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Network design of returnable food containers

by

Haokun Fu

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Wageningen University - Department of Social Sciences

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The purchase of food shipping containers and transportation costs account for a significant portion of the total cost of food transportation. By using returnable containers, the cost of purchasing new ones can be reduced. But at the same time, transportation costs increase due to the added reverse flow. Therefore, whether implementing a closed-loop logistics for returnable food shipping containers improves a company's financial performance is unclear. This research constructed two models to compare the results of them through four scenarios and gain insight on the impact of returnable containers used in the supply chain. Both objective functions are minimizing the total cost. Decision variables were set based on forward/reverse flow and echelon. The result turned out that the total cost of returnable model exceeds the total cost of disposal model by at least 20%, so a disposal waste tax on non-returnable food shipping containers is needed to improve the competitiveness of returnable containers. The purchase price of small containers has a decisive impact on the difference between the total costs of the two models. A critical value (q) was generated in each case. When the price of a small container is less than q, the total cost of the returnable model exceeds the total cost of the disposal model, and vice versa. The network designed in this research is different from other related articles. Future research could consider social and environmental dimensions.

Keywords: Returnable, Disposal, Food shipping containers, Closed-loop logistics

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Student	Haokun Fu
Registration number	1074636
MSc program	Master Food Quality Management
Specialisation	Quality and Food Logistics
Supervisor(s)	Dmytro Krushynskyi
Examiner/2nd supervisor	Rodrigo Romero Silva
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WAGENINGEN UNIVERSITY & RESEARCH

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1. Introduction

Compared with the transportation of other items, the requirements of food transportation are extremely high. Each type of food has its requirements for temperature and humidity (Food Standards Australia & New Zealand, 2021). Due to their short life cycle, perishability, and appearance requests made by customers, transporting them requires special conditions and equipment. Expensive assets such as refrigerators, plastic boxes, pallets, incubators, etc. are used as food containers during transportation (Food Standards Australia & New Zealand, 2021; Tornese et al., 2021). After the food is taken out, these containers are out of function and face the situation of being discarded. However, the costs of these returnable food containers are high, and if they are only used once, it is a huge loss and waste for both the product itself and the manufacturer (Schuermann & Woo, 2022). In addition to economic reasons, improper disposal of these containers can also harm the environment (Accorsi et al., 2022; John et al., 2018). These are why reverse logistics is required. Reverse logistics is a type of supply chain management that re-directs goods that are not needed by customers back to sellers or manufacturers (Jekins, 2021).

In many cases, logistics networks are designed for forward logistics activities without considering the reverse flow of returned products. However, the configuration of the reverse logistics network has a great impact on the performance of the forward logistics network since they share many resources, for example, transport and warehouse capacity. Since designing forward and reverse logistics separately leads to sub-optimal design in terms of cost and service level, the design of forward and reverse logistics networks should be integrated (Pishvaee et al., 2010; Verstrepen et al., 2007; Lee & Dong, 2008).

How to make returnable food containers positively impact the performance of the supply chain is a growing topic. It is one of the most essential strategic decisions in supply chain management. Decisions on the number, location, and capacity of facilities, and the quantity of flow between them affect costs. Effective and efficient network design can constitute a sustainable competitive advantage for companies (Meepetchdee & Shah, 2007; Pishvaee et al., 2010). A study by Schuermann & Woo (2022) shows the benefits of returnable containers and people's willingness to use them. Ferretti et al. (2018) and Goellner & Sparrow (2014) discuss the use of returnable food containers in the cold chain. However, these potential benefits are offset by various potential cost items, such as the initial investment in returnable assets and the additional shipping cost of empty containers. Therefore, it is unclear whether the implementation of a closed-loop supply chain for returnable food containers during transportation improves the financial performance of companies or not. This research will explore the economic effect of using returnable assets in food supply chains.

The objective of this research is to compare the structure and performance of two systems (returnable vs. disposal) by literature study and making mixed integer linear programming (MILP) models. The reason why the comparison of the two models was designed was to have a control group for the results of the returnable system, to see how the results of the two systems differ in the same situation, and to further understand the impact of returnable assets on the supply chain. According to the design of the two systems, both have reverse flow for big containers, only the flow for small containers is different. This is because big containers are too costly in the disposal system if they are used only once.

The main research question is:

How do returnable assets influence the structure and performance of the supply chain?

The sub-questions are:

1) What kind of food containers can be returned and what are their properties?
2) How to construct a network design model for returnable food containers?
3) What are the insights about the optimum structure of the supply chain?

This research considers a 3-echelon network with forward and reverses flows, production/recovery centers, distribution/inspection centers, customer areas, and container suppliers. The capacities of distribution/inspection centers are considered as well as known demands for the customers. The network is designed in a centralized manner.

Both fixed and variable costs are incurred by the central planning body. The size of the food container has an impact on transportation costs. Facility capacity, transportation amount, and location are three important factors that can cause differences in network performance. The objective of the model is to minimize costs.

The thesis is structured as follows: in Section 2, a review of the relevant literature is presented. The methodology, research design, and data description are described in detail in Section 3. Section 4 presents the returnable food containers' properties, while the constructed model designed for returnable food containers during shipping is shown in Section 5. The analysis of computational experiment results is indicated in Section 6. Section 7 provides critical discussions and conclusions about the comparison of the difference between the structure of this supply chain with and without returnable food containers. Finally, limitations and future research are included in Section 8.

2. Literature review

When searching for relevant literature, different combinations of core concepts and their synonyms were made (Table 1). The combinations were searched on Scopus, WUR Library, and Google Scholar.

Table 1 Core concepts of the research and their synonyms

Core concepts	Synonyms
Returnable	Reusable, Recycle
Food container	Food packaging, Shipping container/packaging, Transportation packaging
Network design	Supply chain design, Logistics design
Closed-loop	Integration/Combination of reverse logistics and forward logistics

Figure 1 shows after searching through keyword combinations, how articles are further screened. Language (English), publication year (after 2000), title, abstract, and research questions play important roles. The scientific literature or business articles finally adopted are closely related to this research.

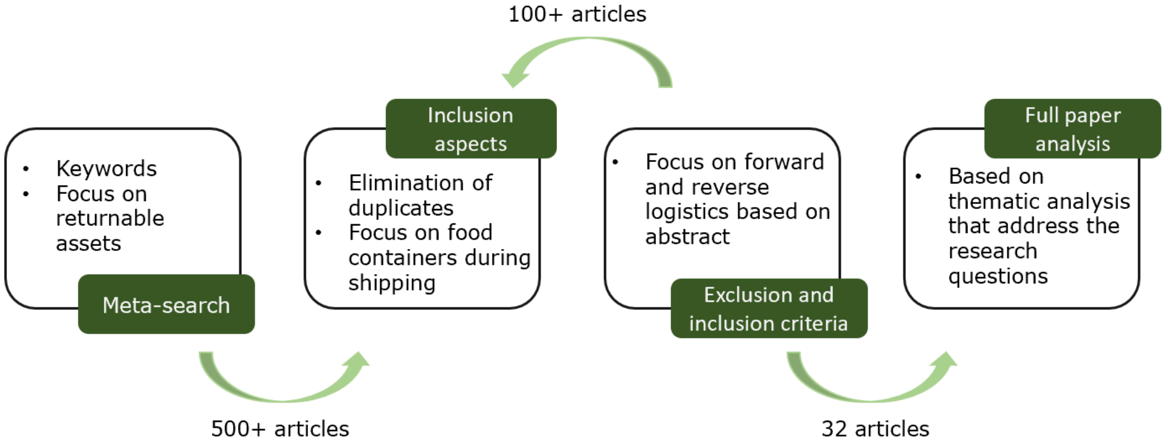

Figure 1 Screening process for literature searched

Sub-question 1 addresses what kind of containers can be called returnable food containers in this study. It locates and complements the overall research context. Sub-question 2 is the most important part of the research. It refers to articles with network design models to get insight on how to construct models this research needs.

The main references for this research are indicated in Table 2. There are articles about returnable food containers (used in supermarkets or homes), shipping containers, and other reusable products. However, there is a lack of articles, especially about returnable food containers during shipping. All related research is at a strategic level. The constructed model of this research integrates forward logistics and reverse logistics, which is a closed-loop network design model at a strategic level. A complete table of literature reviews related to model construction is shown in Appendix A.

Table 2 Review of literature related to returnable containers/packaging

Article	Year	Sector			Network design	
		Food packaging	Shipping packaging	Others	Reverse logistics	Closed-loop supply chain
Accorsi et al.	2020	√				√
Bortolini et al.	2018	√				√
John et al.	2018		√		√	
Pishvaee et al.	2010			√		√
Fleischmann et al.	2001			√		√

This study focuses on the construction of a network design model for returnable food containers during shipping and explores how returnable assets affect the optimal structure of the supply chain. Figure 2 presents the network conceptual model of this research. The numbers of production/recovery centers, distribution/inspection centers, customer areas, and container suppliers are not fixed (input for the model).

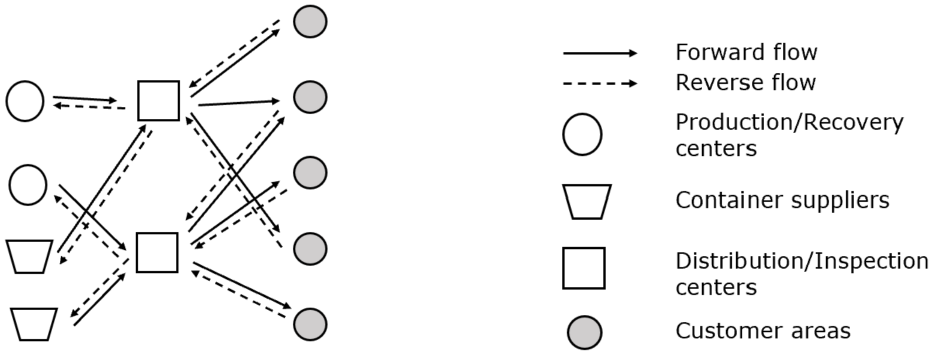

Figure 2 An integrated forward/reverse logistics network (Modified from Pishvaee et al., 2010)

3. Methodology, research design, and data description

Since there are big differences in the capacity and price of different sizes of food shipping containers, in the two models constructed in this research, the containers are divided into two types: big containers and small containers. As shown in Figure 2, in the forward flow, returnable food containers are transported from the production centers to the customer areas with the product through the distribution centers to meet the needs of each customer. In the reverse flow, returned containers are collected at distribution/inspection centers. From production centers to distribution centers, only big containers are shipped. From distribution centers to customer areas, only small containers are shipped. The same holds for the reverse flow.

The reason for this setup is to simplify the model. Although the total customer demands flow in the first echelon and the second echelon are the same, the number of facilities in the first echelon is less than those in the second echelon, in other words, more products are transported from one place to another in the first echelon. Therefore, set big containers transport in the first echelon and small containers transport in the second one.

After testing, small containers stay in distribution/inspection centers. Big containers are shipped back to production centers. End-of-life containers are shipped back to container suppliers. New containers are replenished by container suppliers. When container suppliers provide new containers, big containers and small containers are first delivered to the distribution centers. Then the big new containers return to the production centers together with the returning ones. The small new containers go to the customer areas along with the original ones stored in the distribution centers. Since these containers are not necessarily 100% returned during the reverse flow, there is a possibility of missing containers. Therefore, the container suppliers also need to make up this part when providing new containers.

With this strategy, the over-transportation of returnable containers that are no longer usable can be prevented. The container suppliers will add new containers to the production centers and distribution centers according to the loss in the cycle, so there is no need to worry about running out of containers. This network is a closed-loop logistics network since the returnable containers are inserted into the forward network and considered the same as the new one.

MILP model was applied. We created a model applicable to the research project by referencing existing models in the relevant literature. Computational experiments were performed to answer what are the differences between a situation with returnable assets and one without returnable assets. The realistic numbers (such as purchasing cost, operational cost, transportation cost, etc.) were brought into the model and calculated in the software (FICO Xpress). FICO Xpress software is a platform for developing optimized solutions, which provides many sophisticated and robust optimization algorithms. Among the solvers dealing with MILP problems, FICO Xpress ranks among the best (Jablonský, 2015).

4. Properties of returnable food containers during shipping

The food industry is increasingly interested in developing efficient and innovative solutions for quality assurance and sustainable distribution. One of the main factors influencing these critical aspects is packaging (Battini et al., 2016). According to Reusable Packaging Association (2020), a growing number of companies are investigating the costs and benefits of returnable transport packaging in their supply chains. Some of the benefits that companies hope to realize when using returnable food containers during shipping are reduced consumption of valuable resources, more efficient handling, and better protection of goods during transport (Iassinovskaia et al., 2017).

Food containers can protect food from physical, chemical, and biological external influences (Homestratosphere, 2018). They can be classified as disposable and reusable/returnable. The division of common types of food containers during transportation are pallets, boxes, totes, and refrigerated containers (Table 3). These simple containers support the transportation and storage of food products and facilitate the development of efficient standardized product handling and logistics systems used worldwide (Tornese et al., 2021; Mollenkopf et al., 2005).

Pallets, boxes, and totes are small containers. Refrigerated containers are big containers. For the same type of containers, the two biggest differences between different materials are reflected in the price and loading capacity. Whether it can be stacked has an impact on transportation costs. Foldability may have implications for reverse logistics. Common sizes and average prices for different types of returnable food containers during shipping are listed in Table 3.

Table 3 Different types of food shipping containers

Types	Materials				Stackable	Foldable	Standard Size (m)		Loading Capacity (kg)	Average Price (Euro)			
	Non-electrical			Electrical Appliances									
	Plastic	Cardboard	Wooden							Plastic	Cardboard	Wooden	Others
Pallets	√	√	√		Yes	No	(W*L)	0.8×1.2	500-1500	14	10	22	/
								1×1.2		17	11	26	/
Boxes	√	√	√		Yes	Yes	(W*L)	0.8×1.2	400-1000	200	12	145	/
								1×1.2		204	15	190	/
Totes	√				Yes	Yes	(W*L)	0.4×0.3	30-50	10	8	14	/
Refrigerated containers				√	No	No	(W*L*H)	2.4*3*2.6 10ft	10000-25000	/	/	/	3800
								2.4*6*2.6 20ft		/	/	/	4710

5. The network design model for returnable food containers during shipping

This section presents and explains the model with returnable food containers (5.1) and the model with disposable food containers (5.2), respectively. Notations used in the formulation of the two models are indicated in Tables 4, 5, and 6.

Table 4 Sets and indices

Description	Set	Index
Production/recovery centers	P	p
Distribution/inspection centers	D	d
Customer areas	C	c
Disposal centers	U	u

Table 5 Decision variables

Description	Notation
Quantity of containers delivered from p to d [pcs]	$X1_{pd}$
Quantity of containers delivered from d to c [pcs]	$X2_{dc}$
Quantity of containers delivered from c to d [pcs]	$Y2_{cd}$
Quantity of big containers delivered from d to u [pcs]	$Y3b_{du}$
Quantity of small containers delivered from d to u [pcs]	$Y3s_{du}$
Quantity of containers delivered from d to p [pcs]	$Y1_{dp}$
Quantity of new big containers delivered from u to d [pcs]	$X3b_{ud}$
Quantity of new small containers purchased in d [pcs]	$X3s_{ud}$
Open distribution center d [binary]	Z_d

'X' for the forward flow, 'Y' for the reverse flow;
'1' for the first echelon, '2' for the second echelon, '3' for the third echelon;
'b' for big containers, 's' for small containers.

Table 6 Parameters

Description	Notation
Distance between two locations [km]	d_ij (i,j ∊P∪D∪C∪U)
Demand by c [pcs]	dem_c
Capacity of d [pcs]	$capacity_d$
Fixed cost for d [€]	cf_d
Operating cost for d [€/pc]	co_d
Disposal cost for big containers [€/pc]	cdb
Disposal cost for small containers [€/pc]	cds
Transportation cost for big containers [€/(km*pcs)]	ctb
Transportation cost for small containers [€/(km*pcs)]	cts
Purchasing cost for big containers [€/pc]	cpb
Purchasing cost for small containers [€/pc]	cps
Conversion rate from big containers to small ones	rc
Return rate of big containers from distribution centers	rrb_d
Return rate of small containers from customer areas	rrb_c
Disposal rate of big containers	rdb
Disposal rate of big containers	rds

5.1 Model with returnable food containers: Model-R

The model constructed in this research is a single-period model, assuming that every period repeats itself. Before presenting the proposed mathematical model, we first provide a verbal description of the model as follows.

Minimize costs

= fixed cost + operating cost + transportation cost + container suppliers handling fee (disposal cost + purchase cost for new containers + transportation cost for new containers)

Subject to:

- Meet customer areas' demand
- Containers should be returned
- Capacity constraints
- Flow balance constraints

According to the notations (Tables 4, 5 & 6), the network design problem for returnable food containers during shipping can be calculated as follows:

$$\begin{aligned}\text{Min } W_1 = &\sum_d cf_d * Z_d + \sum_d \sum_c co_d * X2_{dc} \\ &+ \sum_p \sum_d ctb * d_{pd} * (X1_{pd} + Y1_{dp}) + \sum_d \sum_c cts * d_{dc} * (X2_{dc} + Y2_{cd}) \\ &+ \sum_d \sum_u d_{du} * (ctb * Y3b_{du} + cts * Y3s_{du}) \\ &+ \sum_d \sum_u (cdb * Y3b_{du} + cds * Y3s_{du}) \\ &+ \sum_d \sum_u d_{du} * (ctb * X3b_{ud} + cts * X3s_{ud}) \\ &+ \sum_d \sum_u (cpb * X3b_{ud} + cps * X3s_{ud})\end{aligned} \quad (1)$$

$$\sum_d X2_{dc} = dem_c \text{ , } \forall c \quad (2)$$

$$\sum_d Y2_{cd} = rrs_c * dem_c \text{ , } \forall c \quad (3)$$

$$\sum_p Y1_{dp} = rrb_d * \sum_p X1_{pd} \text{ , } \forall d \quad (4)$$

$$rc * \sum_p X1_{pd} = \sum_c X2_{dc} \text{ , } \forall d \quad (5)$$

$$\sum_u Y3b_{du} = rdb * \sum_p Y1_{dp} \text{ , } \forall d \quad (6)$$

$$\sum_u Y3s_{du} = rds * \sum_c Y2_{cd} \text{ , } \forall d \quad (7)$$

$$\sum_u X3b_{ud} = \sum_p X1_{pd} - \sum_p Y1_{dp} + \sum_u Y3b_{du} \text{ , } \forall d \quad (8)$$

$$\sum_u X3s_{ud} = \sum_c X2_{dc} - \sum_c Y2_{cd} + \sum_u Y3s_{du} \text{ , } \forall d \quad (9)$$

$$\sum_c X2_{dc} \le capacity_d * Z_d \text{ , } \forall d \quad (10)$$

$$\sum_c Y2_{cd} \le capacity_d * Z_d \text{ , } \forall d \quad (11)$$

$$\sum_c Y2_{cd} - \sum_u Y3s_{du} \ge 0 \text{ , } \forall d \quad (12)$$

$$Z_d \in \{0,1\} \text{ , } \forall d \quad (13)$$

$$X1_{pd}, X2_{dc}, Y2_{cd}, Y3b_{du}, Y3s_{du}, Y1_{dp}, X3b_{ud}, X3s_{ud} \ge 0 \text{ } integer \text{ , } \forall p, d, c, u \quad (14)$$

The objective function (1) minimizes the total costs including fixed opening costs, operating costs, transportation costs, disposal costs, and purchase costs for new containers. Constraint (2) ensures that all customer needs are met. Constraints (3) and (4) ensures the returned food containers from all customer areas are collected according to the return rate. Equation (5) shows the conversion from big containers to small ones and shows the flow balance at distribution centers. Equations (6)-(9) calculate not only the quantity of disposed food containers according to the disposal rate but also the number of new containers provided by the container suppliers. Constraints (10) and (11) are capacity constraints on distribution centers. Constraint (12) assures that the quantity of disposed small containers does not exceed the quantity returned to the distribution centers.

Finally, the corresponding decision variables are enforced to have restrictions on binary and non-negativity. These are indicated in constraints (13) and (14). The constraints listed above also prohibit the units of containers, returned containers, and end-of-life food containers from being shipped to closed facilities.

5.2 Model without returnable food containers: Model-D (disposable containers)

The goal of this model is the same as the one with returnable containers, which seeks the lowest costs for the company. The logic and elements that the two models contained are roughly the same. The only difference is that big containers are in the cycle, but small containers are single-use. There is no reverse logistics for small containers in this model, only forward logistics. For each new period, completely new small containers are purchased for shipping.

$$\begin{aligned} \text{Min } V_1 = & \sum_d cf_d * Z_d + \sum_d \sum_c co_d * X2_{dc} \\ & + \sum_p \sum_d ctb * d_{pd} * (X1_{pd} + Y1_{dp}) + \sum_d \sum_c cts * d_{dc} * X2_{dc} \\ & + \sum_d \sum_u d_{du} * ctb * Y3b_{du} \\ & + \sum_d \sum_u Y3b_{du} * cdb \\ & + \sum_d \sum_u d_{du} * ctb * X3b_{ud} \\ & + \sum_d \sum_u X3b_{ud} * cpb + \sum_d \sum_c X2_{dc} * cps \end{aligned} \tag{15}$$

$$\sum_d X2_{dc} = dem_c \text{ ,} \forall c \tag{16}$$

$$\sum_p Y1_{dp} = rrb_d * \sum_p X1_{pd} \text{ ,} \forall d \tag{17}$$

$$rc * \sum_p X1_{pd} = \sum_c X2_{dc} \text{ ,} \forall d \tag{18}$$

$$\sum_u Y3b_{du} = rdb * \sum_p Y1_{dp} \text{ ,} \forall d \tag{19}$$

$$\sum_u X3b_{ud} = \sum_p X1_{pd} - \sum_p Y1_{dp} + \sum_u Y3b_{du} \text{ ,} \forall d \tag{20}$$

$$\sum_c X2_{dc} \leq capacity_d * Z_d \text{ ,} \forall\, d \tag{21}$$

$$Z_d \in \{0,1\} \text{ ,} \forall\, d \tag{22}$$

$$X1_{pd}, X2_{dc}, Y3b_{du}, Y1_{dp}, X3b_{ud} \geq 0 \text{ } integer \text{ ,} \forall\, p,d,c,u \tag{23}$$

The objective function (15) minimizes total costs, including fixed opening costs, operating costs, transportation costs, and procurement costs for new containers. Constraint (16) ensures that all customer needs are met. Constraint (17) shows the quantity of returned big food containers collected from distribution centers based on the return rate. The conversion from large to small containers as well as the distribution center's flow balance is indicated in equation (18). Constraints (19) and (20) calculate the quantity of disposed and newly purchased big food containers. Constraint (21) is a capacity constraint on the distribution center. Constraints (22) and (23) show the corresponding decision variables are forced to impose constraints on binary and non-negativity.

6. Comparison of the two models in four scenarios

In this chapter, we present insights into the structure and performance of the supply chain by comparing the results of Model-R and Model-D in four scenarios. Four sections are developed around the results in the four scenarios.

Section 6.1 indicates the general situation (receiving, delivery, return, and purchase) of big and small containers under different distribution centers (DCs) when the return rate is 100% in four cases. After running both models, we found that changing the transportation cost has no explorable effect on the minimum total cost, but the purchase price of small containers does. All data analysis is constructed with a return rate of 100%.

In Section 6.2, three types of comparisons were used to compare the total costs of the two models. To facilitate the observation of trends in different scenarios, the ordinate of each type of comparison is unified:

1) Purchase price for big containers changes, price for small ones remains
2) Purchase price for small containers changes, price for big ones remains
3) Purchase price for both containers changes

Section 6.3 discusses the critical value for the purchase price of small containers when the total cost of Model-D exceeds the total cost of Model-R. Section 6.4, proposes a waste disposal tax on non-returnable food shipping containers, making the total cost of the Model-D higher than the total cost of the Model-R.

The reason why the four scenarios are arranged is to make computational experiments more diverse. s1 compares whether the optimal solutions of the two models are the same when the total demand of customers is less than the capacity of the nearest DC when a small number of facilities and customers exist. s2 changes the capacity of the DCs based on s1 so that the total demand of customers exceeds the capacity of the nearest DC. s3 adds a DC and a container supplier next to a customer that is far away from the production centers based on s2. These three scenarios are layered against each other and can be observed in how the two models change. s4 is set to see how well the two models operate when a larger number of facilities and customers exist. In s1 and s4, the number of facilities and customers are chosen randomly. Settings for distance and costs are realistic data (Appendix B). Descriptions of the four scenarios are listed in Table 7. Detailed data settings are presented in Appendix B.

Table 7 Information of the four scenarios

Scenario	**Description**	**Number of production centers**	**Number of distribution centers**	**Number of customer areas**	**Number of container suppliers**
s1	Total customer demand is less than the capacity of the nearest DC.	2	3	4	2
s2	Total customer demand exceeds the capacity of the nearest DC.	2	3	4	2
s3	Similar to s2, but with an extra DC and a container supplier close to a distant customer.	2	4	4	3
s4	Large number of facilities and customers exists.	6	15	30	3

6.1 General situations of big/small containers in the four scenarios

Both total costs of Model-R and Model-D consist of four parts:1) fixed cost, 2) operating cost, 3) transportation cost, and 4) container supplier cost. Table 8 shows the proportion of those elements in the total costs. The reason why such a small scale of fixed cost is that DCs’ fixed costs are set from 1500 to 3000 Euros. The price setting of 1500 to 3000 euros is because models are single-period and calculated monthly. In the computational experiment settings, each time a big container is transported, it costs 1000 Euros, and a small container costs 60 Euros. As a result, in each scenario, more than 99% of the total cost is transportation cost.

Table 8 The proportion of the fixed cost, operating cost, transportation cost, and container supplier cost in the total cost

Scenario	Model type	Fixed cost	Operating cost	Transportation cost	Container supplier cost
s1	returnable	0.01%	0.18%	99.74%	0.08%
	disposal	0.01%	0.27%	98.93%	0.79%
s2	returnable	0.02%	0.12%	99.80%	0.06%
	disposal	0.02%	0.15%	99.34%	0.48%
s3	returnable	0.03%	0.14%	99.77%	0.06%
	disposal	0.03%	0.17%	99.27%	0.53%
s4	returnable	0.01%	0.13%	99.78%	0.07%
	disposal	0.02%	0.17%	99.18%	0.63%

Figures 3, 4, 5, and 6 indicate the inflows and outflows of the distribution centers in Model-R. To check the data conveniently and intuitively, the return rate in the four cases is always set to 100%.

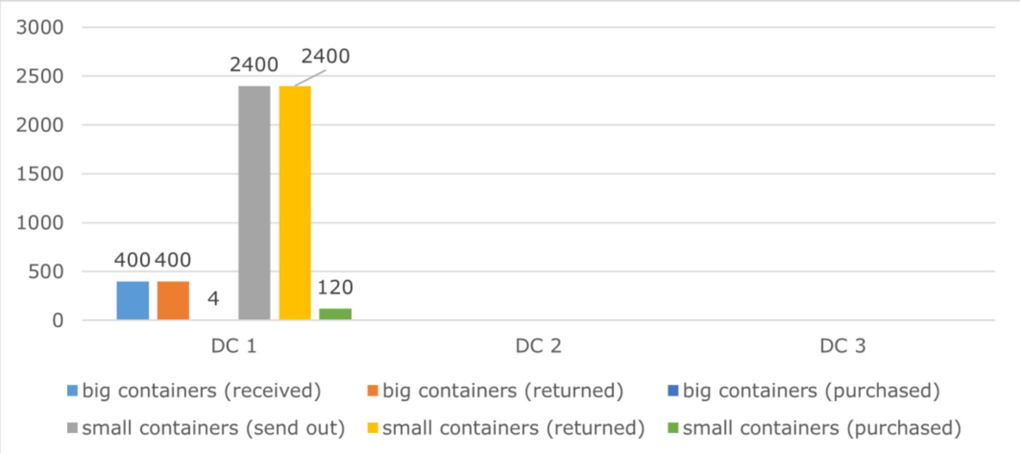

Figure 3 The flow of big and small containers in scenario 1-Model-R

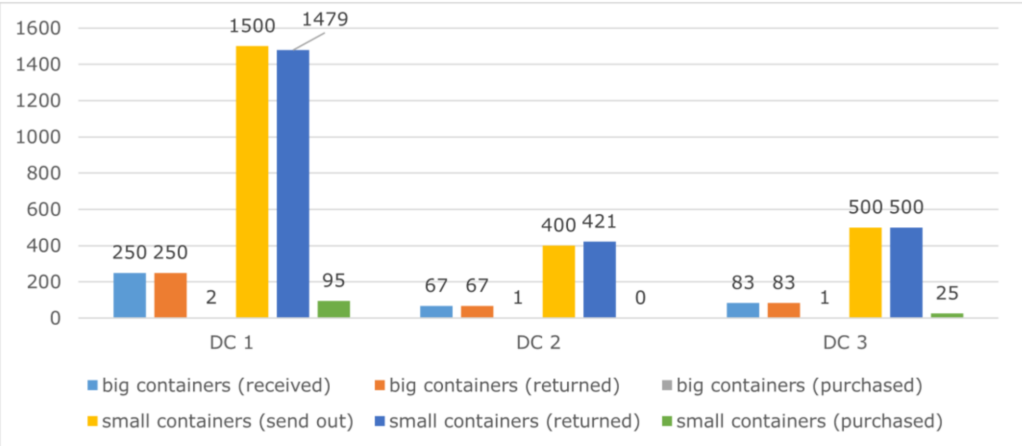

Figure 4 The flow of big and small containers in scenario 2-Model-R

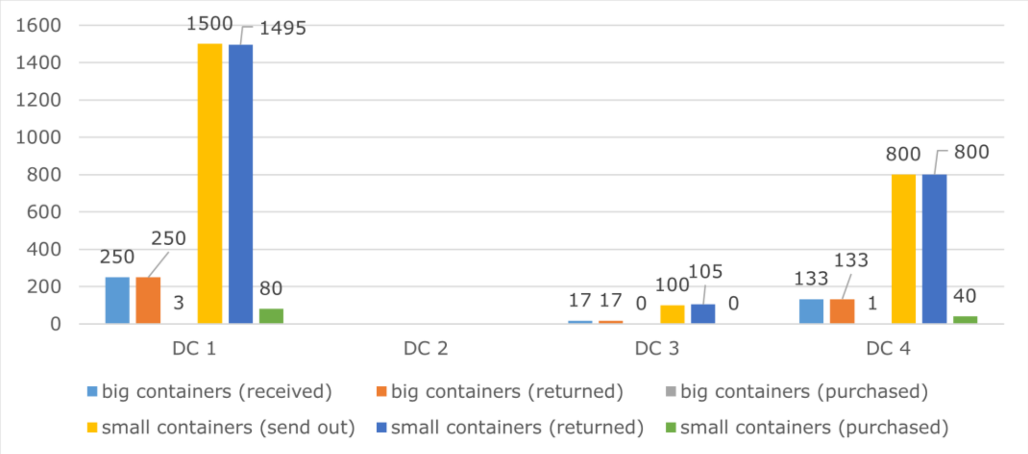

Figure 5 The flow of big and small containers in scenario 3-Model-R

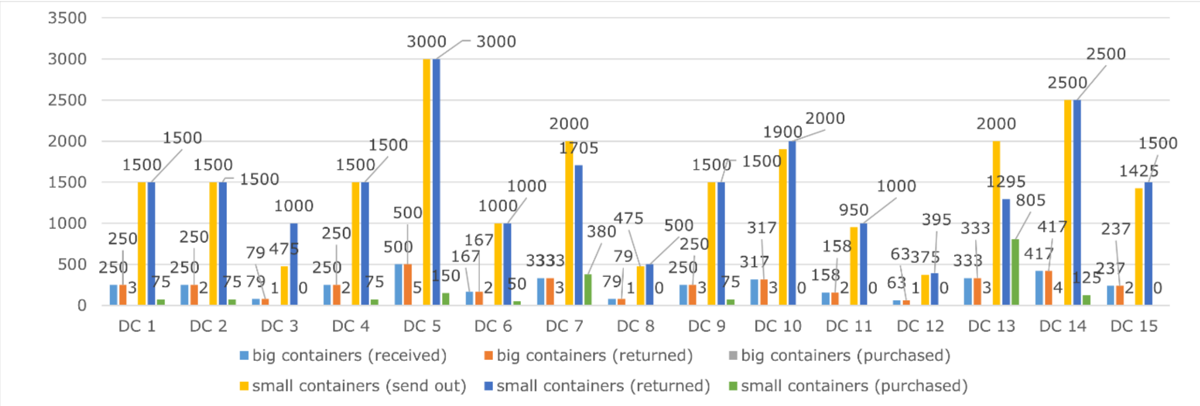

Figure 6 The flow of big and small containers in scenario 4-Model-R

All containers will be returned to distribution centers first, and then the containers that need to be disposed of will be screened. Therefore, at a 100% return rate, the total number of containers received should be equal to the total number of those sent out. After some of the containers are disposed of, the container suppliers will replenish the same quantity of new containers to the distribution centers, which means that the total number of newly purchased containers is equal to the total number of disposed of containers.

The more complicated the situation, the more often it will happen that the quantity of containers returned to a certain DC is larger than the number of containers sent by the DC. This is because the more facilities and customers there are, the larger the database of 'distance' factors, and the more options for commodity flow.

According to Table 9, the optimal solutions of the two models given by FICO Xpress are different after running. But that does not mean they cannot be used with each other. Since there may be more than one optimal solution, but only one of them will be given by the software, further verification is required to confirm that the optimal solutions required by the two models are different. The flow of big and small containers in s2 and s4 of Model-D are presented in Appendix C.

Table 9 Opened DC in two models

Scenario	Opened DC (Model-R)	Opened DC (Model-D)
s1	1	1
s2	1, 2, 3	1, 3
s3	1, 3, 4	1, 3, 4
s4	1 to 15	1 to 11, 13 to 15

6.2 Trend in total costs due to changes in the purchase price

During the calculation, the initial prices of big containers and small containers were set at 4500 Euros and 80 Euros. In this case, the total cost of Model-D is more than 65% of the total cost of Model-R in all four scenarios (Table 10).

Table 10 Total costs of Model-R and Model-D at a real-life purchase price of big and small containers

	Total cost (Euro)			
	s1	s2	s3	s4
Model-R	39,789,160	54,309,449	48,427,393	404,568,881
Model-D	26,752,600	43,736,100	40,170,433	308,929,983
Ratio (%)	67.2%	80.5%	82.9%	76.4%

The total costs of the two models were compared in the following three cases of changing the purchase prices of big and small containers. Since the trends of different scenarios are relatively similar in each comparison, only line charts of the total costs in s1 under the three types of comparisons are placed in the main content. The line charts of s2, s3, and s4 are shown in Appendix D.

In the first case (Figures 7 & 8), the price of the small container is 100 Euros, and the price of large containers increases proportionally. Whereas in the second case (Figures 9 & 10), the price of the large container is 6000 Euros, and the price of small containers increases proportionally. In the third case (Figures 11 & 12), the prices of both large and small containers changed proportionally. The purchase price of a small container is 0.016 times that of a big one, which is based on the real-life purchase prices of big and small food shipping containers (Table 3). Since whether use the price of a small container or the price of a big container as the abscissa will not affect the trend of the total cost, in Figure 9, the purchase price of the small containers is used for display.

The total cost of Model-R in all three types of comparisons and the total cost of Model-D in type 1 comparison increases with the purchase price of big or small containers, but not significantly. This is because expensive big containers do not require a large number of purchase costs since they enter the cycle, so they have little impact on the total cost. In the other two comparisons, the total cost of Model-D increases sharply with the purchase price of the small container.

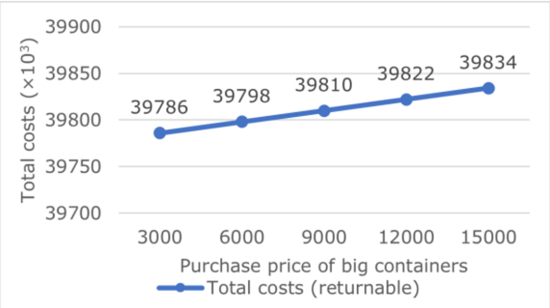

Figure 7 Total costs trend (returnable) when the purchase price for big containers changes in scenario 1

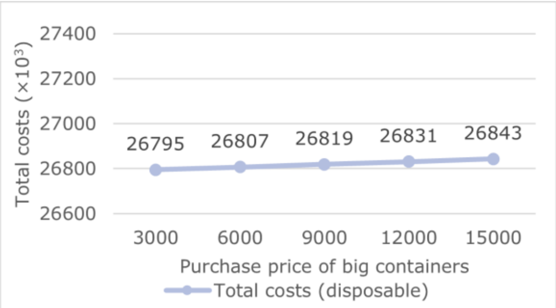

Figure 8 Total costs trend (disposable) when the purchase price for big containers changes in scenario 1

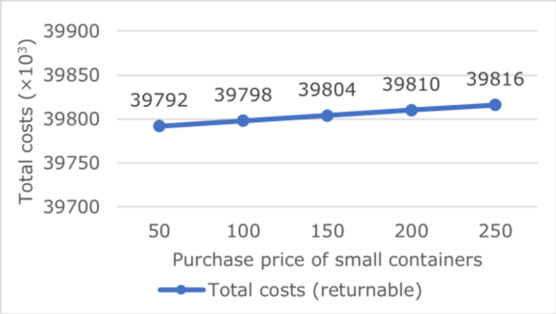

Figure 9 Total costs trend (returnable) when the purchase price for small containers changes in scenario 1

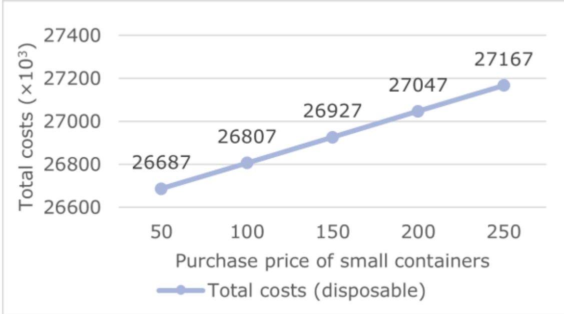

Figure 10 Total costs trend (disposable) when the purchase price for small containers changes in scenario 1

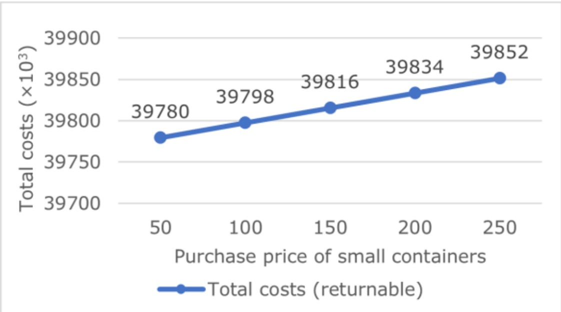

Figure 11 Total costs trend (returnable) when the purchase price for both containers changes in scenario 1

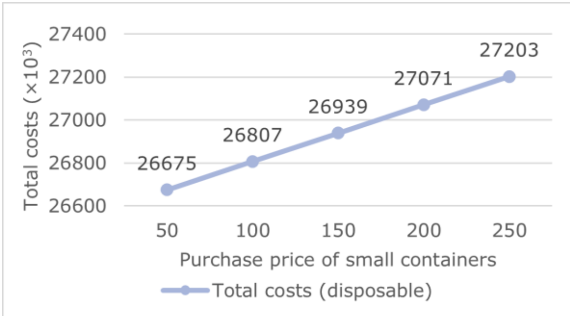

Figure 12 Total costs trend (disposable) when the purchase price for both containers changes in scenario 1

Table 11 was calculated based on Figures 7 to 12 and those figures in Appendix D. Calculated by using the slope formula, we find that the total cost trend is always linear regardless of the scenario, model type, or comparison type. Since the slope of each model is the same in each scenario, the trend is predictable. Table 11 shows that for the same model type under the same scenario, the difference in comparison (both changes) = difference in comparison (big change) + difference in comparison (small change).

Table 11 Increase in costs with a unit increase in container price

Scenario	Model type	Increase in costs (Euro ×10^3)		
		A unit increase in the purchase price of big containers	A unit increase in the purchase price of small containers	A unit increase in the purchase price of both containers
s1	returnable	12	6	18
	disposal	12	120	132
s2	returnable	12	6	18
	disposal	12	120	132
s3	returnable	12	6	18
	disposal	12	120	132
s4	returnable	111	55	166
	disposal	110	1105	1215

Definition 'a unit': For large containers, the scale of one unit is 3000 Euros. For small containers, the scale of one unit is 50 Euros.

6.3 Trend in the purchase price of small containers when the total cost of Model-D exceeds the total cost of Model-R

In both Model-R and Model-D, big containers are returnable, that is, they enter the cycle. The only difference is that small containers in the former one enter the cycle, however, the latter directly throws away the small old containers and buys new ones. This results in the purchase price of big containers not affecting the total cost difference between the two models, while the purchase price of small containers is a decisive factor.

After calculation, it is found that the purchase price of small containers has a critical value (q) in each scenario. When the price of the small container is less than q, the total cost of Model-R exceeds the total cost of Model-D; when the price of the small container is larger than q, the total cost of Model-R is less than the total cost of Model-D. The critical values of the four scenarios are indicated in Table 12.

Table 12 Critical value q in each scenario

Scenario	q (Euros)
s1	5800
s2	4800
s3	3700
s4	4700

6.4 Set a waste disposal tax rate for non-returnable food shipping containers to increase the use of returnable food shipping containers

Model-D does not take into account the cost of waste. But there must be someone to pay for the waste of nonreusable assets: the suppliers or the customers. The government can set taxes to regulate and further promote the use of returnable assets. In this research, it is assumed that the purchase prices of big and small containers used in Model-R and Model-D are the same. In other words, the fact that returnable containers are more expensive to purchase than non-returnable ones is ignored in this research.

If we want to fully promote the use of returnable food shipping containers at an economic level, that is, the total cost of the non-returnable model is more than the total cost of the returnable model, a waste tax should be levied on non-returnable containers.

When big and small containers are at the daily price (4500 Euros for a big one and 80 Euros for a small one), the tax rates in the four scenarios are from 20% to 40%. However, if we want to promote returnable containers when the tax rate is 0%, then in this case it does not depend on the total cost or other factors, but only on the critical value of the purchase price of small containers (Table 12).

Tables 13, 14, and 15 show the tax rate changes in different scenarios under different comparisons. With the increase in the purchase price of the containers, the tax rates are reduced, but not in an obvious way.

Table 13 Tax rate in the four scenarios when the purchase price of big containers changes

Price of big containers	Price of small containers	Tax rate s1	s2	s3	s4
3000	100	48.48%	24.05%	20.42%	30.78%
6000	100	48.46%	24.04%	20.42%	30.77%
9000	100	48.44%	24.04%	20.41%	30.76%
12000	100	48.42%	24.03%	20.40%	30.75%
15000	100	48.40%	24.02%	20.40%	30.74%

Table 14 Tax rate in the four scenarios when the purchase price of small containers changes

Price of big containers	Price of small containers	Tax rate s1	s2	s3	s4
6000	50	49.11%	24.37%	20.76%	31.22%
6000	100	48.46%	24.04%	20.42%	30.77%
6000	150	47.82%	23.72%	20.07%	30.33%
6000	200	47.19%	23.39%	19.73%	29.88%
6000	250	46.56%	23.07%	19.39%	29.44%

Table 15 Tax rate in the four scenarios when the purchase price of both containers changes

Price of big containers	Price of small containers	Tax rate s1	s2	s3	s4
3000	50	49.13%	24.37%	20.77%	31.23%
6000	100	48.46%	24.04%	20.42%	30.77%
9000	150	47.80%	23.71%	20.07%	30.31%
12000	200	47.14%	23.38%	19.72%	29.86%
15000	250	46.50%	23.05%	19.37%	29.41%

When the purchase price of small containers remains, the big one increases and the purchase price of big containers needs to be extraordinarily big to reach a 0% tax rate (Table 16). Raise the price from 3,000 to 300,000, the rate only decreases by 1% - 6% in the four scenarios.

Table 16 Tax rate in the four scenarios when the purchase price of big containers changes (the moment when the price of each big container reaches 300,000)

Scenario	Purchase price of big containers (Euros)	Tax rate (%)
S1	300,000	42.78
S2	300,000	23.41
S3	300,000	19.84
S4	300,000	26.9

7. Discussion & Conclusions

Sub-question 1 was answered by Section 4. According to Section 4, we know that commonly used returnable food shipping containers include pallets, boxes, totes, and refrigerated containers. The first three are listed as small containers and the last one is listed as big containers in this research. Due to the stackable and foldable nature of small containers, there is a possibility that more containers will be sent back on the same route than delivered.

Section 5 solved the question of how to construct a network design model for returnable food containers raised by Sub-question 2. To compare the impact of returnable food shipping containers on the supply chain network, Section 5 also provides Model-D. The difference between Model-R and Model-D is that the big containers and small containers in the former are all in the cycle, while in the latter, only the big containers are in the cycle, the small ones do not go through reverse logistics.

Sub-question 3 was settled in Section 6 by showing the insights about Model-R and Model-D. Section 6 is performed based on a 100% return rate, a 1% disposal rate for big containers, and a 5% disposal rate for small containers. Both return and disposal rates have an impact on the total cost as they relate to the quantity of new food shipping containers procured. A critical value occurs when only small containers are out of circulation. When the purchase price of small containers is higher than this value, the total cost of Model-R will always be lower than the total cost of Model-D, no matter how the purchase price of big containers changes. However, the values found for q are super big. If no actions are taken, it's almost always unattractive to use returnable containers. In this case, the government shall impose a disposal waste tax on non-returnable food shipping containers to increase the attractiveness of the returnable ones. But the tax would be enormous because of the big value of q, usually from 20% to 30%.

Sections 6.3 and 6.4 also tell that the purchase price of the small container is a decisive factor for the differences in total costs of the two models. If the government needs some reference when setting the waste tax of the non-returnable container, it is possible to get some inspiration by calculating the critical value (q) of the small container according to this research.

In network performance, not only is the critical value important but facility capacity and location also play essential roles. It is assumed that there is no capacity in the production center in this research, which means, as much as is needed can be produced. Container suppliers are third-party companies, and there is no capacity setting. Against this background, if the capacity of the nearest DC can meet all the needs of customers (s1), then this scenario needs the least total cost in all scenarios. However, in a real-life situation, the reference value of scenario 4 is the highest among the four scenarios.

Considering the answers to all sub-questions, the answer to the main question emerges. The use of returnable containers or not does not affect the structure and performance of the supply chain when there is only one closest DC and the capacity is greater than the total customer demand. Since the purchase of containers is the same in any scenario, only the cost of transportation and the cost of opening facilities are considered. It is cheapest to open only one DC. In that case, using different containers only has an impact on the total cost. When the supply chain becomes more complex, the decision to use a returnable container or not will have an impact on the number and location of open DCs, and the flow of goods to the next level of customers will vary accordingly, since returnable containers also need to be considered for backhaul. When there are more options, the logistics of returnable containers and disposable containers are different if you want to minimize the total cost. However, this idea needs more computational experiments to further corroborate cause this research does not verify whether the optimal solutions of the two models are interchangeable in the same scenario.

Although the objective functions of all models listed in the references are to minimize the total cost, some of the models in the references contain environmental factors (Bortolini et al., 2018; Fleischmann et al., 2001), some are multi-period (John et al., 2018), some contain extra facilities and processes (Accorsi et al., 2020; Pishvaee et al., 2010). Therefore, the subjects and outcomes are different. The results of this research cannot be compared with other articles' results. However, all references, as well as this research, acknowledge that the use of returnable assets can reduce the consumption of valuable resources, improve handling efficiency, and better protect goods during transportation.

To conclude, the economic appeal of using returnable food shipping containers is minimal if there are no external constraints. At this time, the government needs to use financial means to tax non-returnable food shipping containers to increase the attractiveness of returnable ones. The setting of the tax rate can refer to the critical value of the small container.

8. Limitations & future research

This research explores changes in the supply chain by comparing the returnable food shipping containers model and the non-returnable food shipping containers model. According to the results observed, we discussed how to set the tax value to make more enterprises use returnable food containers for transportation. Since the network designed in this research is different from other related articles, it is valuable for companies or researchers in need. Companies can use the constructed model to plan transport volume and transportation routes. Researchers can extend Model-R to solve more difficult situations.

In this research, several limitations exist. First of all, the first echelon only circulates large containers, and the second echelon only circulates small containers. In reality, in the same echelon, both large containers and small containers can be transported. It will not be so strict that only one type of container can be circulated on one echelon. Secondly, big containers are returnable in both models, while small containers are divided into two types: returnable and disposal. Third, both models constructed in this research are single-period, which simplifies those models. Next, the return rate and disposal rate may affect the total cost, but in this research, no further discussion was made. In all cases, the return rate is set to 100%, the disposal rate of big containers is 1%, and the disposal rate of small containers is 5%. Also, the ways of transportation may impact the results, but in this research, a truck is the only choice. Furthermore, the scenarios applied by the computational experiments in this research are based on real-life data, but they are still not real cases.

In the future, researchers who want to study returnable food shipping containers can try to make a multi-period model which mixes big and small containers. Future research has to consider the social and environmental dimensions of how returnable assets will further influence the network. If researchers are interested in the return rate, disposal rate, or transportation method, they can explore the regular pattern of those three factors on returnable food containers in the future. Real cases shall be used to verify whether the conclusion obtained in this research is accurate or not.

References

Accorsi, R., Baruffaldi, G., & Manzini, R. (2020). A closed-loop packaging network design model to foster infinitely reusable and recyclable containers in food industry. *Sustainable Production and Consumption*, *24*, 48-61.

Accorsi, R., Cholette, S., Manzini, R., & Mucci, L. (2022). Managing uncertain inventories, washing, and transportation of returnable containers in food retailer supply chains. *Sustainable Production and Consumption, 31*, 331-345.

Battini, D., Calzavara, M., Persona, A., & Sgarbossa, F. (2016). Sustainable packaging development for fresh food supply chains. *Packaging Technology and Science, 29*(1), 25-43.

Bortolini, M., Galizia, F. G., Mora, C., Botti, L., & Rosano, M. (2018). Bi-objective design of fresh food supply chain networks with reusable and disposable packaging containers. *Journal of cleaner production*, *184*, 375-388.

Coles, R., McDowell, D., & Kirwan, M. J. (Eds.). (2003). *Food packaging technology* (Vol. 5). CRC press.

Deshwal, G. K., & Panjagari, N. R. (2020). Review on metal packaging: materials, forms, food applications, safety and recyclability. *Journal of food science and technology*, *57*(7), 2377-2392.

Ferretti, I., Mazzoldi, L., & Zanoni, S. (2018). Environmental impacts of cold chain distribution operations: A novel portable refrigerated unit. *International Journal of Logistics Systems and Management, 31*(2), 267-297.

Fikiin, K., & Markov, D. (2014). Efficient loading and unloading of a food cold store. *New Food Magazine, 6*. Retrieved on 21/09/2022 from: www.newfoodmagazine.com

Fleischmann, M., Beullens, P., BLOEMHOF-RUWAARD, J. M., & Van Wassenhove, L. N. (2001). The impact of product recovery on logistics network design. *Production and operations management*, *10*(2), 156-173.

Food Standards Australia & New Zealand. (2021). Transporting food. Retrieved on 19/09/2022 from: www.foodstandards.gov.au

Goellner, K. N., & Sparrow, E. (2014). An environmental impact comparison of single-use and reusable thermally controlled shipping containers. *The International Journal of Life Cycle Assessment, 19*(3), 611-619.

Homestratosphere. (2018). 13 Different types of food storage containers. Retrieved on 27/10/2022 from: www.homestratosphere.com/types-of-food-storage-containers/

Iassinovskaia, G., Limbourg, S., & Riane, F. (2017). The inventory-routing problem of returnable transport items with time windows and simultaneous pickup and delivery in closed-loop supply chains. *International Journal of Production Economics, 183*, 570-582.

Jablonský, J. (2015). Benchmarks for current linear and mixed integer optimization solvers. Acta Universitatis Agriculturae et Silviculturae Mendelianae Brunensis*, 63*(6), 1923-1928.

Jekins, A. (2021). A guide to reverse logistics: how it works, types and strategies. Retrieved on 20/09/2022 from: www.netsuite.com

John, S. T., Sridharan, R., Kumar, P. R., & Krishnamoorthy, M. (2018). Multi-period reverse logistics network design for used refrigerators. *Applied Mathematical Modelling, 54*, 311-331.

Lee, D. H., & Dong, M. (2008). A heuristic approach to logistics network design for end-of-lease computer products recovery. *Transportation Research Part E: Logistics and Transportation Review, 44*(3), 455-474.

Meepetchdee, Y., & Shah, N. (2007). Logistical network design with robustness and complexity considerations. *International Journal of Physical Distribution & Logistics Management, 37*, 201-222.

Mollenkopf, D., Closs, D., Twede, D., Lee, S., & Burgess, G. (2005). Assessing the viability of reusable packaging: a relative cost approach. *Journal of Business Logistics, 26*(1), 169-197.

Pishvaee, M. S., Farahani, R. Z., & Dullaert, W. (2010). A memetic algorithm for bi-objective integrated forward/reverse logistics network design. Computers & operations research*, 37*(6), 1100-1112.

Reusable Packaging Association (2020), *Reusable Transport Packaging: State of the Industry Report 2020*, RPA, Tampa.

Schuermann, H., & Woo, J. (2022). Estimating consumers' willingness to pay for returnable food containers when ordering delivery food: A contingent valuation approach. *Journal of Cleaner Production*, *366*, 133012.

Tornese, F., Gnoni, M. G., Thorn, B. K., Carrano, A. L., & Pazour, J. A. (2021). Management and logistics of returnable transport items: A review analysis on the pallet supply chain. *Sustainability, 13*(22), 12747.

Treasury, H. M. (2018). Tackling the Plastic Problem. Using the Tax System or Charges to Address Single-Use Plastic Waste. HM Treasury, UK https://assets. publishing. service. gov.

uk/government/uploads/system/uploads/attachment_data/file/690293/PU2154_Call_for_evidence_plastics_web. pdf.

Verstrepen, S., Cruijssen, F., De Brito, M. P., & Dullaert, W. (2007). An exploratory analysis of reverse logistics in Flanders. *European Journal of Transport and Infrastructure Research, 7*(4), 301-316.

Appendix A Complete table of literature review

Table 17 Complete table of literature review

Article	Year	Sector			Network design		Approach	Model objective	Constraints
		Food packaging	Shipping packaging	Others	Reverse logistics	Closed-loop supply chain			
Accorsi et al.	2020	√				√	MILP	minimize the infrastructural and operational costs	the facility status; the flows of the reusable plastic containers(RPCs) among the nodes of the network; the status of the RPCs and the management of their residual life
Bortolini et al.	2018	√				√	Bi-objective MILP	minimize the cost and environmental impact	demand; facilities and vehicles capacity; balance flows and inventory level for containers; packaging container direct and reverse logistics; lifetime limitation
John et al.	2018		√		√		MILP	profit maximization	the conservation of flow at dismantling centers; facilities capacity; the total flow of each type of a recyclable item to a recycling center cannot exceed its capacity
Pishvaee et al.	2010			√		√	Bi-objective MIP	minimize the total costs and maximize the responsiveness of a logistics network	demand; collect returned products from all customer zones; the flow balance at each facility; facilities capacity; a facility can be assigned at most one capacity level
Fleischmann et al.	2001			√		√	MILP	minimize the total costs	demand and returns; the flow balance at each facility; enforce a minimum disposal fraction for each return flow to comply with technical (in)feasibility of reuse; facility opening conditions

Appendix B Data settings for four scenarios

Table 18 Containers information used in all scenarios

	Disposal costs	Transportation cost	Disposal rate	Purchasing cost
Big containers	400	1000	1%	4500
Small containers	8	60	5%	80
Conversion rate from big containers to small ones				600%

Table 19 Facilities information used in scenario 1

						Customer				Container supplier	
Capacity	**Fixed costs**	**Operating costs**	**Distribution /Production**	P001	P002	C001	C002	C003	C004	U001	U002
10000	3000	30	D001	20	17	95	82	40	113	55	81
10000	4000	20	D002	95	100	21	10	48	177	72	16
15000	5000	25	D003	90	80	52	60	35	182	22	44
			Demand			500	600	500	800		
			Return rate			100%	100%	100%	100%		
			100.0%								
			100%								
			100%								
				Nijmegen	Arhnem	den Haag	Rotterdam	Utrecht	Dusseldorf (German)	Almere	Zoetermere
			Wageningen								
			Rotterdam								
			Amsterdadm								

Table 20 Facilities information used in scenario 2

						Customer				Container supplier	
Capacity	**Fixed costs**	**Operating costs**	**Distribution /Production**	P001	P002	C001	C002	C003	C004	U001	U002
1500	3000	30	D001	20	17	95	82	40	113	55	81
1500	4000	20	D002	95	100	21	10	48	177	72	16
2000	5000	25	D003	90	80	52	60	35	182	22	44
			Demand			500	600	500	800		
			Return rate			100%	100%	100%	100%		
			100.0%								
			100%								
			100%								
				Nijmegen	Arhnem	den Haag	Rotterdam	Utrecht	Dusseldorf (German)	Almere	Zoetermere
			Wageningen								
			Rotterdam								
			Amsterdadm								

Table 21 Facilities information used in scenario 3

						Customer				Container supplier		
Capacity	**Fixed costs**	**Operating costs**	**Distribution /Production**	P001	P002	C001	C002	C003	C004	U001	U002	U003
1500	3000	30	D001	20	17	95	82	40	113	55	81	109
1500	4000	20	D002	95	100	21	10	48	177	72	16	180
2000	5000	25	D003	90	80	52	60	35	182	22	44	178
1500	5000	25	D004	77	84	183	167	134	23	149	171	18
			Demand			500	600	500	800			
			Return rate			100%	100%	100%	100%			
			100.0%									
			100%									
			100%									
			100%									
				Nijmegen	Arhnem	den Haag	Rotterdam	Utrecht	Dusseldorf (German)	Almere	Zoetermere	Essen (German)
			Wageningen									
			Rotterdam									
			Amsterdadm									
			Duisburg (German)									

Table 22 Facilities information used in scenario 4-part A

Capacity	Fixed costs	Operating costs	Distribution /Production	P001	P002	P003	P004	P005	P006	Customer C001	C002	C003	C004	C005	C006	C007	C008	C009	C010
1500	3000	30	D001	20	17	108	60	90	165	95	82	40	113	5	73	145	130	530	154
1500	4000	20	D002	95	100	182	88	21	110	21	8	48	177	80	55	200	215	613	120
2000	5000	25	D003	90	80	177	112	50	167	52	60	35	182	70	10	215	192	577	173
1500	5000	25	D004	77	84	18	90	185	215	183	167	134	23	96	165	56	83	470	180
3000	6000	20	D005	90	16	90	52	110	172	110	95	58	93	20	88	126	122	520	152
1000	2000	25	D006	15	6	95	67	115	183	105	98	55	100	15	82	136	117	513	166
2000	4000	25	D007	620	110	200	108	6	120	3	20	55	194	93	50	222	227	620	135
2500	5000	30	D008	56	55	147	76	54	150	50	48	6	149	39	35	180	172	565	148
1500	4000	25	D009	53	68	105	5	108	130	110	88	78	90	60	111	117	159	556	102
2000	4000	25	D010	76	60	133	126	130	230	130	128	80	150	68	82	185	120	495	220
1000	2000	20	D011	126	136	58	118	223	227	225	204	180	35	145	214	5	122	477	183
1500	3000	15	D012	122	118	70	160	230	288	227	217	172	101	134	192	123	4	399	258
2000	5000	20	D013	117	118	30	138	226	265	227	212	173	57	133	200	72	51	422	229
2500	5000	30	D014	102	98	193	120	42	160	40	52	46	196	83	17	226	210	595	171
1500	2000	25	D015	122	134	183	78	95	50	96	78	109	165	120	132	182	238	635	42
			Demand							500	600	500	800	1000	1500	400	600	500	2000
			Return rate							100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
			100.0%																
			100.0%																
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Table 23 Facilities information used in scenario 4-part B

																				Container supplier		
C011	C012	C013	C014	C015	C016	C017	C018	C019	C020	C021	C022	C023	C024	C025	C026	C027	C028	C029	C030	U001	U002	U003
120	168	206	138	60	75	28	55	68	152	130	170	108	230	224	197	90	47	68	153	55	81	109
78	110	167	117	59	43	68	71	128	202	171	225	183	260	280	279	145	121	121	187	72	16	180
133	167	223	167	92	88	42	22	83	147	115	238	178	290	292	251	95	87	72	130	22	44	178
166	216	225	156	117	140	124	149	128	198	191	81	18	163	133	138	146	100	137	216	149	171	18
122	172	204	134	62	80	48	73	77	160	142	152	90	213	205	184	98	51	80	165	73	97	90
134	183	218	148	74	90	41	65	61	144	126	162	96	227	215	179	82	35	64	150	65	98	97
96	121	183	136	79	63	74	70	130	198	166	244	199	280	299	289	145	128	121	180	70	12	199
109	151	200	138	60	61	19	32	80	158	131	204	148	255	260	233	100	73	75	150	31	43	147
79	130	153	82	30	52	80	106	127	211	190	138	106	178	191	220	148	102	128	212	105	97	106
185	230	273	205	128	138	62	61	3	84	66	210	133	284	261	174	22	29	13	90	61	120	133
182	227	219	159	147	168	173	200	185	255	248	25	58	112	79	162	202	156	194	273	200	211	57
238	289	306	236	180	200	155	170	121	156	164	142	70	235	179	62	127	105	134	188	170	215	70
215	265	272	205	164	186	200	181	146	199	201	90	32	183	128	93	158	121	157	224	181	213	32
130	160	220	166	97	88	57	40	100	160	127	250	193	298	305	269	111	104	89	140	39	36	192
4	160	221	170	61	48	125	140	185	267	240	196	184	204	245	299	205	167	181	258	140	94	183
700	1500	800	400	300	500	600	800	1500	1000	400	300	500	600	800	400	500	1000	800	300			
100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%			

Appendix C Big and small containers flow in s2 and s4 of Model-D

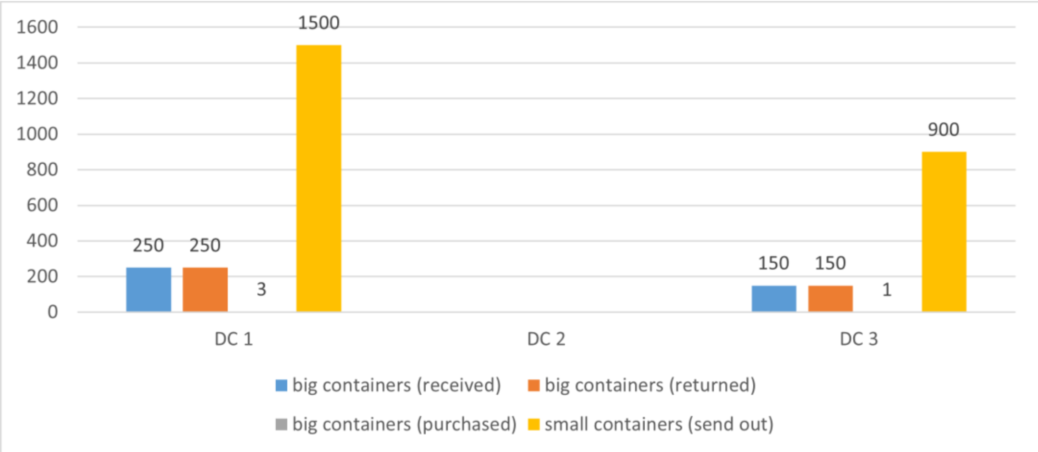

Figure 13 Big and small containers flow in scenario 2-Model-D

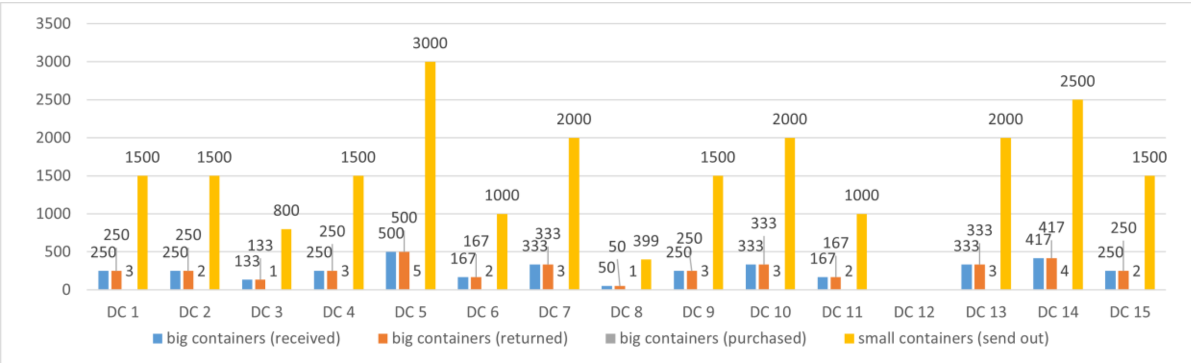

Figure 14 Big and small containers flow in scenario 4-Model-D

Appendix D Total costs trend in s2, s3, s4

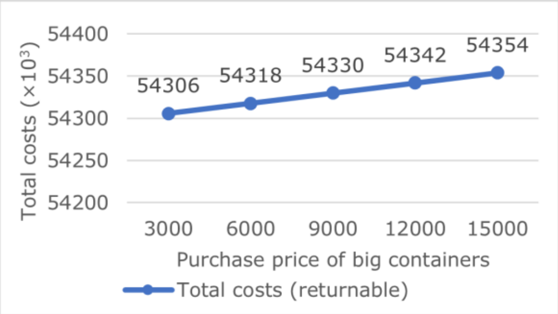

Figure 15 Total costs trend (returnable) when the purchase price for big containers changes in scenario 2

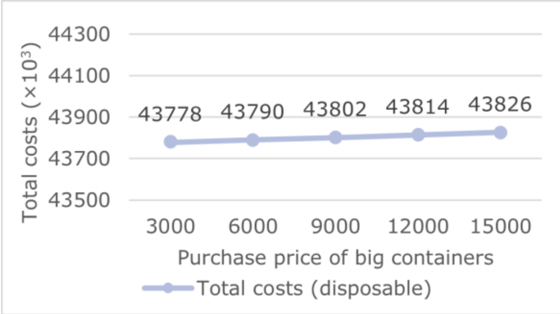

Figure 16 Total costs trend (disposable) when the purchase price for big containers changes in scenario 2

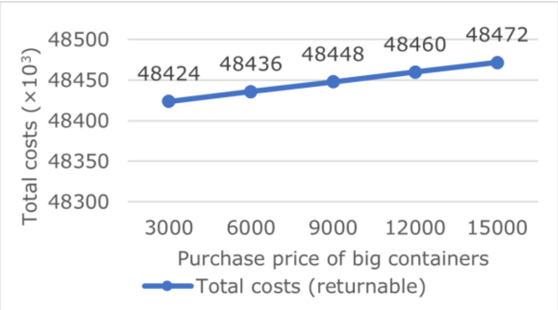

Figure 17 Total costs trend (returnable) when the purchase price for big containers changes in scenario 3

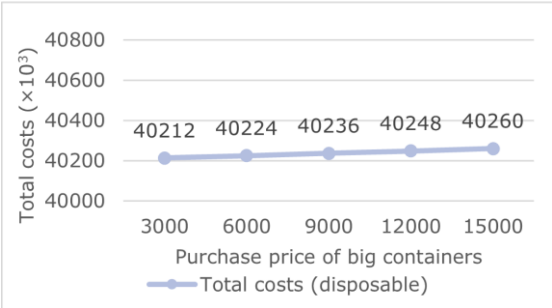

Figure 18 Total costs trend (disposable) when the purchase price for big containers changes in scenario 3

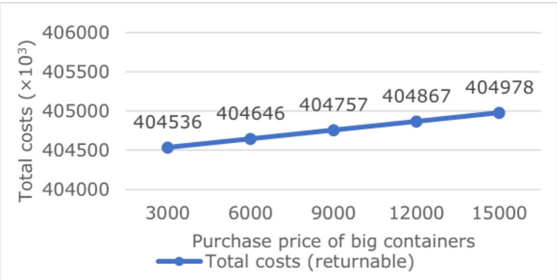

Figure 19 Total costs trend (returnable) when the purchase price for big containers changes in scenario 4

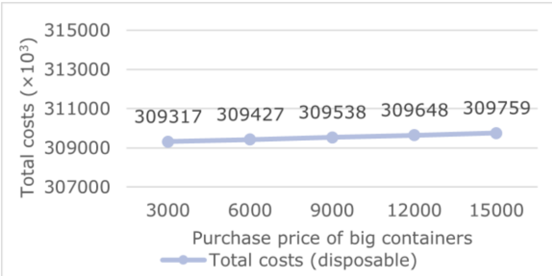

Figure 20 Total costs trend (disposable) when the purchase price for big containers changes in scenario 4

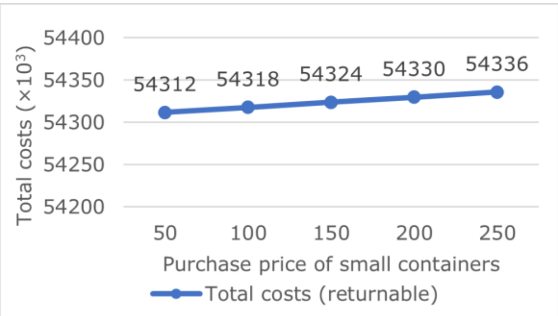

Figure 21 Total costs trend (returnable) when the purchase price for small containers changes in scenario 2

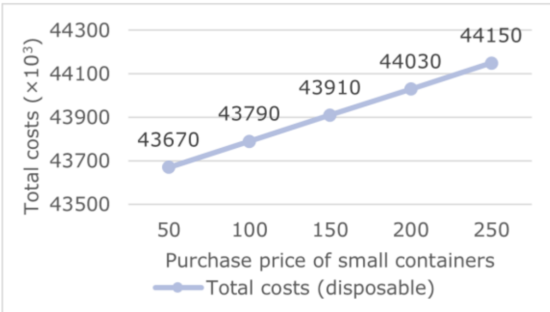

Figure 22 Total costs trend (disposable) when the purchase price for small containers changes in scenario 2

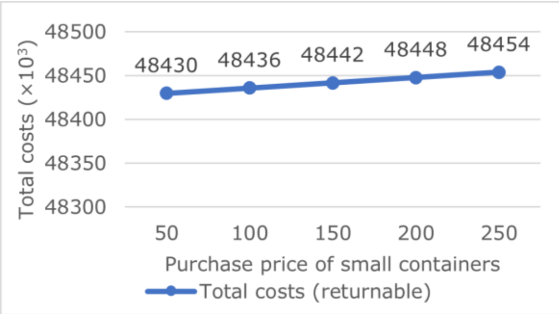

Figure 23 Total costs trend (returnable) when the purchase price for small containers changes in scenario 3

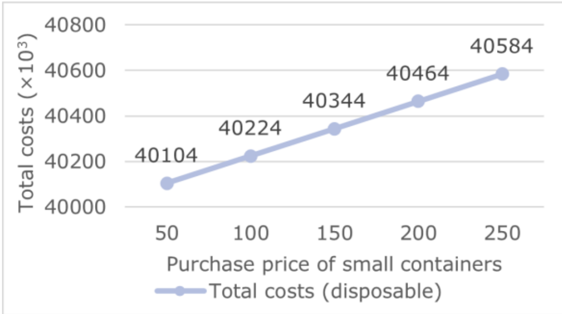

Figure 24 Total costs trend (disposable) when the purchase price for small containers changes in scenario 3

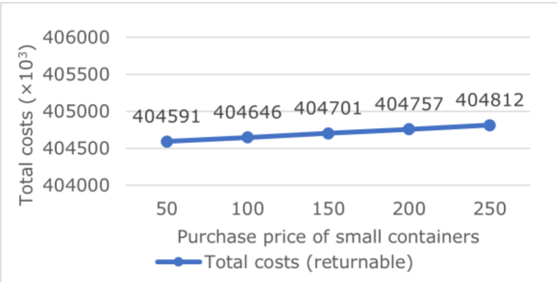

Figure 25 Total costs trend (returnable) when the purchase price for small containers changes in scenario 4

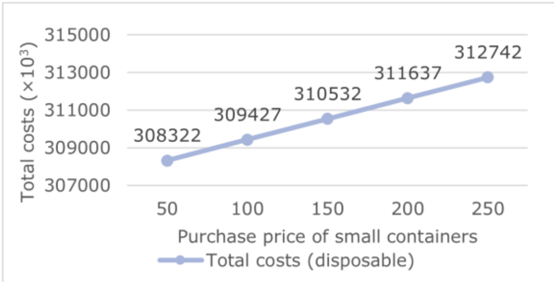

Figure 26 Total costs trend (disposable) when the purchase price for small containers changes in scenario 4

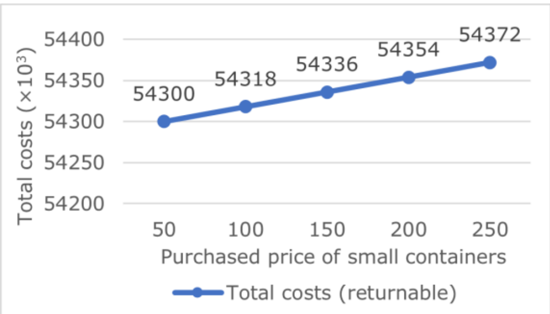

Figure 27 Total costs trend (returnable) when the purchase price for both containers changes in scenario 2

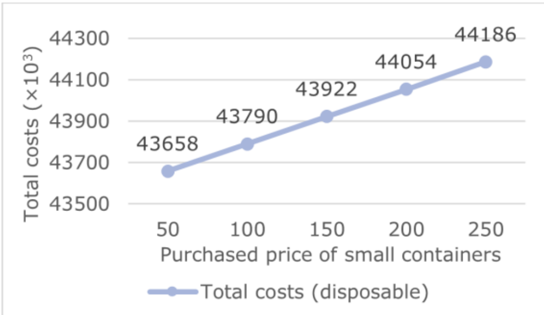

Figure 28 Total costs trend (disposable) when purchase price for both containers changes in scenario 2

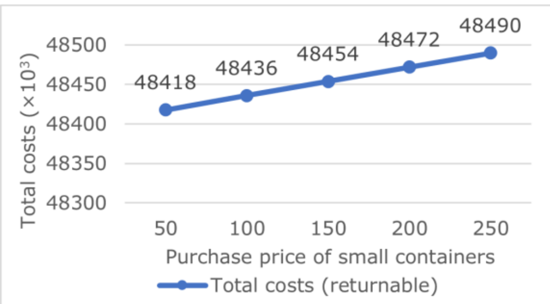

Figure 29 Total costs trend (returnable) when the purchase price for both containers changes in scenario 3

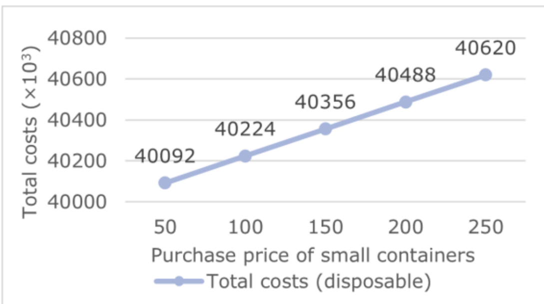

Figure 30 Total costs trend (disposable) when purchase price for both containers changes in scenario 3

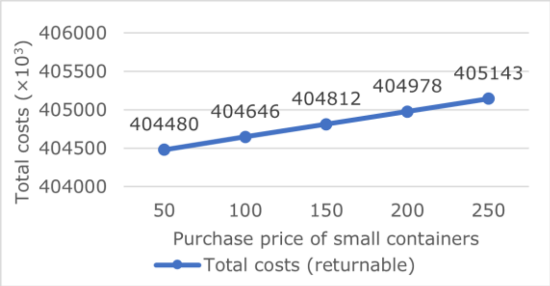

Figure 31 Total costs trend (returnable) when the purchase price for both containers changes in scenario 4

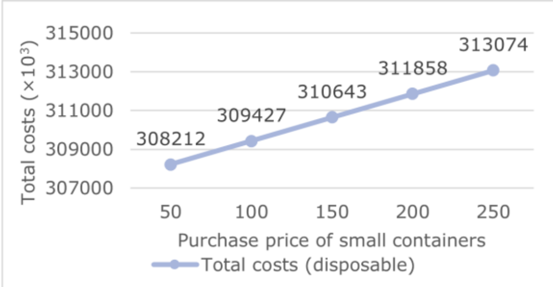

Figure 32 Total costs trend (disposable) when the purchase price for both containers changes in scenario 4