Scenario analysis for food waste recovery in logistic distribution

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Abstract: The present paper builds upon the study by Bottani et al. (2018). This previous work developed a routing and location (R&L) model under Microsoft Excel™ to determine the best location of a set of depots to collect the wasted food from the retailers in the Emilia-Romagna region (Italy) and to compute the cost of the resulting reverse logistics channel. The model was used to investigate different scenarios for the collection of wasted food and the results have shown that the minimum cost of collecting the food waste totals 123.68 €/ton and can be reached by limiting the recovery activities to 749 selected retail stores of the region. Exploiting the same R&L model, in this study we investigate four different configurations for the reverse logistics network of food waste. In general, the rationale behind these configurations is that to be cost effective, the food waste collection should primarily target the hypermarkets, as the retail stores that discard the highest quantity of food. Nonetheless, the number of retail stores considered can vary across the scenarios, with the purpose of identifying the minimum cost configuration. Results of this paper complement the findings of the previous research and allow deriving further useful considerations about the profitability of a reverse logistics channel for food waste recovery in the Emilia-Romagna region.

Keywords: Routing and location; food waste recovery; scenario analysis; reverse logistic.

1. Introduction

"Food waste" is any material intended for human consumption that is discarded, lost or degraded, and consequently no longer has any potential for consumption by humans (Parfitt et al., 2010; FAO 1981). Food waste may include both edible and inedible items (Buzby & Hyman, 2012). Scraps (e.g. banana peels) are inedible foods which represent the customary remains after consumption (Fehr et al., 2002); nonetheless, an entire banana can also become inedible, for instance due to human action or inaction. Food waste also includes a given amount of food that is no longer saleable yet still fit for human consumption (FareShare, 2011). This portion of food waste is sometimes referred to as food "surplus" and can be due, for instance, to cancelled orders, over-ordering, out-of-date promotions, insufficient shelf-life, damaged items or incorrect packaging (Betts & Burnett, 2007).

Food waste represents a significant loss of resources invested in food production, transport and storage (Beretta et al., 2013). Statistics from the Food and Agriculture Organization (FAO) indicate that about one third of the edible food produced globally for human consumption is lost or wasted along the steps of the supply chain (Gustavsson et al., 2011). Higher per capita values of food waste are generally observed in Europe and North America (95–115 kg/year), while lower values affect developing countries, such as Sub-Saharan Africa and South/South-East Asia (6–11 kg/year).

Wasting food raises both economic (Grizzetti et al., 2013; Graham-Rowe et al., 2014; Hyde et al., 2001), environmental (Buzby & Hyman, 2012; Tukker et al., 2006) and ethical (Godfray et al., 2010; Foley et al., 2011) questions; this is why the European Commission has issued a number of directives about waste management (Council Directive 75/442/EEC, Council Directive 91/156/EEC and Council Directive 99/31/EC).

It is recognized in literature that food waste could be diverted to channels alternative to disposal; examples of different use of wasted food include composting (Green, 1999), landfilling with methane capture for power generation (Schoen et al., 1999), charitable organizations (Alexander & Smaje, 2008), animal feeding (Vandermeersch et al., 2014), energy generation or composting (Nahman & de Lange, 2013).

Diverting wasted food to alternative channels firstly requires precise knowledge of the points in the food supply chain (FSC) where food waste is generated. Secondly, in order to make recovery channels efficient, collection, processing and redistribution processes need to be carefully designed, together with their connections (Alexander & Smaje, 2008; Ubeda et al., 2011). In turn, this design should consider both the structure of the reverse logistics channel and the distribution activities, thus requiring facility location and vehicle routing strategies, among others, to be taken into account. Indeed, while the forward channel of a food supply chain is typically defined in terms of the distribution network, the reverse channel often does not exist, especially in the event that food is no longer edible. It therefore actually needs to be fully designed. Moreover, compared to forward flow, the reverse flow of wasted food is more complicated because the food product recovered food from the retailers is likely to be very close to the expiration date (or just expired), which exacerbates the problem relating to food perishability and imposes strict time constraints on transport and storage activities (Amorim & Almada-Lobo, 2014; Dekker et al., 2012).

In line with the above consideration, Bottani et al. (2018) have developed a routing and location (R&L) model able to help design a reverse logistics channel for food waste. The model, developed under Microsoft Excel™, starts from the number of retail stores (RSs) in a given region and of the quantity of food waste discharged at each RS. As output, it provides the structure of the reverse logistics channel, in terms of the number and location of distribution centers (DCs), and the total cost of the reverse logistics activities, in terms of the transport and storage cost. In defining the location of the DCs, the model minimized the transport cost from RSs to DCs.

The previous study has proposed an application of the model to the context of the Emilia-Romagna region, and has provided, as output, a minimum total cost of approximately 124 €/ton. This result was obtained by setting a constraint on the number of RSs to be visited to retrieve food waste, depending on their distance from the DC and the amount of wasted food that could be retrieved from these RSs. The target cost to be achieved, however, was lower and accounted for approximately 100-120 €/ton, which corresponds to the cost for disposing food waste in landfill sites (Legambiente, 2013).

Moving from this consideration, in this study we try to explore additional scenarios for food waste recovery, with the purpose of decreasing the total cost of the system further. More precisely, the following scenarios are considered in this study:

1. A "base" scenario in which the food waste recovery is limited to the hypermarkets (who discard large quantities of food products), neglecting supermarkets and minimarkets;
2. A second scenario where the food waste is collected from the hypermarkets plus supermarkets and minimarkets close to the hypermarkets (in a range of 2 km);
3. A third scenario where, in addition to the retrieving activities of the previous scenario, the food waste is also collected supermarkets and minimarkets in a surrounding area;
4. A fourth situation where capacity and time constraints exist for food waste collection.

The remainder of the paper is organised as follows. The next section describes the context of this study. Section 3 details the scenarios considered and the main results obtained in this study. Section 4 discussing the main findings and concludes by summarising the main contributions of the study and the related limitations and potential improvements.

2. Context: the SORT project

The University of Parma, in partnership with another Italian university and several key companies (primarily food machine manufacturers and logistics operators), is currently developing a research project called SORT (Italian acronym for "Technologies and models to unpack, manage inventory and track wasted food"). The general aim of the project is to develop an integrated solution to efficiently manage the recovery of food waste in the FSC, focussing on the amount of packaged food waste generated by retail stores. In line with this aim, one of the project tasks was to design an efficient reverse logistics channel to recover, store, unpack and reprocess the packaged food waste. The Emilia-Romagna region, in the North of Italy, was selected as the starting point for this analysis (which is expected to cover the whole of Italy in the near future) as it is close to the location of most of the project partners. More precisely, it is known that the treatment plant of food waste will be located in the Emilia-Romagna region, close to its capital city of Bologna. However, a reverse logistics channel for food waste does not exist at present and needs to be completely structured.

Within the SORT project, the University of Parma has dealt specifically with the analysis of the logistics related to food waste recovery. At present, no recovery channels for packaged food waste exist in the Emilia-Romagna region; this wasted food is instead sent for disposal in landfill sites. Therefore, the preliminary step for designing the reverse logistics channel was the development of an R&L model, able to identify a suitable location of recovery facilities for the food waste, as well as efficient routes for the vehicles required to retrieve the wasted food from retailers and ship them to the treatment plant. This step is described in a previous publication (Bottani et al., 2018), where the R&L model is detailed. In the same publication, some preliminary findings on the economic profitability of setting up the reverse logistics channel were provided.

In the present study, we aim at extending the initial findings by exploiting the R&L model to investigate further scenarios for the functioning of the reverse logistics channel.

3. Scenarios analysis

In this section, we provide the analysis of various scenarios for the collection of food waste in the Emilia-Romagna region and for their shipment to the SORT facility. For all the scenarios, an evaluation of the cost of reverse logistics activities required to collect the food waste is provided.

3.1 "Base" scenario

The first scenario analysed is a "base" scenario in which the food waste recovery is limited to the hypermarkets, which typically who discard large quantities of food products; supermarkets and minimarkets are instead neglected.

The location of the DCs was determined using the model developed on Microsoft Excel™ and described in the previous publication. In locating the DCs, the model aims at minimising the total cost generated by collecting the food waste and shipping it to the DCs. Thanks to this tool, the total costs of the different scenarios can be easily compared. This also allows evaluating how many DCs should be added to the reverse logistics channel to minimise the total costs. The model was initially run setting different values of the number of DCs (from 1 to

10), with the purpose of identifying the minimum cost configuration of the "base" scenario. The number of DCs that returns the minimum cost will be kept unchanged also in the remaining scenarios, although the number of RSs visited in those scenarios will be higher.

Figure 1 shows the trend of the total cost as a function of the number of DCs. As can be seen from Figure 1, the total cost of the reverse logistics system varies from more than 4,100 [€/day] to approximately 1,600 [€/day]. The lowest value is obtained setting the number of DCs at 8; higher values do not bring savings, but rather the total costs remain constant or starts increasing.

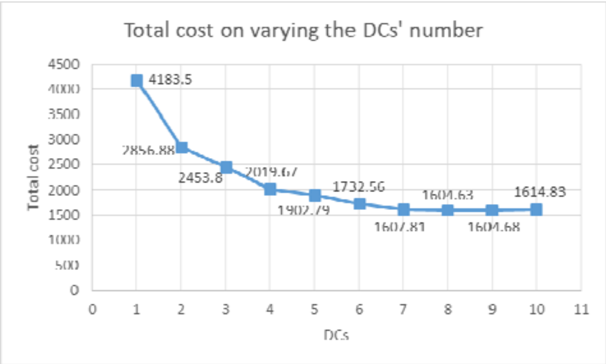

Figure 1: total cost [€/day] varying DCs number

On the basis of this result, the number of DCs has been set at 8. After determining their location, we computed the path that a vehicle should follow to visit all the hypermarkets close to each DC, using the Clarke-Wright (CW) algorithm (Clarke & Wright, 1964). For the sake of brevity, the detailed computation of the path of vehicles is omitted; interested readers can find details about the CW approach and its implementation in Bottani et al. (2018). The computation of the routes of the vehicles is performed for all DCs; as a result, the total distance of the path was estimated to account for 669.38 km. The costs generated by the recovery of food waste from the hypermarkets of the Emilia-Romagna region are displayed in Table 1. Unitary transport costs were derived from Ministero dello Sviluppo Economico (2015), and Ministero delle Infrastrutture e dei Trasporti (2014).

Table 1: total cost of the "base" scenario.

	Number of RSs	Distance covered [km/day]	Cost [€/day]
Hyper	49	669.38	687.46
DC–SORT	-	187.63	306.59
DC cost	-	-	400
Total	**49**	**857.01**	**1394.04**

With respect to the quantity of food discarded, it was appraised through questionnaires and direct visits to several RSs in the Emilia-Romagna region (see Bottani et al. 2018) that on average, this account for 120 kg/day for a hypermarket. In the present scenario, 49 hypermarkets can be visited for food waste recovery; therefore, the amount of food waste recovered account for 5.88 tons. Overall, the unitary cost for food waste recovery in this scenario is 237.08 [€/ton].

3.2 Second scenario

In the second scenario analysed, the food waste is collected from the hypermarkets (as per the "base" scenario) plus the supermarkets and minimarkets close to the hypermarkets. "Close" means in a range of ~2 km from the route that connects the 8 DCs to the hypermarkets.

To determine the supermarket and minimarket to be visited, we began by formulating the equations to describe the straight lines that form the routes of the different DCs. We then eliminated the RSs that are more than 2 km far from each straight line. Figure 2 shows the approach used in this scenario, where "H" shows the hypermarkets and "DC" the distribution centres.

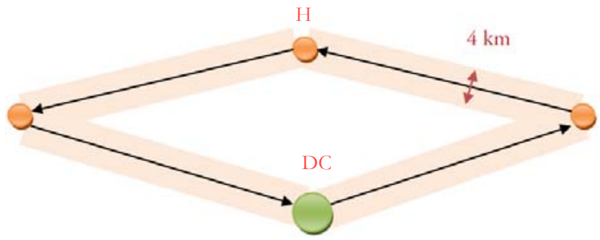

Figure 2: representation of the approach used in second scenario.

Following the approach described above, the hypermarkets, supermarkets and minimarkets that can be served are 49, 376 and 281, respectively (i.e. 657 RSs in addition to those of the "base" scenario). The quantity of food discarded accounts for 28 kg/day for a supermarket and 12 kg/day for a minimarket. Therefore, the amount of food waste collected in this scenario accounts for 13.9 tons/day. The cost generated by the recovery of food waste is shown in Table 2; as the table shows, the amount of food waste recovered account for 19.78 tons, therefore the unitary cost of collecting the wasted food in this scenario is 2008.26/19.78 = 101.53 €/ton.

Table 2: total cost second scenario.

	Number of RSs	Amount of food waste [ton/day]	Distance covered [km/day]	Cost [€/day]
Hyper	49	5.88	669.38	502.71
Super & Mini	657 (376 and 281)	13.9	1063.86	798.96
DC–SORT	-		187.63	306.59
DC cost	-		-	400

Total	**706**	**19.78**	**1920.87**	**2008.26**

3.3 Third scenario

Besides the retrieving activities described in the second scenario, in the third configuration the food waste is also collected from the supermarkets and minimarkets which are located close to the hypermarkets. By "close", we mean within a circumference of radius = 2 km from the location of the hypermarkets. Figure 3 shows the approach used to identify the RSs to be visited in this scenario.

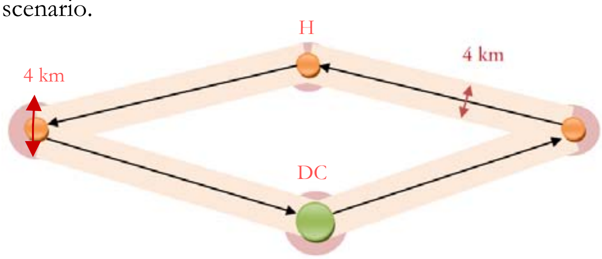

Figure 3: representation of the approach used in third scenario.

The cost generated by the collection of food waste in this scenario is displayed in Table 3. Overall, the logistic cost of wasted food recovered is obtained as for the previous scenario and accounts for 97.02 [€/ton].

Table 3: total cost third scenario

	Number of RSs	Amount of food waste [ton/day]	Distance covered [km/day]	Cost [€/day]
Hyper	49	5.88	669.38	502.71
Super & Mini	713 (309 and 404)	15.02	1089.79	818.43
DC–SORT	-		187.63	306.59
DC cost	-		-	400
Total	**762**	**20.9**	**1946.80**	**2027.73**

3.4 Fourth scenario

We recall that the in Italy, the cost of disposing the food waste in landfill sites ranges from 100 to 120 [€/ton] (Legambiente, 2013). If taking this value as benchmark, the results of the second and third scenarios appear as satisfactory from an economic pint of view. However, it is worth stressing that these results have been obtained without setting constraints about the capacity of the truck or time constraints. On the basis of these considerations, the fourth scenario describes a situation where capacity and time constraints exist for food waste collection.

Looking at the time constraints, it is hypothesized that a truck needs:

- 20 minutes to reach a RS starting from the depot;
- 30 minutes for unloading the product pallets and completing the administrative procedures at the DCs;
- 10 minutes for unloading/loading the pallets at the RSs and;
- 30 minutes for two breaks of the driver.

With these values, the maximum of RSs that can be visited in a day (*N*) is obtained as follow:

$$\frac{(8\,h/day * 60min/h) - (30+30)min}{(20+10)min} = 14.00$$

This means that no more than 14 RSs can be visited in a day. Looking at the capacity constraint, even if the RSs visited were all hypermarkets (which is obviously unrealistic), the resulting amount of food waste collected would be 14*120=1,680 kg on average, which is less than the truck capacity of 3,500 kg. Hence, if adding a constraint on the maximum number of RSs that can be visited daily, the capacity constraint is always met. Therefore, besides the hypermarkets on the route, a truck can visit a variable number of supermarkets and minimarkets, which will be equal to 14 minus the number of hypermarkets on its route. In this scenario, we have analysed two different situations: a first configuration in which both super and mini markets and considered, and a second one in which the supermarkets only are added to the hypermarket. Of these two situations, the most profitable one will be chosen.

The cost generated by food waste recovery considering the time constraints is shown in Table 4, as a function of the number of DCs. The unitary cost of collecting the wasted food, computed as average of the total cost of the DCs, accounts for 194.95 [€/ton].

Table 4: total cost considering constraints.

	DC1	DC2	DC3	DC4
Minimum cost [€/ton]	95.75	84.08	81.03	101.22
Food waste recovered [tons]	1.036	1.404	0.76	1.312
Cost of transport RS-DC [€/day]	99.19	118.05	61.59	132.80
DC cost [€/day]	50	50	50	50
Cost of transport DC–SORT [€/day]	38.32	38.32	38.32	38.32
Total cost [€/ton]	**180.99**	**146.98**	**197.25**	**168.54**

	DC5	DC6	DC7	DC8
Minimum cost [€/ton]	15.88	174.25	117.01	47.05
Food waste recovered [tons]	0.512	0.852	1.036	0.588
Cost of transport RS-DC	8.131	148.46	121.23	27.66

[€/day]				
DC cost [€/day]	50	50	50	50
Cost of transport DC–SORT [€/day]	38.32	38.32	38.32	38.32
Total cost [€/ton]	**188.39**	**277.92**	**202.27**	**197.25**

4. Discussions and conclusions

The present paper has focused on food waste recovery from RSs and builds upon a previous study by Bottani et al. (2018). By means of a simulation model developed in the previous paper, in this study we have investigated several scenarios for the collection of food waste in the Emilia-Romagna region. For all the scenarios, an economic evaluation of the cost of reverse logistics activities required for collecting the food waste is provided. The outcomes obtained in terms of the total cost and the amount of food waste recovered are summarised in Table 5.

Table 5: results as a function of recovery tons

Scenarios	"Base"	Second	Third	Fourth
Number of RSs	49	706	762	14
Recovery Tons	5.88	19.78	20.9	0.988
Total cost [€/ton]	**237.08**	**101.53**	**97.02**	**194.95**

From the outcomes in Table 5, several considerations can be made. Looking at the economic results, a first point is that the total cost of the "base" scenario is significantly higher than the cost of all the remaining scenarios. The minimum total cost is obtained in the third scenario and accounts for less than 100 €/ton. Nonetheless, in this scenario the number of RSs visited daily is very high; this implicitly assumes the presence (and therefore the availability) of several trucks for carrying out the retrieving activities. As this could not always be the case, in the fourth scenario we have added constraints on the maximum number of RSs that can be visited per day if only one truck would be available to retrieve the wasted food from the RSs. Therefore, in this scenario the number of RSs visited daily is significantly lower. It can also be observed that the total cost of the reverse logistics channel decreases progressively with the increase in the number of RSs and the amount of food waste recovered.

The results allow deriving some useful findings about the economic profitability of setting up a reverse logistic channel to collect food waste in the Emilia Romagna region. Future research can be directed to include the cost of the treatment plant in the analysis, to provide an overall evaluation of the collection and processing system of food waster in the targeted region.

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