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Presenting a Planning Model for Urban Waste Transportation and Selling Recycled Products with a Green Chain Approach

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***Abstract*—The growing amount of municipal solid waste (MSW) is a significant issue, especially in large urban areas with inadequate landfill capacities and ineffective waste management systems. Several supply chain options exist for implementing an MSW management system; however, numerous technical, economic, environmental, and social factors must be evaluated to determine the optimal solution. This research aims to illustrate the difficulty of urban solid waste management in a network of supply chains with several levels. Hence, a mathematical model is implemented as a mixed integer linear programming problem that encompasses a variety of functions, comprising trash collection in cities, waste separation in sorting facilities, waste treatment in industries, and waste transportation between processing facilities. In addition, given the significance of urban solid waste management to environmental concerns, we are attempting to model the problem using a green approach. The purpose of the model proposed in this article is to determine the optimal distribution of waste among all units and maximize the net profit of the entire supply chain, along with a green approach. A case study has been undertaken to evaluate the efficacy and efficiency of the suggested model, which is utilized to solve the numerical problem with GAMS software and the grasshopper metaheuristic algorithm. The findings indicate that integrating municipal solid waste can yield economic and environmental benefits.**

***Keywords*—Planning model; urban waste transportation; recycled products; green supply chain**

I. INTRODUCTION

Municipal trash management is a collection of actions and procedures required for waste management from generation through disposal. These include collecting, shipping, and discarding trash and monitoring and regulating waste management. Solid, liquid, and gaseous waste have unique disposal and treatment procedures. Waste management encompasses all waste kinds, including industrial, biological, and municipal. In certain instances, trash can be hazardous to human health. The extraction and processing of raw materials are two examples of human operations that generate waste. Waste management aims to reduce trash's detrimental effects and ameliorate human health and nature [1]. Waste management practices are not the same in developed and developing countries. Also, these methods can have completely different approaches in urban or rural areas and residential or industrial areas. Municipal solid waste, the vast majority of trash produced by residential, industrial, and commercial activity, is the subject of several waste management strategies [2].

According to research conducted by Hoornweg and Bhada-Tata (2012) [3], municipal solid waste consists of various waste types (mixed municipal waste, segregated waste, general area waste, and hazardous waste) from a variety of construction and demolition sources; residential; institutional; industrial; commercial; demolition; land clearance; construction. Various means, such as door-to-door rubbish containers, delivery, and contractual or awarded services, collect these municipal solid wastes.

Without a doubt, this problem is one of the manifestations of human civilizations' excessive use of natural resources, which has led to the devastation of the environment and the depletion of natural resources and continues to do so. Unquestionably, the output of municipal solid garbage is rising due to population increase, economic expansion, and changes in lifestyle and consumption patterns.

According to Ejaz et al. (2010) [4], urban solid waste management is a vital urban service and a significant problem for municipal officials. Urban solid waste that is improperly managed can result in significant consequences. Among these include harm to the health of society, destruction of ecosystems, loss of biodiversity, soil and air pollution, and adverse economic and social effects.

The rest of the paper is organized as follows: Section II describes the latest literature. Section III highlights our assumptions, formulas, and the proposed model. Section IV represents the solution method. Finally, Section V wraps the conclusion and future studies.

II. LITERATURE REVIEW

Mohammadi et al. (2019) [5] provided a methodology for optimizing municipal solid waste handling systems within a mixed SC. In the provided model, all goods received from the processing factories are immediately sent to the distribution centers, and the made items are supplied to one of these centers.

According to Tanwer et al. (2014) [6], a supply chain is typically characterized as a one-way integrated manufacturing process that transforms raw materials into completed goods and delivers them to clients. Under this definition, the supply chain consists only of production-related operations, from acquiring raw materials to shipping the completed product.

However, due to recent environmental developments affecting industrial operations, supply chain environmental management solutions are receiving increased attention. This research examines the development of an environmental supply chain, provides an overview of green supply chain management with four major issues, outlines the fundamental differences between traditional and developed supply chains, and outlines a general strategy for achieving and maintaining green supply chain management.

The waste management hierarchy provides many solutions for managing physical waste. Soltani et al. (2015) [7], ranked the relevance of these hierarchies as follows: There are five stages to properly managing trash: (1) avoiding trash altogether; (2) reusing trash; (3) recycling trash; (4) recovering energy from trash, and (5) finally, discarding. Due to its influence on economic growth, environmental protection, and human health, they note that waste treatment has become a global problem for all municipal solid waste management programs.

Tolis et al. (2010) and Ozdenkci et al. (2017) [8, 9] provide scant evidence of the use and societal adaption of environmental friendly municipal solid waste management systems, such as recycling and composting. Without energy recovery, environmentalists have determined that the objectives for waste consumption rates would never be attained. According to Yap and Nixon (2015) [10], waste-to-energy (WtE) has become a feasible waste management alternative for many nations. In addition, Pen et al. (2015) and Kovacic et al. (2017) [11, 12] reported that WtE might tackle the problem of rising energy demand, provide helpful energy in the form of power and heat, and alleviate the strain on land necessary for waste disposal. Additionally, decrease the amount of rubbish delivered. Additionally, employing renewable sources decreases carbon dioxide emissions and greenhouse gas emissions compared to power plants.

Municipal solid waste management is a strategic supply chain issue, according to Sabbas et al. (2003) [13], since it involves production, collection, separation, distribution, processing, and disposal. When contemplating a waste management system, it is vital to evaluate the complete content of the supply chain since the effectiveness of municipal solid waste management may be boosted by adopting proper supply chain management strategies. Cooper et al. (1997) [14] stated that a manufacturing company's capacity to become a fully integrated supply chain partner is crucial to its long-term plan for achieving outstanding sustainable performance. According to Cohen and Russell (2005) [15], The foundation of this strategy is the mixture of internal and external activities of the business throughout the supply chain, improving the performance of each network member and providing superior service. According to Hicks et al. (2004) and Niziolek et al. (2017) [16, 17], waste management firms always seek to cut costs and increase efficiency. In addition, national and international waste management requirements are expanding, and consumer awareness of environmental protection is growing. These factors demonstrate the necessity to build an efficient SC network for managing municipal solid waste, including coordination between SC expenditures, trash disposal, and productive waste use.

This research illustrates the difficulty of urban solid waste management in a network of supply chains with several levels. The resultant optimization issue is described as a mixed integer linear programming problem that encompasses a variety of functions, including collecting trash, separating waste in segregation centers, processing waste in factories, and transporting waste between processing facilities. In addition, given the significance of urban garbage management to environmental concerns, we are attempting to model the problem using a green methodology. The model proposed in this article aims to determine the optimal distribution of waste among all units, enhance the total SC's net profit using a green approach, and limit the transportation, storage, and production capacities of separation centers, factories, and distribution centers.

III. MATHEMATICAL MODELING

A. *Problem Description*

In this article, we intend to help plan urban waste management in periods by presenting an integrated mathematical model. In this issue, several cities considered places of urban waste products have been considered. Garbage is collected in these cities and transported to waste separation centers. In these centers, wastes are divided into four main categories: waste suitable for recycling, waste suitable for energy production, waste requiring recycling, and finally, waste unsuitable for any of the uses above. Next, the waste is transferred to waste disposal centers. Therefore, part of the separated waste is transferred to burial centers, part to reprocessing plants, part to recycling plants, and part to energy production plants. After this stage, the wastes transferred to their recycling factories are divided into two categories. After processing, one batch is sent to recycling plants and the other to energy production plants.

Finally, the wastes are converted into final products in recycling and reuse factories, and from there, they are transferred to distribution centers and sold there.

Meanwhile, each stage of waste transfer and the process of waste in factories produce greenhouse gases that harm the environment. Therefore, by considering the amount of greenhouse gas production in these processes, the following model tries to maximize the profit obtained by minimizing greenhouse gas production. The Fig. 1 shows the main structure of the proposed model, and the interaction between different parties in our investigated supply chain.

B. *Assumptions*

- Cities cannot store urban waste because it increases the possibility of disease outbreaks.
- Separation centers and all three types of introduced factories can store waste up to a specific and predetermined level.
- The capacity to carry waste on the roads is limited.
- The capacity of landfills is assumed to be unlimited.

C. Modeling

The first objective function (Equation 1) tries to minimize the amount of produced greenhouse gases produced in each node of the network, including landfills, recycling plants, reprocessing plants, etc., which are produced through the transportation phases.

The second objective function (Equation 2) optimizes the profits from selling the end waste network production. Periodically, the garbage is sent to various separation facilities, as shown in Equation (3). Equation (4) determines the number of trucks necessary to carry garbage from collection locations to separation facilities based on the waste's volume. All waste categories are supposed to be collected simultaneously.

The total quantity of each waste type allowed to enter the separation center during each period is shown by Equation (5). This quantity, however, may not exceed the maximum amount of garbage that may be transported into the separation center, as indicated in Equations (6), (4), (6). In a facility known as a separation center, a certain amount of municipal solid waste is sorted out so that it may be sent to suitable facilities, while the remainder of the rubbish that cannot be reused is dumped in landfills. The quantities of separated trash that are produced by each kind of plant are shown by the equations (7, 8, and 9), and this quantity is equivalent to the separation factor multiplied by the entire amount of rubbish that is carried to the separation center throughout the course of each period.

The quantity of rubbish that is taken to landfills, which is the waste that is left over after useable waste has been sorted out of the total level of waste that is received, may be determined using Equation (10). Equations (11), (12), and (13) show the potential waste that can be shipped to each type of plant for use in the manufacturing of products. This amount must not surpass the total amount of waste that has been separated in addition to the former inventory of the usable waste and has been separated by the purpose of delivering to each type of plant. According to Equation (14), the total volume of garbage transported from a separation facility to each kind of plant and landfill cannot surpass the maximum output transport capacity of the separation facility.

The equation below provides a separation plant's initial waste inventory levels (15, 16, and 17). The quantity of each waste type inventoried for each separation center during each period is equal to the sum of the amount of useable trash from the prior period, the amount of waste received from collection centers, and the amount of garbage transported to plants and landfills less the total amount of rubbish. This equation is shown in Equation 1; (18, 19 and 20). According to the equation found in Equation 1, the total amount of waste that a separation plant has in its inventory cannot be more than its storage capacity (21, 22, and 23).

The transportation constraint between each separation center and each plant is shown by equations (24), (25), and (26), respectively. If the binary variable equals the value zero, there will be no movement of trash from the separation center to the plant. Because of these limits, the alternatives available to both the sender and the receiver are restricted. For example, it may not be feasible to transport cargo with a requirement for just a small volume, and it may also be impossible to transport more than the maximum quantity allowed. Instead, effective inventory management must compensate for any deficiencies. In addition, these limits mandate an optimum and practical transfer throughout each time. Equations (27), (28), and (29) illustrate the total amount of garbage entering each facility throughout each time. As Equation (27) demonstrated, recycling-type facilities accept garbage from both separator centers and reprocessing-type facilities. Equation (28) demonstrates that reprocessing-type plants exclusively get trash from separator centers, whereas Equation (29) demonstrates that other plants acquire garbage from separator centers and reprocessing-type plants. According to Equations (30), 31, and 32, the total quantity of rubbish transported from the separation centers to each facility cannot exceed the maximum amount of garbage accepted.

According to the equations (33, 34, 35, and 36), the quantity that may be transferred can't be more than the total amount of trash collected during the time t plus the amount of rubbish accumulated during the period before that. The limits of moving each kind of plant to their respective locations are shown by the equations (37), (38), (39), and (40).

The initial waste inventory level at plants at the onset of the planning horizon is represented by equations (41), (42), (43), and (44), respectively. Equations (45), (46), (47), and (48) are used to denote the trash inventory level at each plant after each period. These equations represent the quantity of waste available from the period before the current one, the amount of garbage received during each period minus the amount of waste supplied. The following equation represents each facility's maximum capacity for waste storage: (49, 50, 51, and 52).

Equations (53 and 54) limit greenhouse gas production. Equation (53) implies that the total amount of greenhouse gases created in each period by trash transportation over the whole network must be less than the associated threshold. Equation (54) suggests that plants' total amount of greenhouse gases produced in each period through waste processing must also be below the associated threshold. Table I to Table IV reveal the details and mathematical formulations of our proposed model: Sets, parameters, variables, objectibes, and constraints.

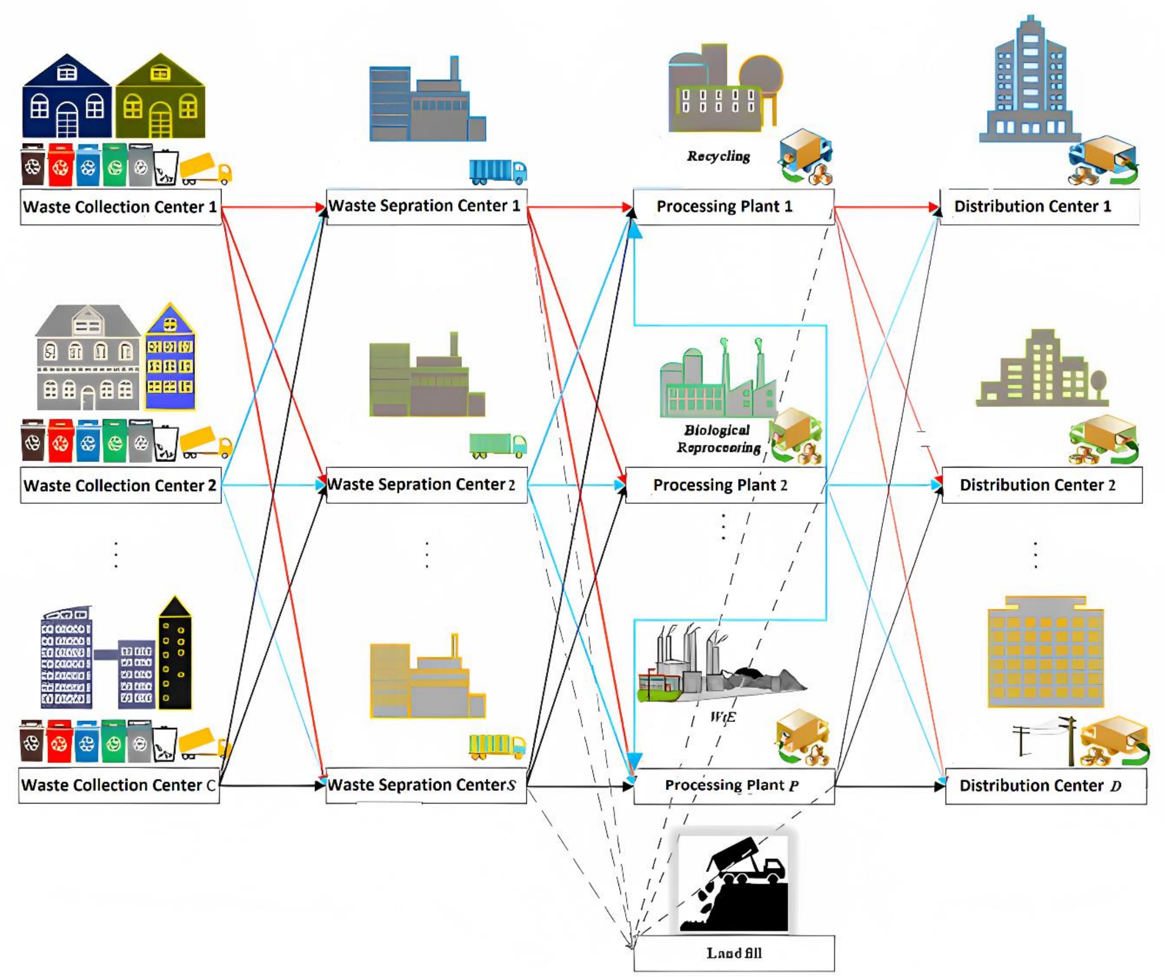

Fig. 1. The structure of waste management.

TABLE I. SETS

w	**Waste type**
c	Collecting center (city)
s	Separating center
l	Landfill
p_{rep}	Waste reprocessing plant
p_{rec}	Waste recycling plant
p_{wte}	Waste energy recovering
J	Distribution center
V	Vehicle type
T	Period
μ	$\mathrm{c} \cup \mathrm{s} \cup \mathrm{l} \cup \mathrm{p}_{\mathrm{rep}} \cup \mathrm{p}_{\mathrm{rec}} \cup \mathrm{p}_{\mathrm{wte}} \cup \mathrm{j}$

TABLE II. PARAMETERS

A_{wct}	Tonnage of garbage collected from city c during time t.
p_{wjt}	Selling price of waste w in distribution center j in period t (€/ton or €/kWh)

$c_{\mu\mu v}$	Cost of transporting waste from each node of the network to another one by vehicle v (€)
$c_{w\mu}$	Cost of processing on waste w in node µ
$GHG_{\mu\mu v}$	Greenhouse gas produced by vehicle v from each node of the network to another one
$GHGP_{w\mu}$	Greenhouse gas produced in node µ by processing on waste w
L_v	Capacity limit of vehicle type v (yd3)
$TC_{wst}^{in}, TC_{wst}^{out}$	Capacity of incoming and outgoing waste transportation in separation centers S for period t (ton)
$TL_{wsp_{rec}t}^{low}, TL_{wsp_{rep}t}^{low},$ $TL_{wsp_{wte}t}^{low}, TL_{wsp_{rec}t}^{up},$ $TL_{wsp_{rep}t}^{up}, TL_{wsp_{wte}t}^{up}$	Lower and higher transit limits for waste w from separation centers s to recycling, reprocessing, and energy recovery plants p during time t. (ton)
TC_{wlt}^{in}	Input transport capability for waste w in landfill l during time t (ton)
$TC_{wp_{rec}t}^{in}, TC_{wp_{rep}t}^{in},$ $TC_{wp_{wte}t}^{in}$	Input transportation capacity for waste w in the recycling, reprocessing, and energy recovery type plant p throughout the time t. (ton)
$CL_{wp_{rec}j}^{low}, CL_{wp_{rec}j}^{up}$	Lower and higher transport limits for waste materials from the recycling facility to the distribution location (ton)
$CL_{wp_{wte}j}^{low}, CL_{wp_{wte}j}^{up}$	Lower and upper restrictions for transporting trash w from the recycling plant p to the distribution center j. (ton)
$CL_{wp_{rec}p_{wte}}^{low},$ $CL_{wp_{rec}p_{wte}}^{up}$	Lower and maximum transport limits for waste materials from a reprocessing facility to an energy recovery plant ṕ (ton)
$CL_{wp_{rec}p_{rec}}^{low},$ $CL_{wp_{rec}p_{rec}}^{up}$	Lower and maximum transportation limits for waste being transported from a reprocessing facility to a recycling plant ṕ (ton)
$S_{ws}^{rec}, S_{ws}^{rep}, S_{ws}^{wte}$	Storage capacity of trash in separation facilities for energy recovery, recycling, and reprocessing (ton)
$S_{ws}^{rec}, S_{ws}^{rep}, S_{ws}^{wte}$	Storage capacity for trash in the recycling, reprocessing, and energy recovery plants' separation facilities (ton)
$U_{wst}^{p_{rec}}, U_{wst}^{p_{rep}}, U_{wst}^{p_{wte}}$	Initial waste w inventory in separation centers for recycling plant, reprocessing plant, and energy recovery plant p. (ton)
$U_{wp_{rec}t}, U_{wp_{wte}t}$	Initial inventory level of waste w in recycling type plant p and reusing kind plant ṕ (ton)
$U_{wp_{rep}t}^{rec}, U_{wp_{rep}t}^{wte}$	Initial stock amount of waste w in reprocessing type plant p destined for energy recovery and recycling plants (ton)
$\alpha_{ws}^{sep-rec}$	Factors that separate waste in centers for waste separation throughout the recycling process (%)
$\alpha_{ws}^{sep-rep}$	Factors used to separate waste in waste separation facilities for the reprocessing process (%)
$\alpha_{ws}^{sep-wte}$	Separating factors for trash in separation facilities for the process of recovering energy (%)

TABLE III. POSITIVE VARIABLES AND BINARY VARIABLES

q_{wcsvt}	Amount of waste w transported from city c to separation centers s by vehicle type v during time interval t (ton)
$q_{wsp_{rec}vt}$	Amount of w from separation centers s to recycling plants p by vehicle type v during time t. (ton)
$q_{wsp_{rep}vt}$	Amount of waste transported from separation centers to reprocessing plants during time t, broken down by vehicle type (ton)
$q_{wsp_{wte}vt}$	Amount of garbage transported from separation centers to energy recovery plants in time t, broken down by vehicle type (ton)
q_{wslvt}	Amount of garbage transported from separation centers to landfills during the period t, broken down by vehicle type (ton)

$q_{wp_{rec}jt}, q_{wp_{wte}jt}, q_{wp_{rec}jt}$	Amount of waste w distributed from recycling and energy recovery kind plant p to distribution center j in period t (ton)
$q_{wp_{rep}p_{rec}vt}$	Quantity of waste w distributed from reprocessing kind plant p to recycling kind plant ṕ in period t (ton)
$q_{wp_{rep}p_{wte}vt}$	Amount of waste w distributed from reprocessing kind plant p to energy recovery kind plant ṕ in period t (ton)
q_{wst}^{in}	Amount of waste w transferred to separation center s in period t (ton)
$q_{wst}^{sep-rec}$	Amount of separated waste w in separation center s by the purpose of sending to recycling kind plant in period t (ton)
$q_{wst}^{sep-rep}$	Amount of separated waste w in separation center s by the purpose of sending to reprocessing kind plant in period t (ton)
$q_{wst}^{sep-wte}$	Amount of separated waste w in separation center s by the purpose of sending to energy recovery kind plant in period t (ton)
q_{wlt}	Amount of waste w inlet to landfill l in period t (ton)
$q_{wp_{rec}t}^{in}, q_{wp_{rep}t}^{in-rec}, q_{wp_{rep}t}^{in-wte}, q_{wp_{wte}t}^{in}$	Amount of waste w transported to recycling, reprocessing, and energy recovery kind plant p in period t (ton)
$i_{wst}^{rec}, i_{wst}^{rep}, i_{wst}^{wte}, i_{wp_{rec}t}, i_{wp_{wte}t}, i_{wp_{rep-rec}t}, i_{wp_{rep-wte}t}$	The amount of garbage that is now being kept in centers for recycling, reprocessing, and energy recovery; waste w stored in recycling, reprocessing, and energy recovery kind plant p; (ton)
$Z_{wsp_{rec}t}^{tran}, Z_{wsp_{rep}t}^{tran}, Z_{wsp_{wte}t}^{tran}$	Equals one if w is moved from a sorting facility to a factory that performs recycling, reprocessing, or energy recovery in time period t; if not, it equals zero.
$Z_{wp_{rep}p_{wte}t}^{sent}$	Equals one if w is moved from a reprocessing type plant to an energy recovery type plant in time t; if not, equals zero.
$Z_{wp_{rep}p_{rec}t}^{sent}$	Equals one if w is moved from a reprocessing type facility to a recycling type plant in period t; if not, it equals zero.
$Z_{wp_{wte}jt}^{sent}$	Equals one if w is moved from energy recovery plant p to distribution center j during time t; else equals zero.
$Z_{wp_{rec}jt}^{sent}$	Equals one if waste w is moved from reprocessing plant p to distribution center j during the time t; else, equals zero.

TABLE IV. OBJECTIVES AND CONSTRIANTS

$$\min \sum_{t}\sum_{\mu}\sum_{\mu}\sum_{v}\left(Z_{\mu\mu v t}\times GHG_{\mu\mu v}\right)+\sum_{\mu}\sum_{w}(q_{w\mu t}^{in}\times GHGP_{w\mu}) \tag{1}$$

$$\max \sum_{w}\sum_{p_{rec}}\sum_{j}\sum_{t}\left\{\left(\sum_{v} q_{wp_{rec}jvt}\right)\times p_{wp_{rec}jt}\right\}+\sum_{w}\sum_{p_{wte}}\sum_{j}\sum_{t}\left\{\left(\sum_{v} q_{wp_{wte}jvt}\right)\times p_{wp_{wte}jt}\right\} \tag{2}$$

$$-\sum_{t}\sum_{\mu}\sum_{\mu}\sum_{v}\left(Z_{\mu\mu v t}\times c_{\mu\mu v}\right)+\sum_{t}\sum_{\mu}\sum_{w}(q_{w\mu t}^{in}\times c_{w\mu})$$

$$A_{wct}=\sum_{s}\sum_{v} q_{wcsvt} \tag{3}$$

$$y_{csvt}-1\le \frac{\sum_{w}\left(\gamma_{w}.q_{wcsvt}\right)}{L_{v}}\le y_{csvt} \tag{4}$$

$$q_{wst}^{in}=\sum_{c}\sum_{v} q_{wcsvt} \tag{5}$$

$$q_{wst}^{in}\le TC_{wst}^{in} \tag{6}$$

$$q_{wst}^{sep-rec}=\alpha_{ws}^{sep-rec}\times q_{wst}^{in} \tag{7}$$

$$q_{wst}^{sep-rep} = \alpha_{ws}^{sep-rep} \times q_{wst}^{in} \tag{8}$$

$$q_{wst}^{sep-wte} = \alpha_{ws}^{sep-wte} \times q_{wst}^{in} \tag{9}$$

$$\sum_{l}\sum_{v} q_{wslvt} \le q_{wst}^{in} - q_{wst}^{sep-rec} - q_{wst}^{sep-rep} - q_{wst}^{sep-wte} \tag{10}$$

$$\sum_{p}\sum_{v} q_{wspvt}^{rec} \le i_{ws(t-1)}^{rec} + q_{wst}^{sep-rec} \tag{11}$$

$$\sum_{p}\sum_{v} q_{wspvt}^{rep} \le i_{ws(t-1)}^{rep} + q_{wst}^{sep-rep} \tag{12}$$

$$\sum_{p}\sum_{v} q_{wspvt}^{wte} \le i_{ws(t-1)}^{wte} + q_{wst}^{sep-wte} \tag{13}$$

$$\sum_{l}\sum_{v} q_{wslvt} + \sum_{p}\sum_{v} q_{wspvt} \le TC_{wst}^{out} \tag{14}$$

$$i_{wst}^{rec} = U_{wst}^{rec} \tag{15}$$

$$i_{wst}^{rep} = U_{wst}^{rep} \tag{16}$$

$$i_{wst}^{wte} = U_{wst}^{wte} \tag{17}$$

$$i_{wst}^{rec} = i_{ws(t-1)}^{rec} + q_{wst}^{sep-rec} - \sum_{p}\sum_{v} q_{wspvt}^{rec} \tag{18}$$

$$i_{wst}^{rep} = i_{ws(t-1)}^{rep} + q_{wst}^{sep-rep} - \sum_{p}\sum_{v} q_{wspvt}^{rep} \tag{19}$$

$$i_{wst}^{wte} = i_{ws(t-1)}^{wte} + q_{wst}^{sep-wte} - \sum_{p}\sum_{v} q_{wspvt}^{wte} \tag{20}$$

$$i_{wst}^{rec} \le S_{ws}^{rec} \tag{21}$$

$$i_{wst}^{rep} \le S_{ws}^{rep} \tag{22}$$

$$i_{wst}^{wte} \le S_{ws}^{wte} \tag{23}$$

$$TL_{wsp_{rec}t}^{low} . z_{wsp_{rec}t}^{tran} \le \sum_{v} q_{wsp_{rec}vt} \le TL_{wsp_{rec}t}^{up} . z_{wsp_{rec}t}^{tran} \tag{24}$$

$$TL_{wsp_{rep}t}^{low} . z_{wsp_{rep}t}^{tran} \le \sum_{v} q_{wsp_{rep}vt} \le TL_{wsp_{rep}t}^{up} . z_{wsp_{rep}t}^{tran} \tag{25}$$

$$TL_{wsp_{wte}t}^{low} . z_{wsp_{wte}t}^{tran} \le \sum_{v} q_{wsp_{wte}vt} \le TL_{wsp_{wte}t}^{up} . z_{wsp_{wte}t}^{tran} \tag{26}$$

$$q_{wp_{rec}t}^{in} = \sum_{s}\sum_{v} q_{wspvt}^{rec} + \sum_{p_{rep}}\sum_{v} q_{wp_{rep}p_{rec}vt} \tag{27}$$

$$q_{wp_{rep}t}^{in} = \sum_{s}\sum_{v} q_{wsp_{rep}vt}^{rep} \tag{28}$$

$$q_{wp_{wte}t}^{in} = \sum_{s}\sum_{v} q_{wsp_{wte}vt}^{wte} + \sum_{p_{rep}}\sum_{v} q_{wp_{rep}p_{wte}vt} \tag{29}$$

$$q_{wp_{wte}t}^{in} \le TC_{wp_{wte}t}^{in} \tag{30}$$

$$q_{wp_{rep}t}^{in} \le TC_{wp_{rep}t}^{in} \tag{31}$$

$$q_{wp_{wte}t}^{in} \le TC_{wp_{wte}t}^{in} \tag{32}$$

$$\sum_{j} q_{wp_{rec}jt} \le i_{wp_{rec}(t-1)} + q_{wp_{rec}t} \tag{33}$$

$$\sum_{j} q_{wp_{wte}jt} \leq i_{wp_{wte}(t-1)} + q_{wp_{wte}t} \tag{34}$$

$$\sum_{p_{rec}} q_{wp_{rep}p_{rec}vt} \leq i_{wp_{rep-rec}(t-1)} + q^{rec}_{wp_{rep}t} \tag{35}$$

$$\sum_{p_{wte}} q_{wp_{rep}p_{wte}vt} \leq i_{wp_{rep-wte}(t-1)} + q^{wte}_{wp_{rep}t} \tag{36}$$

$$CL^{low}_{wp_{rep}p_{rec}}.z^{sent}_{wp_{rep}p_{rec}t} \leq q_{wp_{rep}p_{rec}t} \leq CL^{up}_{wp_{rep}p_{rec}}.z^{send}_{wp_{rep}p_{rec}t} \tag{37}$$

$$CL^{low}_{wp_{rep}p_{wte}}.z^{sent}_{wp_{rep}p_{wte}t} \leq q_{wp_{rep}p_{wte}t} \leq CL^{up}_{wp_{rep}p_{wte}}.z^{send}_{wp_{rep}p_{wte}t} \tag{38}$$

$$CL^{low}_{wp_{rec}j}.z^{sent}_{wp_{rec}jt} \leq q_{wp_{rec}jt} \leq CL^{up}_{wp_{rec}j}.z^{send}_{wp_{rec}jt} \tag{39}$$

$$CL^{low}_{wp_{wte}j}.z^{sent}_{wp_{wte}jt} \leq q_{wp_{wte}jt} \leq CL^{up}_{wp_{wte}j}.z^{send}_{wp_{wte}jt} \tag{40}$$

$$i_{wp_{rec}t} = U_{wp_{rec}t} \tag{41}$$

$$i^{rec}_{wp_{rec}t} = U^{rec}_{wp_{rec}t} \tag{42}$$

$$i^{wte}_{wp_{rep}t} = U^{wte}_{wp_{rep}t} \tag{43}$$

$$i_{wp_{wte}t} = U_{wp_{wte}t} \tag{44}$$

$$i_{wp_{rec}t} = i_{wp_{rec}(t-1)+\, q_{wp_{rec}t}-\sum_j q_{wp_{rec}jt}} \tag{45}$$

$$i_{wp_{rep-wte}t} = i_{wp_{rep-rec}(t-1)+\, q_{wp_{rep-wte}t}-\sum_j q_{wp_{rep-wte}jt}} \tag{46}$$

$$i_{wp_{rep-wte}t} = i_{wp_{rep-rec}(t-1)+\, q_{wp_{rep-rec}t}-\sum_j q_{wp_{rep-rec}jt}} \tag{47}$$

$$i_{wp_{wte}t} = i_{wp_{wte}(t-1)+}q_{wp_{wte}t} - \sum_{j} q_{wp_{wte}jt} \tag{48}$$

$$i_{wp_{wte}t} \leq S_{wp_{wte}} \tag{49}$$

$$i_{wp_{rec}t} \leq S_{wp_{rec}} \tag{50}$$

$$i_{wp_{rep-rec}t} \leq S_{wp_{rep-rec}} \tag{51}$$

$$i_{wp_{rep-wte}t} \leq S_{wp_{rep-wte}} \tag{52}$$

$$\sum_{\mu}\sum_{v}\left(Z_{\mu vt} \times GHG_{\mu v}\right) \leq \max GHG_t \tag{53}$$

$$\sum_{w\mu}\left(q^{in}_{w\mu t} \times GHGP_{w\mu}\right) \leq \max GHGP_t \tag{54}$$

$$L_p = \left(\sum_{j=1}^{k} w_j \left[\frac{f_j\left(x^{\max j}\right) - f_j(x)}{f_j\left(x^{\max j}\right) - f_j\left(x^{\min j}\right)}\right]^p\right)^{\frac{1}{p}} \tag{55}$$

IV. SOLUTION APPROACH

The presented model is a multi-objective model, therefore to solve this model, it is essential to combine the model into a single objective problem [18, 19]. In this regard, we use the LP-Metric approach based on Eq. (55).

After that, we have a single objective deterministic model to solve the model, we code it in GAMS software to achieve a precise solution, but as the size of the problem grows, the GAMS approach leads to a long solving time and massive CPU usage. Therefore we use the grasshopper algorithm (GOA) to solve large-scale problems. We code the algorithm in MATLAB and solve the problems in rational duration and CPU usage.

This algorithm tries to simulate grasshoppers' manners and normal living for solving operation research problems [20]. This mathematical model tries to simulate the attraction and repulsion forces between grasshoppers. The repulsion forces enable grasshoppers to investigate the solution space (problem space), but the attraction forces encourage them to stay in the motivator solution area (local optimum solutions).

To balance exploring the solution space and staying in local optimum solutions, GOA uses a coefficient to reduce the conformability of grasshoppers in local optimum solutions [21]. Ultimately, the best-found solution using a swarm will be achieved and improved. This algorithm is in the group of nature-inspired algorithms and is used to solve ongoing optimization problems [22].

V. CONCLUSION AND FUTURE STUDIES

This research sheds light on the issue of urban solid waste management in supply chains with many tiers. A mixed integer linear programming issue is presented in the following optimization challenge. It encompasses different tasks, including waste transportation between processing facilities, waste processing in factories, collecting waste in cities, and separating them in segregation centers. In addition, since managing urban was is vital to the more significant problem of environmental degradation, one of our goals was considering a green approach. Also, to improve the margin profit of the total SC through the use of environmental friendly methods and to limit the transportation, storage, and production capacities of separation centers, factories, and distribution hubs, the main objective of the model was to determine the optimal distribution of waste among all units. An in-depth case study was carried out to evaluate the usefulness and efficacy of the recommended model. This model is used to precisely tackle the numerical problem using the GAMS program and the grasshopper metaheuristic algorithm. The outcomes demonstrate that it is feasible to implement a distributed processing system to reuse MSW while maximizing the supply chain's net profit. The effectiveness of the supply chain is evaluated using sensitivity studies, which consider the influence of various factors, including time and product pricing. In addition, the obtained Pareto solutions can provide decision-makers with valuable insights for selecting the solution that represents the best compromise among the considered objectives. To mention future studies, the model can be extended to consider waste management in regions where waste management has not been established or where there is no established method of waste control. In addition, this work can serve as a starting point for the addition of additional objectives, such as social, safety, and health objectives, among others, as well as the waste management system's schedule. Additionally, the model can be expanded to account for associated uncertainty.

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