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Multi-objective Optimization Model for Medical Waste Supply Chain Management Without Landfill Tax During COVID-19 In Indonesia

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Abstract
The COVID-19 pandemic has brought various problems into our daily lifes, and one of them is an increase in the volume of medical waste, which poses a risk to the environment and health. An evaluation of how optimal the supply chain management of medical waste as a whole can assist in the development of medical waste management and policy making. In this paper, the study on observing and reformulating the existing medical waste supply chain optimization model using Mixed Integer Linear Programming (MILP) is discussed. This study is done by modifying the objective function and the constraints with considering elimination of the landfill tax variable. The resulted model is also a multi-objective optimization problem. To this end, the Lexicographic Method is employed to obtained the optimal solution. In this model, the most prioritizes that is considered in the environmental condition to the medical waste supply chain. A numerical experiment is done in this paper which it results suggests two things, first, the cost of medical waste processing is much greater than its revenue, and second, the waste processing through incineration is not favorable.

Keywords: *Medical waste management, Optimization, COVID-19, Lexicographic method, MILP, Supply chain.*

1. Introduction

Waste production is a globally severe problem, considering they are one of the main factors of global warming. According to the World Bank Group [1], waste production is expected to increase globally by 70% by 2050 if there is no serious action. Waste management in Indonesia still depends mostly on open dumping, which means Indonesia is not immune to pollution caused by the accumulation of waste [2]. One of the impacts of COVID-19 is the increase in waste production globally, especially medical waste [3]. In 2021, Indonesia produced 29.5 tons of waste, and during the first 60 days of the pandemic, there were approximately 12.740 tons of medical waste produced [4, 5].

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Medical waste poses a threat for the environment and human health if were not handled correctly [6]. Proper waste management can prevent and reduce unwanted health and environmental impacts, and neglecting this can majorly affect the residents of the city and its surrounding. Research on medical waste management continues to evolve from various perspectives. Research conducted by Berg et al. [7] before the COVID-19 pandemic presented a way to choose a waste management method using the normalization method from the initial data to obtain an index of potential environmental hazards of each method.

Apart from causing the increase in medical waste volume, COVID-19 has made waste management become a more sensitive process with tighter regulations to prevent bacterial and germ contaminations. Kargar et al. [8] developed a tri-objective model using MILP, fuzzy goal programming and robust probabilistic programming using a case study located in Iran that focused on minimizing the total cost, maximizing the selection of appropriate waste management strategies, and minimizing the total medical waste generated to landfill. Mei et al. [9] developed a logistic chain model that focused on minimizing cost, time, and safety risk using mixed integer non-linear programming (MINLP) with a case study in the United States. Govindan et al. [10] developed an MINLP model that minimizes the total cost and risk of exposure to pollution using a fuzzy goal programming approach with a study case located in Iran.

Munguía-Lopez et al. [3] developed a circular framework model for all types of waste management using MILP that minimizes environmental impact and maximize economic impact and incorporate green taxes to promote the processing of energy production with a study case located in the United States. Zarrinpoor [11] developed a waste management model with a study case in Iran that focused on minimizing the cost and environmental impacts using MILP and credibility-based possibilistic programming for its uncertainty factor. Bani et al. [12] developed a vaccine waste supply chain model with a study case in Iran that focused on minimizing the cost and carbon emission using mixed integer programming (MIP) and fuzzy goal programming for its uncertainty factor. There are still many opportunities for the development of waste management process optimization, especially in Indonesia.

This study discusses the application of the optimization model for medical waste supply chain management. Multi-objective MILP model by Munguía-Lopez et al. [3], which focused on the economic benefits and environmental impact of waste management, is reformulated to focus on medical waste and considering the conditions and regulations of Indonesia by eliminating the tax variable in the model. The sections of this study are organized as follows. In section 2, the methods used in this study are discussed. Section 3 presents the results and discussion of this study. Finally, section 4 discussed the conclusions and suggestions for future studies.

2. Materials and Methods

In this study, the method of optimization model reformulation modelling is by analyzing the actual case of medical waste management in Indonesia. Firstly, the regulations and conditions regarding medical waste management in Indonesia are researched. A medical waste management structure and model are created accordingly. Finally, the model is tested with the case in Indonesia in 2021. The value for relevant parameters is obtained through *Direktorat Jenderal Pengelolaan Sampah, Limbah dan B3* website and literature research.

2.1. **Systematic Literature Review.** Literature review is a comprehensive review and analysis of academic literature that demonstrates knowledge and understanding on a particular topic. Literature review shows the development of a research topic to ensure that topic is current and relevant [13]. Bibliometric analysis was done to see the mapping of research and citation distribution from various literature with the keywords “optimization”, “medical waste”, “linear programming”, and “COVID-19” with the publication period from 2020 to 2022. Furthermore, the state of art of this study was determined using The Preferred Reporting Items for Systematic Reviews and Meta Analysis (PRISMA). For PRISMA stage, the databases were taken from Science Direct and Dimensions because these two databases contain complete articles that can be downloaded from the database immediately. Figure 1 depicted the PRISMA flowchart.

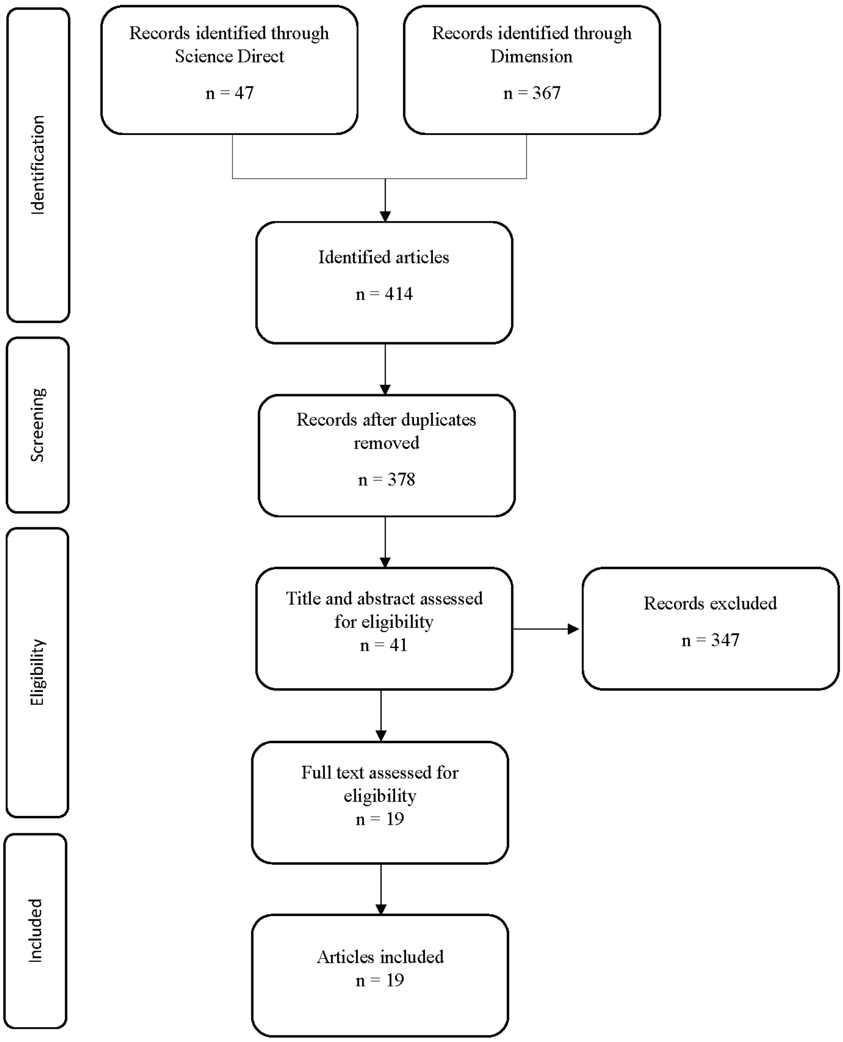

Figure 1. PRISMA flowchart

Articles are deemed irrelevant if they do not discuss medical waste management, are not relevant to COVID-19, are written in languages other than English, or do not discuss optimization. This literature review examined the potential of medical waste management optimization research in Indonesia. The distinction of this study is the location of this study which is conducted in Indonesia. Table 1 depicted the differences between this study and other studies.

2.2. **Mixed Integer Linear Programming.** Mixed integer linear programming is a linear programming optimization problem where some variables are integers. MILP is often used to analyze systems and optimization problems because of the characteristic of MILP, where they present a flexible method to solve big and complex problems [28]. According to Rao [29], the

Table 1. State of the art

Research	**Supply chain**	**Medical waste management**	**Study case location**	**Optimization methods**
Yu et al [15], 2020	✓	✓	China	MILP
Kargar et al. [8], 2020	✓	✓	Iran	MILP, Fuzzy goal programming, Robust possibilistic programming
Valizadeh et al. [16], 2021		✓	Iran	Stochastic programming, Bender Decomposition, Karush Kuhn-Tucker condition
Tirkolaee & Aydin [17], 2021		✓	-	MILP, Meta-Goal programming
He et al. [18], 2021		✓	China	MILP, Dynamic programming
Mishra & Rani [19], 2021	✓	✓	India	Fermeatan Fuzzy, Weighted aggregated sum product assessment
Mei et al. [9], 2021	✓	✓	United States	MINLP
Govindan et al. [10], 2021	✓	✓	Iran	MILP, Fuzzy goal programming
Aydemir-Karadag [20], 2021		✓	-	MINLP, Adaptive Large Neighborhood Search
Lotfi et al. [21], 2021	✓	✓	Iran	MINLP, Robust stochastic programming
Polat [22], 2021	✓	✓	Turkey	MIP, Jimenez method, Time series
Munguía-Lopez et al. [3], 2022	✓	✓	United States	MILP
Luo & Liao [23], 2022	✓	✓	China	MILP
Govindan et al. [24], 2022	✓	✓	Iran	MILP, Queueing theory
Erdem [25], 2022	✓	✓	Turkey	MIP, Adaptive Large Neighborhood Search

Research	Supply chain	Medical waste management	Study case location	Optimization methods
Zarrinpoor [11], 2022	✓	✓	Iran	MILP, Fuzzy goal programming, Credibility-based possibilistic programming
Bani et al. [12], 2022, 2022	✓	✓	Iran	MIP, Robust optimization, Fuzzy goal programming
Kordi et al. [26], 2022		✓	Iran	MILP, Fuzzy goal programming
Tirkolaee et al. [27], 2022		✓	-	MILP, Multi-objective simulated annealing algorithm, Multi-objective invasive weed optimization algorithm

general form of MILP is

$$\begin{aligned} &\min f(\boldsymbol{x}) = \boldsymbol{c^T x} \\ &s.t\ g_j(\boldsymbol{x}) \geq 0,\ j = 1, 2, \ldots, m \\ &h_k(\boldsymbol{x}) = 0,\ k = 1, 2, \ldots, p \\ &\boldsymbol{x_j} = integer\ ,\ j = 1, 2, \ldots, n_0 (n_0 \leq\ n) \end{aligned} \tag{1}$$

where $\boldsymbol{x} = (x_1, x_2, \ldots, x_n)^T$, $g_j(\boldsymbol{x})$ represents inequality constraint functions, and $h_k(\boldsymbol{x})$ represents equality constraint functions.

2.3. **Multiobjective Optimization.** Multiobjective optimization is an optimization problem where there are more than one objective function [30]. Multiobjective optimization problem include three elements: decision maker, one set of feasible solution defined by the constraint functions, and several objective functions [31]. Based on Rao [29], the general form of multiobjective optimization problem is as the following :

$$\begin{aligned} &\min f_1(\boldsymbol{x}),\ f_2(\boldsymbol{x}), \ldots, f_k(\boldsymbol{x}) \\ &s.t \quad g_j(\boldsymbol{x}) \leq 0; j = 1, 2, \ldots, m \end{aligned} \tag{2}$$

where $f_k(\boldsymbol{x})$ is the objective functions, $g_j(\boldsymbol{x})$ is the constraint functions, and k is the number of objective functions to be minimized.

One of the methods to solve multiobjective optimization problems is the lexicographic method. The usage of lexicographic method optimization dates back to the 70s in the papers by Isermann (1974), Fishburn (1974), and Behringer (1977) [32]. In Lexicographic Method, the objective functions are ranked based on their importance and solved one by one with the previous objective function as a constraint. The first problem is formulated as

$$\begin{aligned} &\min f_1(\boldsymbol{x}) \\ &s.t \quad g_j(\boldsymbol{x}) \leq 0; j = 1, 2, \ldots, m \end{aligned} \tag{3}$$

and the solutions obtained from the Equation (3) are x_1^* and $f_1^* = f_1(x_1^*)$. The second problem is formulated as

$$\begin{aligned} &\min f_2(\boldsymbol{x}) \\ &s.t \quad g_j(\boldsymbol{x}) \leq 0; j = 1, 2, \ldots, m \\ &\qquad f_2(\boldsymbol{x}) = f_1^* \end{aligned} \tag{4}$$

and the solutions obtained from the Equation (4) are x_2^* and $f_2^* = f_2(x_2^*)$. The procedure is repeated until all objectives have been considered. The ith problem is formulated as

$$\begin{aligned} &\min f_i(\boldsymbol{x}) \\ &s.t \quad g_j(\boldsymbol{x}) \leq 0; j = 1, 2, \ldots, m \\ &\qquad f_l(\boldsymbol{x}) = f_l^*, l = 1, 2, \ldots, i-1 \end{aligned} \tag{5}$$

and the solutions obtained from the problem (2.3) are x_i^* and $f_i^* = f_i(x_i^*)$. The final solution for multiobjective optimization problem is x_i^* [29].

In multi-objective optimization, there might be several conflicting solutions and comparing each one of them is not an easy task. The most common method in comparing the alternative solutions is by using Pareto dominant relation [33]. Pareto optimality is an efficiency concept used in economics, social study, and political study, where resources cannot be allocated if detrimenting one party [34]. Based on Arora [35], theoretically, lexicographic method always provides Pareto optimal solution. According to Lai et al. [32], this is because in the lexicographic method the objective functions is already sorted based on its importance. Hence there is only a single solution that is Pareto optimal.

2.4. **Medical Waste Management.** Medical waste is all kinds of waste generated by healthcare activities [36]. Improper disposal of medical waste potentially causes environmental pollution, which potentially spreads viruses, germs, chemical pollutants, and even radioactive materials [37]. According to World Health Organization, medical waste is divided into two categories, which are hazardous waste (15%) and non-hazardous waste (85%) [36]. Medical waste is further divided into several types, such as infectious waste, pathological waste, sharp waste, chemical waste, pharmaceutical waste, cytotoxic waste, radioactive waste, and general waste [38]. In Indonesia, infectious and pathological waste makes up to 10%, chemical and pharmaceutical waste makes up to 3% and sharp waste makes up to 1% of medical waste [39].

Before COVID-19, non-hazardous waste does not need specific treatment, unlike hazardous waste, and can directly enter the municipal waste management network [8]. Hazardous waste needs special treatment where they will be separated and stored according to their types before being further processed using technologies such as incineration, chemical disinfection, and thermal sterilization [40]. The structure of the medical waste management process is shown in Figure 2.

Incineration is the most common medical waste processing method where the waste is combusted between $800^o\ C - 1200^o\ C$ [40]. This method effectively reduces the waste volume by 90% and kills pathogens [41], although this method cannot be used for sharp waste and waste made of plastic, according to Permenkes Nomor 18 Tahun 2020. Even though medical waste processing through incineration does not cost a lot of money, but this method consumes the most energy and produces the biggest amount of pollutants [3].

Chemical disinfection is the most common pre-treatment for COVID-19 waste. This method is done through a combination of prior mechanical shredding, and later, the waste is mixed with a chemical disinfectant [40]. Chemical disinfection effectively kills pathogens

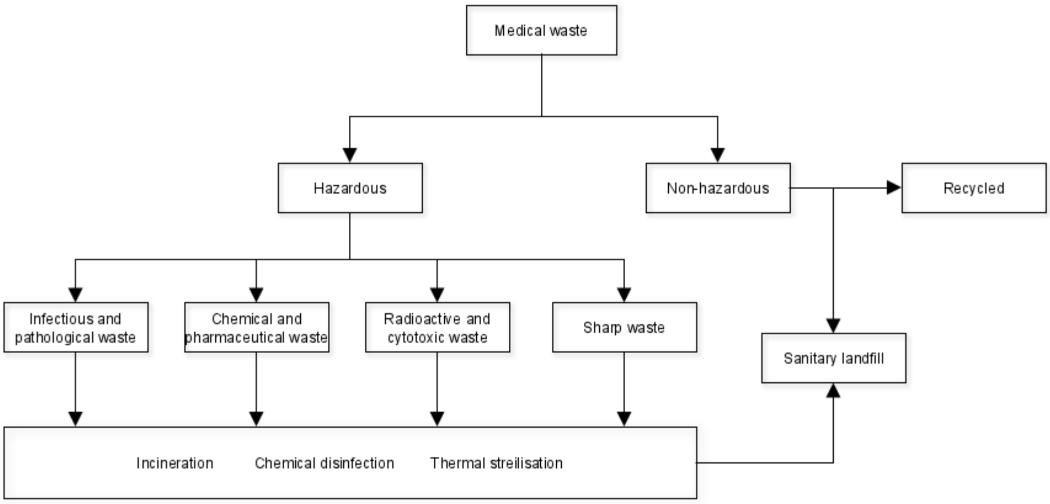

FIGURE 2. Medical waste management structure pre COVID-19

in small volumes, has stable performance and has a low negative impact to the environment [41,42].

There are primarily two types of thermal sterilization which are the pyrolysis technique and the microwave technique. The pyrolysis technique is more technologically advanced than incineration and is done in high temperatures ranging from 540^o C to 830^o C [43]. This method is expensive but leaves almost no residue and has a low negative impact on the environment [41,42]. Microwave technique includes reverse polymerization in 117^o $C - 540^o$ C [40]. This technique uses small energy and has a low impact on the environment but has a narrow disinfection spectrum [41].

A landfill tax is an environmental tax imposed on waste disposal in landfills. This tax is designed as one of the actions done by the government of many countries to encourage recycling and the reduction of the amount of waste sent to landfills [44]. In Indonesia, landfill tax has been proposed several times but has not been imposed until now [45].

The structure of medical waste management process during COVID-19 is shown in Figure 3.

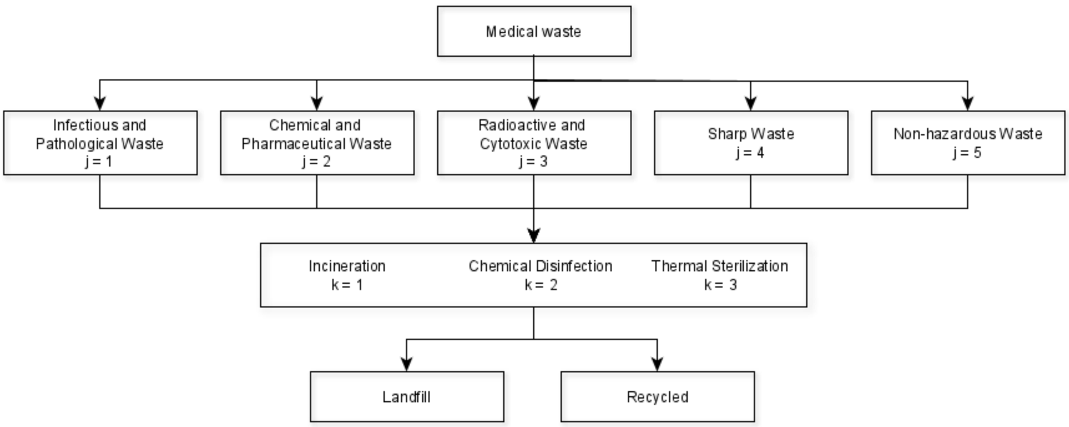

FIGURE 3. Medical waste management structure during COVID-19

2.5. **Waste Supply Chain Model.** Munguía-Lopez et al. [3] (2022) formulated an optimization model for the supply chain management of all types of solid wastes as depicted in Figure 4. The model designed by Munguía-Lopez et al. [3] (2022) focuses on process intensification by proposing a strategy of different tax rates depending on the amount of waste disposed to the landfill.

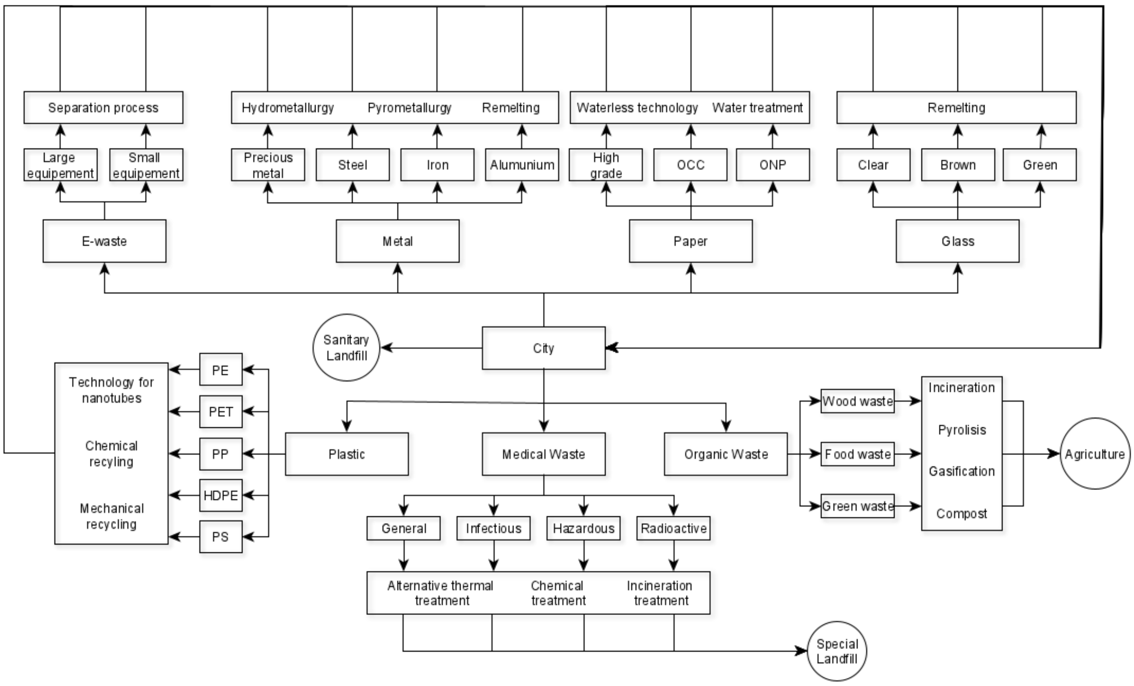

FIGURE 4. Munguía-Lopez et al. (2022) solid waste management structure

The total waste (TW) in a city or place each year must be segregated and categorised based on their types of waste. $T^{landfill}$ represent the amount of waste disposed directly to the landfill i represent a set of types of waste, wf represents the fraction of waste that directly disposed to the landfill, T_i represents waste type i that will be processed, and α_i represents the fraction of waste i.

$$\boldsymbol{T}_i = (\mathbf{1} - \boldsymbol{wf})\,\boldsymbol{TW} \cdot \alpha_i, \forall \boldsymbol{i} \in \boldsymbol{I} \tag{6}$$

$$\boldsymbol{T}^{landfill} = \boldsymbol{wf} \cdot \boldsymbol{TW} \tag{7}$$

Furthermore, waste type i further segregated according to their subtypes. Classified waste type i subtype j is represented by $cw_{i,j}$, j represents a set of subtypes of waste and $\beta_{i,j}$ represents the fraction of waste i subtype j.

$$\boldsymbol{cw}_{ij} = \beta_{ij} \cdot T_i, \forall i \in I, \quad j \in J \tag{8}$$

The classified waste is further sent into different processing facilities as depicted by Equation (9). $f_{j,k}$ represents waste subtype j processed using technology k.

$$\boldsymbol{cw}_{i,j} = \sum_{\boldsymbol{k} \in \boldsymbol{K}} \boldsymbol{f}_{j,k}, \forall \boldsymbol{i} \in \boldsymbol{I}, \quad \boldsymbol{j} \in \boldsymbol{J} \tag{9}$$

The decision to choose the right technology for each subtype of waste is decided by binary variable $h_{j,k}$. If $h_{j,k} = 1$, the technology is used and if $h_{j,k} = 0$ the technology is discarded. The inequality to decide the technology and the amount of waste that is processed by the specific technology is decided by Equation (10) to (12).

$$f_{j,k} \geq \delta_{j,k}^{min} \cdot h_{j,k}, \forall\ j \in J,\ k \in K \tag{10}$$

$$f_{j,k} \leq \delta_{j,k}^{max} \cdot h_{j,k}, \forall\ j \in J,\ k \in K \tag{11}$$

$$cost_{j,k} = kf\left(A_{j,k} \cdot h_{j,k} + B_{j,k} \cdot f_{j,k}\right),\ \forall\ j \in J,\ k \in K \tag{12}$$

Investment in solid waste processing varies depending on the technology employed, the processing capacity, and the expenses connected with solid waste transportation in waste management. The costs and income related to waste processing are presented as follows:

$$TC = Transport + Treatment\ cost + Taxes \tag{13}$$

$$Transport\ cost = RMTC + PTC \tag{14}$$

$$RMTC = TCPT\left(\sum_{i \in I} T_i\right) + \sum_{i \in I} \left(SC_i \cdot T_i\right) \tag{15}$$

$$PTC = TCPT\left(\sum_{j \in J} \sum_{k \in K} p_{j,k}\right) \tag{16}$$

$$Treatment\ cost = \sum_{j \in J} \sum_{k \in K} cost_{j,k} \tag{17}$$

$$Revenue = \omega_{j,k} \cdot p_{j,k} \tag{18}$$

$$Total\ profit = TC - Revenue \tag{19}$$

The calculate the revenue from tax, T^{landL} and T^{landH} was introduced to separate between the waste that is charged with high tax and low tax. T^{landL} represents the amount of waste subjected to low tax rate and T^{landH} represents the amount of waste subjected to high tax rate.

$$T^{landfill} = T^{landL} + T^{landH} \tag{20}$$

The decision to choose the tax rate is decided by the binary variable $h^{landfill}$, where if $h^{landfill} = 1$ means the waste is subjected to lower tax rate and if $h^{landfill} = 0$ means the waste is subjected to higher tax rate. T^{II} represents the upper bound for the waste with lower tax and T^{III} represents the upper bound for the waste with higher tax.

$$T^{landL} < T^{II} \cdot h^{landfill} \tag{21}$$

$$T^{landL} \geq T^{II}(1 - h^{landfill}) \tag{22}$$

$$T^{landH} \leq T^{III}(1 - h^{landfill}) \tag{23}$$

Tax revenue from waste that is subject to low and high tax rates is obtained through the relations in Equation (24) and Equation (25). $Taxes^L$ represents tax revenue from lower tax rate, $Taxes^H$ represents tax revenue from higher tax rate, TPT^L represents unitary tax with lower tax rate, and TPT^H represents unitary tax with high tax rate. The total tax revenue is represented in Equation (26).

$$Taxes^L = TPT^L \cdot T^{landL} \tag{24}$$

$$Taxes^H = TPT^H \cdot T^{landH} \tag{25}$$

$$Taxes = Taxes^L + Taxes^H \tag{26}$$

The objective of the model is to reduce the amount of waste sent to the landfill and maximize the amount of profit gained through the waste management process as represented in Equation (27).

$$\begin{gathered} \min T^{landfill} \\ \max\ Total\ profit \end{gathered} \tag{27}$$

The complete optimization problem designed by Munguía-Lopez et al. [3] (2022) is as follows.

$$\begin{aligned}
\min \quad & T^{landfill} \\
\max \quad & Total\ profit \\
s.t \quad & f_{j,k} \geq \delta_{j,k}^{min} \cdot h_{j,k}, \forall\ j \in J,\ k \in K \\
& f_{j,k} \leq \delta_{j,k}^{max} \cdot h_{j,k}, \forall\ j \in J,\ k \in K \\
& T^{landL} < T^{II} \cdot h^{landfill} \\
& T^{landL} \geq T^{II}(1 - h^{landfill}) \\
& T^{landH} \leq T^{III}\left(1 - h^{landfill}\right) \\
& h_{j,k}, h^{landfill} \in [0,1] \\
& f_{j,k} \geq 0
\end{aligned} \tag{28}$$

3. Result and Discussions

In this section, an extented application of Model (6)-(2.5) of Munguía-Lopez et al. [3] is presented. A study of formulating the application on optimization model of medical waste management is presented.

3.1. Model Assumption.

In this paper, a study of formulating the application on optimization model of medical waste management is presented. Medical waste moves from healthcare facilities, waste separation facilities, waste treatment sites, and sanitary landfills. The following are the assumptions that are applied to the following model.

a. COVID-19 causes all medical waste is treated like hazardous medical waste, thus need to be processed before being recycled or entering sanitary landfills.
b. All medical waste that has been processed is sent to landfill.
c. Landfill tax is not applied to the model.=1
d. Medical waste made of plastic can be recycled and generate income.
e. Sharp medical waste and medical waste made of plastic cannot be processed using incinerators.

3.2. Mathematical Model.

The existing model from Munguía-Lopez et al. [3] focuses on all types of waste, while this study only focuses on medical waste, so the sets of i from the existing model is removed. The medical waste generated per year is represented in Equations (29) and (30).

$$\boldsymbol{T_{medical} = (1 - wf)\, TMW} \tag{29}$$

$$\boldsymbol{T^{landfill} = wf \cdot TMW} \tag{30}$$

with T_{medis} represents the total medical waste being processed, wf represents fraction of medical waste that cannot be processed, TMW represents the total medical waste, and $T^{landfill}$ represents the total medical waste sent to the landfill without being processed.

All medical waste is processed by different technologies which is represented by Equation (8). Set j represents the subtypes of medical waste ($j = 1, 2, 3, 4, 5$) and set k represents the technology used to process medical waste ($k = 1, 2, 3$).

$$cw_j = \beta_j \cdot T_{medical}, \quad j \in J \tag{31}$$

with cw_j represents classified waste subtype j and β_j represents the fraction of medical waste subtype j. Then, the medical waste is sent to the processing facilities to be processed.

$$\boldsymbol{cw_j = \sum_{k \in K} f_{j,k}, \quad j \in J} \tag{32}$$

where $f_{j,k}$ represents classified medical waste subtype j will be processed using technology k.

The decision on what types of technology that are going to be used depends on the binary variable $h_{j,k}$. The model to choose the technologies are

$$f_{j,k} \geq \delta_{j,k}^{min} \cdot h_{j,k}, \forall\, j \in J,\ k \in K \tag{33}$$

$$f_{j,k} \leq \delta_{j,k}^{max} \cdot h_{j,k}, \forall\, j \in J,\ k \in K \tag{34}$$

$$cost_{j,k} = kf\left(A_{j,k} \cdot h_{j,k} + B_{j,k} \cdot f_{j,k}\right),\ \forall\, j \in J,\ k \in K \tag{35}$$

where $\delta_{j,k}^{min}$ represents the minimum processing capacity, $\delta_{j,k}^{max}$ the maximum processing capacity, $cost_{j,k}$ represents the cost to implement technology k, kf represents the annualization factor, $A_{j,k}$ represents the fixed cost and $B_{j,k}$ represents the variable cost for using technology k for medical waste subtype j.

In medical waste processing in Indonesia, cost numeration is separated based on in-vestment and operations. The waste management costs per ton incurred in both self-managed and outsourcing systems already include direct management and trans-portation cost. Considering that medical waste made of plastic can be recycled and gener-ate revenue, the equation related to costs and revenue is as follows.

$$TC = TSC + Treatment\ cost \tag{36}$$

$$TSC = SC_{medical} \cdot T_{medical} \tag{37}$$

$$Treatment\ cost = \sum_{j \in J} \sum_{k \in K} cost_{j,k} \tag{38}$$

$$Revenue = \omega_{j,k} \cdot p_{j,k} \tag{39}$$

where TC is total cost, TSC is total separation cost, $\omega_{j,k}$ represents revenue per tonne, and $p_{j,k}$ represents the product obtained from the treatment. Considering the expenses and income from medical waste processing, the equation for the profit is as follows.

$$Total\ profit = Revenue - TC \tag{40}$$

The amount of medical waste that can be processed is limited. Thus, some of the waste cannot be processed and must be sent directly to the landfill. Therefore, the optimization model was created with the aim of maximizing the amount of medical waste that is processed so that the amount of waste directly disposed to the landfill is lowered in order to reduce the impact on the environment. In addition, the waste management process needs to pay attention to the amount of expenditure and income generated, so the model aims to maximize profit. The rank of objectives' importance for this model is minimizing $T^{landfill}$ and maximizing $Total\ profit$.

$$\begin{array}{ll} \min & T^{landfill} \\ \max & Total\ profit \end{array} \tag{41}$$

The complete optimization model for medical waste management is as follows.

$$\begin{array}{ll} \min & T^{landfill} \\ \max & Total\ profit \\ s.t & f_{j,k} \geq \delta_{j,k}^{min} \cdot h_{j,k}, \forall\, j \in J,\ k \in K \\ & f_{j,k} \leq \delta_{j,k}^{max} \cdot h_{j,k}, \forall\, j \in J,\ k \in K \\ & \sum_{k \in K} f_{j,k} \leq \beta_j \cdot T_{medical} \\ & \sum_{j \in J} \sum_{k \in K} f_{j,k} \leq TMW \\ & f_{j,k} \geq 0 \\ & h_{j,k} \in [0, 1] \end{array} \tag{42}$$

3.3. **Case Study.** The case study for the application of the optimization model is Indonesia, where Indonesia is one of the largest waste contributors in the world [46]. In 2021, the average medical waste accumulation in Indonesia reaches 493 tones/day [47]. Medical waste management capacity in Indonesia reaches 458.5 tones/day, with an estimated 58.7% of hazardous waste being processed using incinerator [48,49].

According to *Direktorat Jenderal Pengelolaan Sampah, Limbah dan B3* [50], around 22.5% of hazardous waste is being recycled, with the utilization price index reaching Rp 541,406/ton. The annualization factor for the cost of waste processing is 30% [51]. The average US Dollar exchange rate to Rupiah in 2021 is Rp 14,308 [52]. The separation cost for medical waste is Rp 13,582/ton [49]. The fixed cost and variable cost for medical waste processing technologies is shown in Table 2.

Table 2. Medical waste processing cost

Technology (k)	**Fixed cost** ($A_{j,k}$)	**Variable cost** ($B_{j,k}$)	**Source**
Incineration	4,000,000 \$US	380 \$US/ton	[53]
Chemical disinfection	2,090,000 \$US	200 \$US/ton	[53]
Thermal sterilization	2,000,000 \$US	400 \$US/ton	[53]

3.4. **Result.** In this section, formulation of the medical waste management optimization model is presented. A case study located in Indonesia with the decision variables $h_{j,k}$ and $f_{j,k}$ is discussed. The final model in Equation (9) is a multiobjective mixed integer linear programming problem and solve using lexicographic method. The model respectively is ranked as minimizing $T^{landfill}$ and maximizing $Total\ profit$.

To solve multiobjective optimization using lexicographic method, the process of obtaining the results is divided into several steps, depending on the number of objective functions. Since the final model has two objective functions, the process is divided into two steps.

(1) Step 1
Solve the first objective function as the following. The optimal value of the first objective function $f_1\left(h_{j,k}, f_{j,k}\right)$ is f_1^*.

$$
\begin{aligned}
\min \quad & T^{landfill} \\
\max \quad & Total\ profit \\
s.t \quad & f_{j,k} \geq \delta_{j,k}^{min} \cdot h_{j,k}, \forall\ j \in J,\ k \in K \\
& f_{j,k} \leq \delta_{j,k}^{max} \cdot h_{j,k}, \forall\ j \in J,\ k \in K \\
& \sum_{k \in K} f_{j,k} \leq \beta_j \cdot T_{medical} \\
& \sum_{j \in J} \sum_{k \in K} f_{j,k} \leq TMW \\
& f_{j,k} \geq 0 \\
& h_{j,k} \in [0,1]
\end{aligned}
\tag{43}
$$

(2) Step 2
Solve the second objective function $f_2\left(h_{j,k}, f_{j,k}\right)$ with the first objective function $f_1(h_{j,k}, f_{j,k})$ as a constraint as the following.

$$
\begin{aligned}
\max \quad & Total\ profit \\
s.t \quad & T^{landfill} \leq f_1^* \\
& f_{j,k} \geq \delta_{j,k}^{min} \cdot h_{j,k}, \forall\ j \in J,\ k \in K \\
& f_{j,k} \leq \delta_{j,k}^{max} \cdot h_{j,k}, \forall\ j \in J,\ k \in K \\
& \sum_{k \in K} f_{j,k} \leq \beta_j \cdot T_{medical} \\
& \sum_{j \in J} \sum_{k \in K} f_{j,k} \leq TMW \\
& f_{j,k} \geq 0 \\
& h_{j,k} \in [0, 1]
\end{aligned} \tag{44}
$$

The model was solved using Python with PuLP library for solving the MILP and Panda library for creating data frame. The algorithm to solve the optimization model using Python as presented in Algorithm 1, 2 and 3.

Algorithm 1: Library installation

Begin

Step 1: Install the PuLP library with the syntax "pip install pulp"
Step 2: Step 2: Import the required library and create the shortcut using "import pulp as lp"

Algorithm 2: Solving the minimum problem

Begin

Step 1: Define the problem, obj1, using syntax "lp.LpProblem", then "lp.LpMinimize", and the variables using syntax "lp.LpVariable"
Step 2: Define the objective function
Step 3: Define the constraint functions
Step 4: Use the PuLP module to solve obj1 using "solve()"
Step 5: Print the problem's status using "lp.LpStatus"
Step 6: Define the solution using "lp.value"

The details of the optimization result are depicted in Table 3.

Algorithm 3: Solving the maximum problem

Begin

Step 1: Define the problem, obj2, using syntax "lp.LpProblem", then "lp.LpMaximize"
Step 2: Define the objective function
Step 3: Define the first objective as constraint using "<= solution"
Step 4: Define the constraint functions
Step 5: Use the PuLP module to solve obj1 using "solve()"
Step 6: Print the problem's status using "lp.LpStatus"
Step 7: Print the result using the following syntaxes
  For $j \in J$ **do**
    For $k \in K$ **do**
      Print $h_{j,k}$
      Print $f_{j,k}$
    End For
  End For
Step 8: Step 8: Print the solutions for obj1 and obj2 using "lp.value"

End

Table 3. Optimization model solution

$[j,k]$	$h_{j,k}$	$f_{j,k}$
$[1,1]$	0	0
$[1,2]$	1	16,735.25
$[1,3]$	0	0
$[2,1]$	0	0
$[2,2]$	1	5,020.575
$[2,3]$	0	0
$[3,1]$	0	0
$[3,2]$	1	1,673.525
$[3,3]$	0	0
$[4,1]$	0	0
$[4,2]$	1	1,673.525
$[4,3]$	0	0
$[5,1]$	0	0
$[5,2]$	1	34,558.2
$[5,3]$	1	34,s558.2

The following results are obtained:

(1) There are 34.5 tones gap between the medical waste production and processing capacity per day. This means not all medical waste can be processed, and some of them need to go straight to the landfill.
(2) The model proposes 94,219.275 tones of medical waste being processed, and the remaining waste was sent to the landfill directly.

(3) The expense from the medical waste management process is Rp 89,912,971,114.43, which means the cost of medical waste processing is much greater than the revenue. Even though the revenue is not as big as the total cost, the revenue itself is around Rp 21,920,243,100.75, which pretty significantly helps with the cost

From the solution above, the solutions do not recommend incineration as a way to process medical waste as it is a method that produces most pollutants.

4. Conclusions

In this paper, the reformulation of the optimization model for medical waste supply chain management without landfill tax is generated while considering the conditions and regulations of Indonesia. A multiobjective MILP optimization model with objectives of minimizing the environmental impact of medical waste management by minimizing the amount of waste generated to sanitary landfill and maximizing the economic benefit was constructed. The model is applied to Indonesia as a case study. The result is obtained using the lexicographic method where the objective functions are sorted by their importance, which in this study prioritizes the environmental impact first. The amount of medical waste generated is greater than the medical waste processing capacity. Thus, not all medical waste can be processed. The result suggests there is hardly any revenue generated, and the cost of medical waste processing is much greater. In addition, the solution suggests discarding incineration as a method for medical waste processing.

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