Multi Product Multi Period Network Design for Reverse Logistics

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Abstract

Waste management in health institutions has become important in recent years because of the increase in population and industrialization. Waste generated from health institutions has risks for human health and the environment. Therefore, this paper presents a reverse logistics optimization for waste collection and disposal in Turkish health institutions. A multiperiod, multitype product waste reverse logistics network was designed to build an effective collection and disposal system for waste generated from health institutions in Turkey. A mixed integer linear programming model was developed to determine the optimal number and locations of the facilities for efficient waste management in health care by minimizing the total cost. In this context, a sensitivity analysis was conducted to examine the impact of the incremental changes of waste amounts on the optimal reverse logistics network. According to increasing waste amounts, the numbers of changes in facilities are analyzed and strategies are specified.

Keywords
Reverse logistics, Optimization, Mixed integer linear programming, Medical waste, Domestic waste, Multiperiod

1. Introduction

In recent years, waste management in health institutions has gained importance because of the damage of medical waste on human health and the environment. Medical waste occurring as a result of increased population and industrialization has become an important environmental problem (Bajeva *et al.,* 2000). In fact, although waste generated from health institutions occupies less space in terms of quantity, it has the greatest risk of all waste groups. Additionally, disposal processes could be a significant problem in terms of cost management.

Today, the reverse logistics models for the proper collection and disposal of waste generated from health institutions have gained importance in health-care waste management, in order to reduce the hazards of waste and prevent its negative effects on the environment. The application of reverse logistics on waste generated from health institutions helps to manage and optimize the flow of waste, and to design an effective disposal system. This study investigates domestic and medical waste collection and disposal from health institutions in Turkey, considering the reverse logistics activities of collection, storage, and transportation of waste, as well as processing waste according to the different types, and its final distribution to regular storage areas. Consequently, the design of a cost-effective and efficient reverse logistics network system is a very important issue for the disposal of waste generated from health institutions.

The aim of this study is to create a reverse logistics optimization for waste collection and disposal from health institutions in Turkey. In this context, for the incremental waste quantities, the optimized number and location of facilities are determined. For the analysis, the reverse logistics network is illustrated and a mixed integer linear programming model is developed, to optimize the collection and disposal system for waste generated from health institutions in Turkey.

The rest of the paper is organized as follows. Section 2 presents a brief literature review of reverse logistics of waste. Section 3 describes waste disposal and collection processes in Turkish health institutions. In section 4, a mixed integer linear model is proposed for a medical and domestic reverse logistics network. Section 5 describes the case study. Section 6 focuses on sensitivity analysis and optimization results. Finally, section 7 concludes the paper.

2. Literature Review

Reverse logistics is the process of planning, implementing, and controlling the efficient, cost-effective flow of raw materials, in-process inventory, finished goods, and related information, from the point of consumption to the point of origin, for the purpose of recapturing value or proper disposal (Rogers & Tibben-Lembke, 1999). Today, reverse logistics systems are considered very important for businesses to improve their overall environmental and financial performance (Nikolau *et al.,* 2013). Since the 1980s, many studies have been performed on this subject. Initial studies focused on the definition, objective, and importance of reverse logistics (Fleishman *et al.,* 2000).

Shih (2001) utilized a mixed integer programming model for electrical and electronical appliances in Taiwan, which optimized the infrastructure design and the reverse network flow. Hu *et al.* (2002) proposed a cost-minimization model for a multitime-step, multitype hazardous-waste reverse logistics system. Min *et al.* (2006) designed a proposed reverse logistics network by using nonlinear mixed integer programming model and a genetic algorithm to solve reverse logistics problem. Ahluwalia and Nema (2006) proposed a decision-support tool for selecting an optimum configuration of computer waste-management facilities, and allocating the waste from these facilities using an integer linear programming method. Lu *et al.* (2007) presented a remanufacturing network which considered both forward and reserve flows. A 0–1 mixed integer model was proposed by developing a Lagrangian heuristics algorithm, and the model was tested on data adapted from classical test problems. Pati *et al.* (2008) designed a paper recycling network and formulated mixed integer goal programming to manage a paper recycling logistics system in India. Shi *et al.* (2009) designed a problem for medical waste reverse logistics networks, using a mixed integer linear program to minimize the total cost, which included fixed costs of all nodes, transportation costs, and operating costs. El-Sayed *et al.* (2010) developed a multiperiod, multi-echelon forward–reverse logistics network design-under-risk model to maximize total expected profit. Dat *et al.* (2012), developed a mathematical programming model which minimized the total processing cost of multiple types of electrical and electronic waste products (WEEPs). As a result, the optimal facility locations and the material flows in the reverse logistic network could be determined. Finally, a sensitivity analysis of the model was also presented by Zhang *et al.* (2014), who designed a multi-echelon, multiperiod solid-waste-management system (MSWM).

It is found that despite many studies on waste, there are few studies on health-care waste when looking at logistics studies in general. The studies on health-care waste mainly use survey methods and focus generally on the main concepts of waste management in health-care facilities. Lee *et al.* (2004) presented a study about medical waste type, composition, and disposal methods. Alagoz and Kocasoy (2007) compared different treatment technologies in Istanbul, the largest city in Turkey, and compared the capital investment, transportation, and operational costs for each method. Alagoz and Kocasoy (2008) also investigated the current situation of health-care waste management in Istanbul. The amount of waste generated, as well as waste collection, segregation, storage, and transportation processes were analyzed in depth. The paper suggested main concepts for the safe handling and transportation of health-care waste by considering environmental and economic factors. Windfeld *et al.* (2015) defined medical waste-management processes, such as governing legislation and handling and disposal methods. The study showed that the unnecessary classification of waste as infectious results in higher disposal costs and an increase in undesirable environmental impacts. Moreover, the authors revealed that standardized sorting of medical waste streams was key for efficient waste management in health-care facilities. Nikolic *et al.* (2016) applied a fault tree analysis (FTA) method to the risk assessment of infectious medical waste management in the biggest health institution in southeast Europe, the Clinical Center of Serbia. Three aspects were considered, which are functional, qualitative, and quantitative. As a result,

important failures in medical waste management were identified, and the prevention of failures contributed to positive effects on the system.

Moreover, the relevant literature revealed that there has not been any multiperiod reverse logistics optimization study for waste generated by health institutions, considering the multitype processing centers, including domestic and medical waste. Also, this is the first study done for the case of Turkey at a macro level. This paper aims to fill this gap in the literature, by proposing a mixed integer linear programming model to determine the required number of facilities, as well as their locations, by minimizing the cost. In this context, a multiperiod reverse logistics network was designed for the waste collection and disposal from health institutions in Turkey by studying all of the researchers' methodologies and results outlined above. Thereafter, the optimization was conducted and sensitivity analysis was done.

3. Waste Collection and Disposal in Health Institutions of Turkey

There are four types of waste generated by health institutions in Turkey, namely: medical, domestic, hazardous, and radioactive waste. This waste is generated from many sources; mostly from university hospitals and clinics, medical and biomedical laboratories, health centers, medical centers, and dispensaries. The definition of waste is given according to the Medical waste control regulations in Turkey (MWCR, 2005):

The first type is *medical waste,* which is a group containing infectious, pathological, and cutting-perforating waste**.** The second type is *domestic waste,* containing noncontaminated waste, generated by the administrative offices, kitchens, rooms, including bed linen, utensils, paper, etc. Domestic waste is divided into two subcategories: general waste and packaging waste. The third type is *hazardous waste,* which is a group containing genotoxic, pharmaceutical, and chemical waste, and waste including heavy metals. Finally, the last type of waste is *radioactive waste,* which is subject to different procedures, according to the rules of the Turkish Atomic Energy Authority. Hazardous waste comprises 1% of total waste, and there is also a different regulation for its collection. Because of the different procedures for hazardous and radioactive waste, they are not included in this study. Also, according to the regulations of the Ministry of Environment and Forest, of Turkey, in 2005, it is necessary to handle the disposal of domestic and medical wastes generated from health institutions in an integrated manner.

A reverse logistics network for the collection and disposal of waste generated from health institutions in Turkey is shown in Figure 1**.** There are four layers in this reverse logistics network, which are the collection points, storage points, processing centers, and landfill areas, respectively. Four types of processing centers are defined in the network: sterilization; burning; burying with lime; and grinding. As the grinding centers are used for domestic-waste disposal, the other three centers are used for medical-waste disposal.
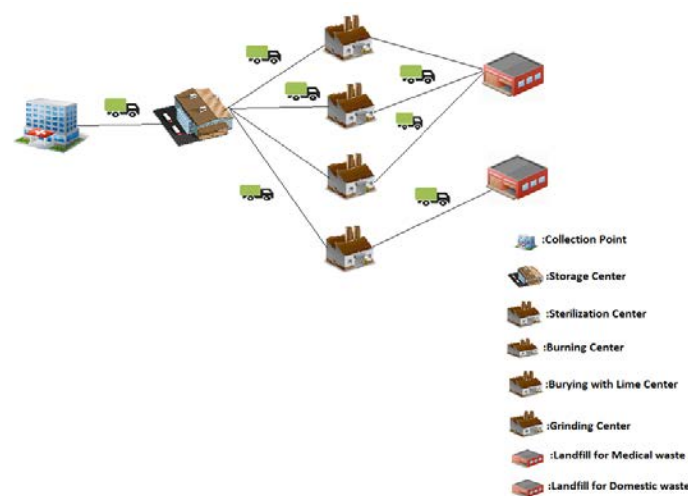

Figure 1. Reverse logistics network for waste generated from health institutions (MWCR, 2005).

In accordance with the processes mentioned above, it is aimed to conduct a strategic network optimization for waste collection and disposal in the health institutions of Turkey.

4. Proposed Optimization Model for Reverse Logistics Network

In this study, the proposed reverse logistics network model for the waste disposal in health institutions is a MILP model. In the model, collection points, storage, as well as processing, and regular storage centers are represented as nodes, which are also indicated in Figure 1. The objective function is formed to minimize the total cost of waste-disposal activities considering transportation, processing, inventory, and fixed costs. The decision variables in the model are:

1. Waste inventory levels in each center;
2. Total amounts of waste transported between nodes;
3. Binary decision variables for selection of storage and processing centers.

In the model, there are *j* numbers of storage centers, *m* numbers of sterilization centers, *n* numbers of burning centers, *1* numbers of burying with lime centers, *k* numbers of grinding centers, *y* numbers of regular storage centers for medical waste, and *x* numbers of regular storage centers for domestic waste. Medical and domestic waste are taken to separate processing centers. Domestic waste is taken to the grinding centers, and medical waste to other types of centers. The final point is defined as the point to which sterilized, burnt, or ground waste are sent. At this last point, waste is stored regularly according to its type. Three types of constraints are considered in the model. The first is flow constraint, which balances the waste amounts between nodes including inventory level; the second is capacity constraint at different types of centers, which considers the maximum inventory level; and the third is limiting the number of new facilities that are opened. The objective function and constraints are given in Equations (5)–(36).

Notations

1. Sets
i = Collection points *{1,2,.....,81}*
j = Storage centers *{1,2...,39}*
m = Sterilization centers *{1,2,...,30 }*
n = Burning centers *{1,2,...,9}*
l = Burying with lime centers *{1,2,...,26}*
k = Grinding centers *{1,2,..30}*
y = Regular storage centers for medical waste *{1,..7}*
x = Regular storage centers for domestic waste *{1,..11}*
t = Time Period *{1,2,3}*

2. Parameters
Q_i^t = Total amount of waste at collection point *I* in period t
CS_j^t = Annual fixed cost for storage center *j* in period t
CSC_m^t = Annual fixed cost for sterilization center *m* in period t
CB_n^t = Annual fixed cost for burning center *n* in period t
CBL_l^t = Annual fixed cost for burying with lime center *l* in period t
CG_k^t = Annual fixed cost for grinding center *k* in period t
$TCAPS_j$ = Maximum capacity of storage center *j*
$TCAPC_m$ = Maximum capacity of sterilization center *m*
$TCAPB_n$ = Maximum capacity of burning center *n*
$TCAPL_l$ = Maximum capacity of burying with lime center *l*
$TCAPG_k$ = Maximum capacity of grinding center *k*
MS_{ij} = Distance from collecting point i to storage center *j*
MC_{jm} = Distance from storage site *j* to sterilization center *m*
MB_{jn} = Distance from storage site *j* to burning center *n*
ML_{jl} = Distance from storage site *j* to burying with lime center *l*
MG_{jk} = Distance from storage site *j* to grinding center *k*

MR_{my} = Distance from sterilization center m to regular storage center y for medical waste

ME_{ny} = Distance from burning center n to regular storage center y for medical waste

MT_{kx} = Distance from grinding center k to regular storage center x for domestic waste

$Jmax$ = Maximum number of potential storage centers

$Mmax$ = Maximum number of potential sterilization centers

$Nmax$ = Maximum number of potential burning centers

$Lmax$ = Maximum number of potential burying with lime centers

$Kmax$ = Maximum number of potential grinding centers

IMS^t = Unit operation cost of medical waste at the sterilization center in period t

IMB^t = Unit operation cost of medical waste at the burning center in period t

IML^t = Unit operation cost of medical waste at the burying with lime center in period t

IMG^t = Unit operation cost of domestic waste at the grinding center in period t

TM^t = Unit transportation cost of medical waste in period t

TD^t = Unit transportation cost of domestic waste in period t

TP^t = Unit transportation cost of processed waste in period t

TF^t = Unit transportation cost of waste transported from collection point to storage center in period t

SO = Percentage of medical waste transferred to the sterilization center

YO = Percentage of medical waste transferred to the burning center

KG = Percentage of medical waste transferred to the burying with lime center

EA = Percentage of domestic waste transferred to the grinding center

MIC = Maximum inventory capacity

UIC^t = Unit inventory cost of waste in period t

α = Yearly waste processing rate

3. Decision variables

QS_{ij}^t = Amount of waste transported from collecting point i to storage center j in period t

QC_{jm}^t = Amount of medical waste transported from storage site j to sterilization center m in period t

QB_{jn}^t = Amount of medical waste transported from storage site j to burning center n in period t

QL_{jl}^t = Amount of medical waste transported from storage site j to burying with lime center l in period t

QG_{jk}^t = Amount of domestic waste transported from storage site j to grinding center k in period t

QR_{my}^t = Amount of medical waste transported from sterilization center m to regular storage center y in period t

QE_{ny}^t = Amount of medical waste transported from burning center n to regular storage center y in period t

QT_{kx}^t = Amount of domestic waste transported from grinding k to regular storage center x in period t

IS_j^t = Waste inventory level of storage center j in period t

IC_m^t = Waste inventory level of sterilization center m in period t

IB_n^t = Waste inventory level of burning center n in period t

IG_k^t = Waste inventory level of grinding center k in period t

P_j^t = 0/1 variable for selection of storage center j in period t

Z_m^t = 0/1 variable for selection of sterilization center m in period t

D_n^t = 0/1 variable for selection of burning center n in period t

V_l^t = 0/1 variable for selection of burying with lime center l in period t

U_k^t = 0/1 variable for selection of grinding center k in period t

Mathematical formulation

Objective Function

$Min\ z =$

$$\sum_t \left[\sum_j CS_j^t * P_j^t + \sum_m CSC_m^t * Z_m^t + \sum_n CB_n^t * D_n^t + \sum_l CBL_l^t * V_l^t + \sum_k CG_k^t * U_k^t + \sum_j \sum_m QC_{jm}^t * IMS^t + \right.$$
$$\sum_j \sum_n QB_{jn}^t * IMB^t + \sum_j \sum_l QL_{jl}^t * IML^t + \sum_j \sum_k QG_{jk}^t * IMG^t + \sum_i \sum_j MS_{ij} * TF^t * QS_{ij}^t +$$
$$\sum_j \sum_m MC_{jm} * TM^t * QC_{jm}^t + \sum_j \sum_n MB_{jn} * TM^t * QB_{jn}^t + \sum_j \sum_l ML_{jl} * TM^t * QL_{jl}^t + \sum_j \sum_k MG_{jk} * TD^t *$$
$$QG_{jk}^t + \sum_m \sum_y MR_{my} * TP^t * QR_{my}^t + \sum_n \sum_y ME_{ny} * TP^t * QE_{ny}^t + \sum_k \sum_x MT_{kx} * TP^t * QT_{kx}^t + \sum_j IS_j^t *$$
$$\left. UIC^t + \sum_m IC_m^t * UIC^t + \sum_n IB_n^t * UIC^t + \sum_k IG_k^t * UIC^t \right] \quad (1)$$

Constraints

1. Flow constraints

$$\sum_{j=1}^{J} QS_{ij}^{t} = Q_i^t \ , \forall \, t, i \tag{2}$$

$$\sum_{m=1}^{M} QC_{jm}^{t} = SO \sum_{i=1}^{I} \alpha * (QS_{ij}^{t} + IS_j^{t-1}) \ \ , \forall \, t, j \tag{3}$$

$$\sum_{j=1}^{J} \alpha * QC_{jm}^{t} = \sum_{y=1}^{Y} QR_{my}^{t} \ \ , \ \forall \, t, m \tag{4}$$

$$\sum_{n=1}^{N} QB_{jn}^{t} = YO \sum_{i=1}^{I} \alpha * (QS_{ij}^{t} + IS_j^{t-1}) \ \ , \forall \, t, j \tag{5}$$

$$\sum_{j=1}^{J} \alpha * QB_{jn}^{t} = \sum_{y=1}^{Y} QE_{ny}^{t} \ \ , \forall \, t, n \tag{6}$$

$$\sum_{l=1}^{L} QL_{jl}^{t} = KG \sum_{i=1}^{I} \alpha * (QS_{ij}^{t} + IS_j^{t-1}) \ , \forall \, t, j \tag{7}$$

$$\sum_{k=1}^{K} QG_{jk}^{t} = EA \sum_{i=1}^{I} \alpha * (QS_{ij}^{t} + IS_j^{t-1}) \ , \forall \, t, j \tag{8}$$

$$\sum_{j=1}^{J} \alpha * QG_{jk}^{t} = \sum_{x=1}^{X} QT_{kx}^{t} \ , \forall \, t, k \tag{9}$$

$$IS_j^{t} = IS_j^{t-1} + QS_{ij}^{t} - \left[\sum_{m:1}^{M} QC_{jm}^{t} + \sum_{n:1}^{N} QB_{jn}^{t} + \sum_{l:1}^{L} QL_{jl}^{t} + \sum_{k:1}^{K} QG_{jk}^{t} \right], \forall \, t, j \tag{10}$$

$$IC_m^{t} = IC_m^{t-1} + \sum_{j:1}^{J} QC_{jm}^{t} - \sum_{y:1}^{Y} QR_{my}^{t} \ , \forall \, t, m \tag{11}$$

$$IB_n^{t} = IB_n^{t-1} + \sum_{j:1}^{J} QB_{jn}^{t} - \sum_{y:1}^{Y} QE_{ny}^{t} \ , \forall \, t, n \tag{12}$$

$$IG_k^{t} = IG_k^{t-1} + \sum_{j:1}^{J} QG_{jk}^{t} - \sum_{x:1}^{X} QT_{kx}^{t} \ , \forall \, t, k \tag{13}$$

2. Capacity constraints

$$\sum_{i:1}^{I} QS_{ij}^{t} \le TCAPS_j * P_j^t \ , \forall \, j, t \tag{14}$$

$$\sum_{j:1}^{J} QC_{jm}^{t} \le TCAPC_m * Z_m^t \ , \forall \, m, t \tag{15}$$

$$\sum_{j:1}^{J} QB_{jn}^{t} \le TCAPB_n * D_n^t , \forall \, n, t \tag{16}$$

$$\sum_{j:1}^{J} QL_{jl}^{t} \le TCAPL_l * V_l^t \ , \forall \, l, t \tag{17}$$

$$\sum_{j:1}^{J} QG_{jk}^{t} \le TCAPG_k * U_k^t \ , \forall \, k, t \tag{18}$$

$$IS_j^{t} \le MIC \ , \forall \, t, j \tag{19}$$

$$IC_m^{t} \le MIC \ , \forall \, t, m \tag{20}$$

$$IB_n^{t} \le MIC \ , \forall \, t, n \tag{21}$$

$$IG_k^{t} \le MIC \ , \forall \, t, k \tag{22}$$

3. Number limit of facilities

$$\sum_{j=1}^{J} P_j^t \leq P_j^{t+1} \leq Jmax, \forall\ t \tag{23}$$

$$\sum_{m=1}^{M} Z_m^t \leq Z_m^{t+1} \leq Mmax, \forall\ t \tag{24}$$

$$\sum_{l=1}^{L} V_l^t \leq V_l^{t+1} \leq Lmax, \forall\ t \tag{25}$$

$$\sum_{n=1}^{N} D_n^t \leq D_n^{t+1} \leq Nmax, \forall\ t \tag{26}$$

$$\sum_{k=1}^{K} U_k^t \leq U_k^{t+1} \leq Kmax, \forall\ t \tag{27}$$

4.0/1 integer variables**:** $P_j^t, Z_m^t, V_l^t, D_n^t, U_k^t$

In the proposed model, the objective function (1) minimizes the total reverse logistics costs, including transportation, inventory, fixed, and operation. Constraints (2)–(13) represent balanced flow among the centers, and also determine the total amount of waste transferred to each center, and inventory amounts. Constraints (14)–(18) limit the capacity of storage, sterilization, burning, burying with lime, and grinding centers by Constraints (19)–(22), represent handling at the storage, and processing centers cannot exceed the maximum level. Constraints (23)–(27) limit the number of new facilities that are opened. Constraint (28) guarantees the binary decision variables

5. Case Study

With the publication of the regulation of waste management unit by the Ministry of Environment and Forests of Turkey (MWCR 2005) in the 2000s, many processing and storage centers opened for the disposal of medical waste. Currently, there are 17 sterilization centers and 2 burning centers in operation throughout Turkey. Centers that bury with lime provide a service in cities where the secure disposal of medical waste cannot be achieved. It is determined that there are 13 burying with lime centers in operation (HWP, 2008).

According to a circular published in Turkey, 16% of medical waste is taken to burning centers, 34% to sterilization centers, and 50% to burying with lime centers, while 39 storage centers are taken into consideration in the model since the transportation of waste generated by health institutions is provided. In Turkey, grinding centers are used not only for waste generated from health institutions but also for many types of solid waste. It is assumed that 17 grinding centers are only used for waste generated by health institutions. Additionally, the locations of grinding centers are same as the sterilization centers 39 storage centers, 30 sterilization centers, 9 burning centers, 26 burying with lime centers, and 30 grinding centers are taken into consideration in the study. It is determined there are 17 sterilization centers, 2 burning centers, and 13 burying with lime centers are in operation throughout Turkey, for this study; 13 potential sterilization centers, 7 potential burning centers, and 13 potential burying with lime centers are determined as potential centers.

6. Analysis and Results

For analysis, firstly, a 3-year planning horizon was considered, and sensitivity analysis was also performed according to the increased amount of waste and the results obtained. All the cost values were assumed to increase by the yearly inflation rate over the planning horizon. Also, the yearly waste processing rate factors were taken as one unit for all facilities.

Waste amounts arising from health institutions in Turkey vary by region. Hence, there is uncertainty about the increase rate in the waste amounts on a yearly basis. The experts working in the Turkish Ministry of Environment and Forests were asked for the yearly increase rate of the waste amounts, and it was estimated that the yearly increase rate in the waste amount was approximately 10%. With sensitivity analysis, we conducted how the facility necessity changed according to the incremental waste amounts, and the impact of changes weree analyzed in the strategic network design of the disposal system, including cost factors over the planning horizon.

For the analysis, 5 different scenarios were simulated in which the increase rate changed from 10% to 40%, as shown in Table 1. Scenario 1 represents the current situation.

Table 1. Increased rate in waste amounts for different scenarios.

Scenarios	1	2	3	4	5
Increase rate in waste	-	10%	20%	30%	40%

For the analysis of the reverse logistics network of waste disposal in health-care institutions of Turkey, the mixed integer mathematical model is solved using Xpress IVE optimization software with the given parameters in the above sections.

In Table 2, the required number of opening facilities is given for the optimal solution of each scenario. Time periods for each scenario were examined in detail. The numbers of sterilization, burning, and burying with lime centers increase as the waste amount increases in the long-term planning. However, the total number of grinding centers almost doesn't change depending on the increasing waste amounts, due to their large annual capacities.

Table 2. Total number of opening facilities for optimal solution of each scenario.

Number	Scenario1			Scenario 2			Scenario 3			Scenario 4			Scenario 5		
Period	T1	T2	T3	T1	T2	T3	T1	T2	T3	T1	T2	T3	T1	T2	T3
SP	38	39	39	39	39	39	39	39	39	39	39	39	39	39	39
SC	13	13	19	13	14	20	14	15	22	15	16	23	16	17	23
BC	6	6	9	6	6	9	6	7	9	7	7	9	7	8	9
BWL	16	17	20	17	18	21	18	19	21	19	20	21	20	20	22
GC	10	10	15	10	10	15	10	10	15	11	11	16	11	11	17

SP: Storage Point; SC: Sterilization center; BC: Burning center; BWL: Burying with lime center; GC: Grinding center

According to the results of the model, all storage centers are expected to open for the optimal solution. A maximum of 39 units is sufficient to meet the temporary storage requirements in the long-term planning. There is not a significant increase in facilities for sterilization. There are 17 centers currently in operation, so planning can be done by changing the position of these 17 centers in the long-term planning. For sterilization centers, it is sufficient to establish 13 facilities in the first scenario, however, the number of facilities that are expected to be opened at the end of each time period increased up to 23.

The existing two burning centers are not sufficient for the optimal solution of the reverse logistics system. A total of 6 burning centers are needed to minimize the total costs. If the waste amount is increased by more than 30%, more burning centers should be opened. Although 6 burning centers are considered to be enough for the first scenario in the first time period, in the end of the third period it increases to 9, which is the maximum number of centers expected to be opened.

No dramatic increase is expected in the number of burying with lime centers; 16 centers are sufficient for the current situation according to the optimal solution. However, an increase up to 22 is expected in the number of facilities of burying with lime for the end of the planning horizon.

A dramatic reduction in the number of open grinding centers is noticed according to the optimized solution of scenario 1, which demonstrates the current situation. However, a rapid increase is observed in the number of opening centers at the end of the third time period for each scenario. In the long-term planning, the number of grinding centers established only for waste arising from health-care facilities should be an average of 17 units.

As seen in Figure 2, when considering the waste quantity to be delivered to the facilities for the first scenario, grinding centers receive the highest flow. This is due to domestic waste as a substantial percentage of total amount of waste. For medical waste, the highest flow is observed for burying with lime centers. Lime-burying is a cost-efficient and safe process. Therefore a large part of waste is processed in lime-burying facilities. The facility and processing costs of burning centers are higher than other facilities. As a result, the lowest waste flow is observed in burning centers.
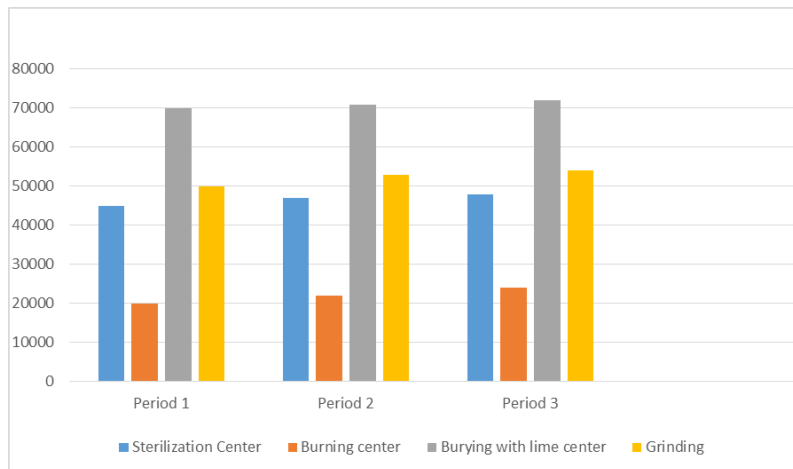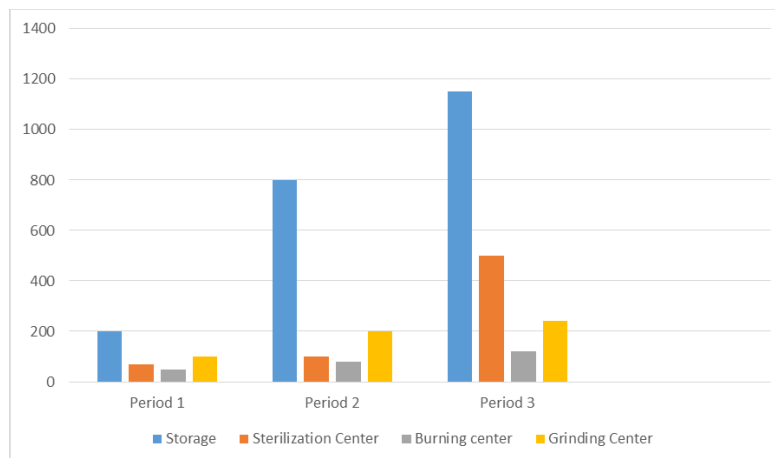
Figure 2.Total amount of flow.

Figure 3. Average inventory level for last scenario.

Waste inventory levels for each time period of the last scenario are shown in Figure 3. When examining the inventory levels in the model, it is seen that there is a significant increase at the end of the time period as the amount of waste increased by 30%, whereas for the first 3 scenarios the maximum inventory level was determined as 1,000, and for the 4th and 5th periods it was determined as 1,100 and 1,200, respectively. In the last scenario, in which the increased waste amount is 40%, a higher amount of inventory is observed in comparison to the other scenarios. In particular, in some storage centers, the amounts reach the maximum inventory level. At the end of each period as the amount of waste increases, the inventory level also rises. In terms of the facilities, the highest inventory is in the grinding centers, followed by the sterilization and, finally, the burning centers. Burying with lime centers, on the other hand, have no inventory. Waste received at these centers is buried directly and no inventory is kept.

Cost analysis of reverse logistics network is examined in 4 main cost factors: transportation, inventory, opening, and processing costs. Figure 4 also depicts the total costs analysis of disposal system graphically**.**

For all scenarios, while inventory costs are fairly low in the first period, they reach maximum levels at the end of the period. As it can be seen from Figure 7, the highest inventory is kept in storage centers, as the majority of the inventory costs are due to the waste amounts kept in storage centers. Processing and inventory costs, on the other hand, increase in every period, especially after the second period, depending on the increasing amount of waste and cost units. In addition, it is seen that cost values have started to increase significantly in time period 3. For each scenario, all cost factors increased due to increased waste amounts of 10%.

Figure 8 presents the total costs in the reverse logistics network on the basis of 3 periods and different scenarios. As can be seen from the graph, at the end of the time periods the total cost increases, in line with the increasing unit processing, transportation, and facility costs. Depending on the scenario, a 10% increase in waste causes significant changes in the total cost. According to the multiperiod model, investments that are essential for further periods may be carried out with the consideration of the long-term planning results.

Some of specific results can be proposed from the Turkish aspect. Sterilization centers are expected to be established in locations with high population density. It is also observed that sterilization centers are generally opened in the central part of the country and sea coast cities. Burying with lime centers are generally established in cities that do not have a sterilization center. Opening these facilities in cities with low population density could be encouraged and planning could be designed accordingly for the future.

When analyzing results, it is seen that opening rates of facilities increased, especially after scenario 4. In addition, the opening rates of facilities closest to the storage centers were higher. This is important, once again, in terms of eliminating transportation cost. When considering cost analysis, it is observed that the operation cost factor has the largest value, and the transportation cost factor has the second largest. The total fixed costs of the facilities and inventory cost are quite low compared to other cost factors. Some of general discussions can be obtained by using the proposed multitype waste, multiperiod, multitype facility reverse logistics model;
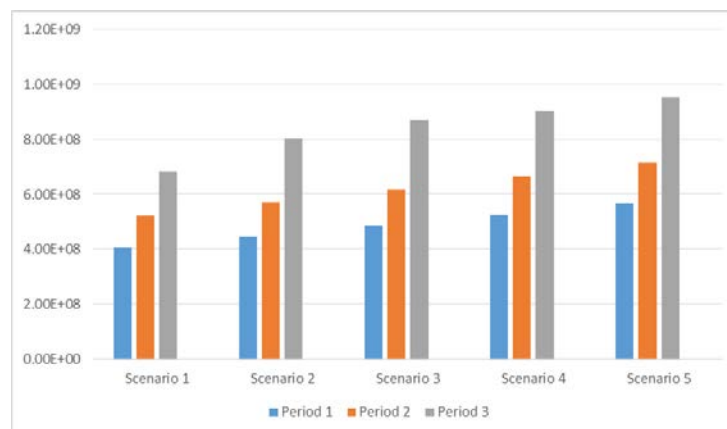

Figure 4. Total cost of reverse logistics network over the planning horizon.

Despite increasing waste amounts and cost factors according to the inflation rate, the environmental decision support system provides a minimized system cost and allocates waste flows to different facilities cost-effectively. The proposed model provided important highlights about how a multiperiod reverse logistics network may evolve over time. It also obtained some essential insights into the fact that processing centers are located according to potential savings in transportation costs between facilities. Moreover, by using the proposed multiperiod, multitype waste reverse logistics network, it is able to provide an environmentally friendly decision support for both the current situation and long-term planning, which can be concluded by waste disposal planning and inventory control in an integrated process.

The practical approach of the proposed reverse logistics model covers many factors, such as suppliers, waste managers, processing centers, distributors, and operational elements, so that a systematic strategic model can be obtained between all echelons in a multitype waste, multiperiod reverse logistics network, rather than individual operational and inventory planning. Using the proposed reverse logistics network design would lead to optimized productivity with effective inventory management within capacity constraints.

7. Conclusions
Waste management in health institutions has become more important in the contemporary world. The waste arising from health institutions generates serious risks due to the increasing number of facilities. Also, in Turkey, the health sector has developed in recent years owing to the increase in population and industrialization. Moreover, cost optimization has become important for efficient waste management in health institutions. In this study, a reverse logistics optimization was conducted for waste collection and disposal in health institutions in Turkey. Hence, the

reverse logistics system for waste generated from health institutions in Turkey was discussed, and different scenarios were simulated for different waste quantities. For the analysis, a 3-year multiperiod was considered and mixed integer linear programming model was proposed to determine the required numbers, types, and locations of facilities to minimize the The proposed multiperiod model considers several features of practical relevance, namely: a multiperiod setting, modular capacities and waste quantities, variable operational costs, finite capacity and inventory levels, and a cost-oriented objective function. A possible avenue for future research is to develop a decision support model for the waste collection and disposal system of health institutions in Turkey.

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