which vehicles are interchangeable,
- \( 52/47 \) : necessary vehicle stock

- Case of the not dedicated vehicles (either interchangeable between various flows, or usable on several communities) : the minimum number of vehicles necessary is :

\[ N_{V,E,f} = \frac{T_{a_v,E,f}}{T_{ma_e}} \]

Economic analysis
Two types of costs are defined :
- on the one hand, the production cost that expresses the costs engaged by the purchase and the use of the production factors that are the vehicle and the crew,
- on the other hand, the cost of the waste service, related to a community, that includes all direct and associated costs.

Here we only deal with the production cost. Direct costs are those generated by production equipments in the sense of production theory. Indirect costs, such as financial expenses, overheads and benefit, administrative expenses of the company, are not taken into account in these costs. The nature of costs and their aggregation result from the accountancy of the ONYX operator (table 1).

Collection production cost on a territory
The collection production cost of a flow on a territory is obtained by the formula :

\[ Cd = (A \times T_{a_e}) + (N_{V} \times a) + (c_{s} \times D_{a_e}) + (T_{a_e} \times l_{e})^{8} \]

\[ l_{e}^{8} \text{ : hour cost of a crew } (l_{e} = \frac{aL}{T_{ma_e}}) \]
Collection production cost on a community

The collection production cost on a community is given by:

\[
C_p = \left( \sum_{n=1}^{n_f} \sum_{t=1}^{n_t} C_d \right) + C_i = \left( \sum_{n=1}^{n_f} \sum_{t=1}^{n_t} C_d + CI \right) \times \delta
\]

Table 1: Production cost composition

<table>
<thead>
<tr>
<th>Fixed costs: CF</th>
<th>Variable costs: CV</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Capital cost</strong></td>
<td></td>
</tr>
<tr>
<td>Vehicle amortization</td>
<td>( A = \frac{I_v}{d^9} )</td>
</tr>
<tr>
<td><strong>Operating cost</strong></td>
<td></td>
</tr>
</tbody>
</table>
| Vehicle: insurance, inspection | \( a \) | - Maintenance
| Staff: salaries, clothes, bonus | \( \frac{L^{10}}{\alpha} \) | - Consumption
| | | - Tires
| | | - Supervisory and managerial staff
| | | - Taxes (TP, organic)
| | | - CI (€/year) et \( \delta \) (%)

**APPLICATION and DISCUSSION**

The model developed in the simulator relates to the treatment production costs of the packaging and newspaper-magazines flows and that of the residual household refuse. The data-processing tool makes it possible to carry out the following approaches in order to optimize and to assess the costs:

- to evaluate the economical impact of a technical lever,
- to evaluate, in a given situation, different possibilities of changes among one or many technical activities (pre-collection, collection, haul, sorting),
- to simulate various organization scenarios (current or prospective) of the group of activities at the community scale.

**Technical levers influence on the collection costs**

The study of the levers influence on the production costs of the packaging collection shows that the major levers are: collection mode (curbside, drop-off), frequency, type of container and crew composition and to a lesser extent the type of body vehicle (mono or bi-compartments). The number of shifts and the vehicles, dedicated or not, don’t have a significant effect on the costs.

**Scenarios organization simulation**

The economic estimation of the combination of the levers in prospective scenarios, starting from basic scenarios, was studied on various sizes of communities combining various types of housing (rural, suburban, urban, dense urban). This reveals that:

- Transport is less than 5 % of the total direct costs,

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9 \( I_v \): Vehicle purchase; \( d \): vehicle life duration expectancy, (22 000 h for 1 or 33 000h for 2 crew work day per day)

10 \( L = l_d + n_c \times l_c \): annual salary of a crew (one driver, \( n_c \) loaders)

\( l_d \): annual salary of the driver; \( l_c \): annual salary of the loader
- Collection and sorting have an equivalent part on the total direct costs,
- Collection organization have a sensitive impact on the sorting costs,
- According to the scenarios and the communities, the direct collection costs can decrease up to 20 % and those of the sorting can be divided by a factor 3 with the favour of the economies of scale (great capacity, not dedicated to a flow, automation on a commingled flow),
- A combination of the optimized technical modules can lead to profits going from 40 % to 50 % on the total direct costs.

CONCLUSION

This paper presents the collection modelling which is a part of a large model including the collection, transfer and sorting of various waste flows (packaging, newspaper, glass, residual waste). The technical model is based on the relation linking the collection efficiency with the collection kilometrical load. This relation was established with the observations of the collection performance on circuits corresponding to a given organization and for a given type of housing. A data-processing tool for simulation was developed, with the assistance of the know-how of a major operator (ONYX), that will allow the operators and the local decision makers to choose the technical organization on the basis of the economic analysis. The application of this model showed that significant sources of savings exist on the whole stream of domestic packaging waste, especially on collection activity. The use of this tool, produced on French data, is transposable to all countries, since the collection operator can obtain the necessary data from collection follow-ups.

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REFERENCES


