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(Interpretative study on Solid Waste Management Optimization using Linear Program)

(GROUP 16)

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Abstract

Waste production rates are growing on a global scale. In many developing nations and cities, waste management is still a problem while crucial to creating sustainable and habitable communities because of the costs associated with efficient waste management. According to the World Bank, 2.01 billion tons of municipal solid waste are generated in a year; an extremely conservative estimate states that at least 33% of this waste is not managed in a way that protects the environment. Prevention, Reuse, Recycling, Recovery, and Disposal are the five phases to complete an effective solid waste collection however it gives a bigger bite on the budget when it comes to the term of the transportation process. It influences cost management depending upon the points from where the waste is being collected, the routes they take to the next ones, and the end-stoppage to the garbage management facility.

The objective of this study is to review available case studies where it will discuss how the linear programming model can be effective and compare solid waste management measures taken in Sri Lanka and Hongkong. The case studies are followed by linear and integer linear programming which explains comparative outcomes. Possible recommendations are also illustrated in the paper.

Chapter 1: Introduction

The pace of garbage production is increasing globally. Global solid waste production was projected to reach 2.24 billion tons in 2020, or 0.79 kilos per person daily (World Bank,2022). According to UNEP, Ecosystems and human health are seriously at danger due to the growing amount and complexity of garbage produced by the modern economy. An estimated 11.2 billion tons of solid trash are collected year, and around 5% of the greenhouse gas emissions in the globe are caused by organic waste's decomposition. In numerous industrialized and developing nations, the problem of solid waste disposal is severe and pervasive in urban and rural regions. One of the most significant issues facing urban environments today in most nations is the collection and disposal of municipal solid waste. (Hussein et al., 2018).

Solid waste management (SWM) refers to a set of rules for managing wastes in accordance with the best public health standards, economics, environmental considerations, aesthetics, and public health principles during generation, storage, collection, transport, treatment, and landfilling. Numerous nations that are addressing these issues are lacking in comprehensive and useful answers. Government managers and planners should thus strive to create the best possible environment for sustainable approaches to SWM. Several techniques, such as mixed integer linear programming, linear programming (LP), multi-objective programming, and nonlinear programming, have been used in research to solve this issue. Municipal authorities have been driven to create new plans for collecting and transporting solid waste, especially in metropolitan areas, to cut collection and transportation costs. (Khan et al., 2014). By enhancing garbage collection and transportation operation, linear programming techniques were used to reduce logistical costs, fossil fuel use, and emission output. (Joseph et al.,2022)

A number of factors contribute to the environmental disaster, one of which is a solid waste issue that directly endangers human life. Globally, solid waste has a detrimental effect on people's health and is on the verge of becoming a catastrophe that endangers people's lives. As with other environmental issues, rising consumption and a growing population have together increased the creation of solid waste.

Different methodologies, such as linear programming (LP), nonlinear programming, mixed integer linear programming, and multiple objective programming, have been used in numerous studies to examine MSWM challenges. The difficulties associated with many towns and multiple facilities make regionalization of MSWM initiatives more difficult.

Therefore, numerous analytical and mathematical modeling approaches have been developed to waste management. Every town can modify the techniques to manage waste streams in an inexpensive and ecologically friendly manner.

WM is included in the purview of the strategic supply chain (SC) challenge since it encompasses waste creation, collection, separation, distribution, processing, and disposal. By reducing waste both inside and outside of their internal and external SCs, WM firms are continually exploring for methods to save costs. 5 WM firms must consider the entirety of the SC when creating their WM system since adopting proper SC management approaches may increase their efficiency. According to the number of studies on vehicle routing problems in the literature, the approach to solutions is primarily heuristic, and mathematical modeling and algorithms that offer better solutions are not sufficiently explored. The decision-maker has the flexibility and breadth necessary to make a crucial choice thanks to the mathematical models' ability to undertake sensitivity analysis as well as analysis after they have already provided the best option. However, linear programming is the most straightforward method of performing optimization (LP).

Using the mathematical modeling approach of linear programming, a linear function is maximized or reduced depending on the restrictions it is exposed to. In commercial planning, industrial engineering, and to a lesser extent in the social and physical sciences, this method has proven helpful for directing quantitative judgments. The Soviet mathematician Leonid Kantorovich and the American economist Wassily Leontief made the first significant attempts to use the linear programming approach in the late 1930s, but their work was disregarded for a long time. During World War II, linear programming was widely employed to manage transportation, scheduling, and resource allocation according to specific constraints like costs and availability. The polynomial-time method was developed significantly by the Russian mathematician Leonid Khachiyan in 1979 and the Indian mathematician Narendra Karmarkar in 1984.

Finding the best value of the linear expression (biggest or lowest, depending on the situation) is all that is required to solve a linear programming problem (called the objective function).

$$f = c_1x_1 + \dots\dots\dots + c_nx_n$$

In accordance with a set of constraints defined as inequalities:

$$a_{11}x_1 + \dots\dots\dots + a_{1n}x_n \le b_1$$

$$a_{m1}x_1 + \dots + a_{mn}x_n \le b_m \ with \ \forall x_i \ge 0$$

The problem's capacities, demands, expenses, profits, and other requirements and limits all influence the values of the constants a, b, and c. The fundamental premise behind the implementation of this approach is that the different connections between availability and demand are linear; specifically, that no X_i is raised to a power other than 1. Finding the answer to the system of linear inequalities is important in order to solve this issue (that is, the set of n values of the variables X_i that simultaneously satisfies all the inequalities). Substituting the values of the X_i in the equation that determines f leads to the evaluation of the objective function.

Chapter 2: Literature Review

This section reviews the relevant literature on location and vehicle routing problems for municipal solid waste (MSW) collection.

Joseph R. & Gunaratne M.D.N (2022) proposed a vehicle plan for municipal waste collection in a city of Sri Lanka system with specific routes, labor costs, fuel costs, and traffic. In the study, people are responsible for keeping domestic waste in waste collection spots. Their research aimed to cover all demand points and employ an innovative method to optimize routes and the number of vehicles.

Lee et al. (2016) presented a novel and integrated approach to waste collection and disposal in Hong Kong. Their methodology was developed using Nganda's (2007) model, which provides appropriate information for decision-makers to plan how to use waste management infrastructures to minimize waste management costs. The following are the fundamental principles of Nganda's work: Create waste flow diagrams for waste collection points, incinerators, replacement truck warehouses, and landfills. The method employed integer linear programming to determine information such as the number of trucks required between two points, the total number of trucks in the system, the amount of waste received in each incinerator and landfill, the amount of waste collected in each waste collection point, and the total minimal waste management cost if information regarding the transportation cost per trip is available. On the other hand, Suja et al. (2014) and Fei-Baffoe et al. (2014), who studied e-waste management scenarios in Malaysia and municipal solid waste in Ghana, respectively, looked at distinct aspects of waste management scenarios.

Najma (2002) created a tool for evaluating various MSW management alternatives and determining the best combination of technologies for handling, treating, and disposing of MSW in an economically and environmentally sustainable manner. The rates of solid waste creation, composition, collection, treatment, and disposal, as well as the possible environmental effects of different MSW management systems, were all taken into account by the model. The study used a linear programming formulation with a dynamic optimization framework.

In order to identify multiple disposal facilities for local hazardous waste and determine the optimal transportation path between them, Zhao (2016) suggested a multiobjective continuous network flow model. Their goal was to reduce total cost and risk. They assessed their model in a hypothetical and realistic case in the Chinese province of Sichuan. Sánchez (2018) claims that a multiobjective optimization algorithm based on the variable neighborhood descent (VND) approach was developed to address an issue with rubbish collection in a city in southern Spain. The goals were to reduce travel costs and balance vehicle routes.

Mohammadi(2019) presented research on developing a mixed integer linear programming model for coordinating tactical and operational decisions in waste supply chain networks, including logistics, production, and distribution. The model seeks to maximize overall supply chain profit while meeting demand, production, transportation, and inventory constraints imposed by various network entities, whereas a case study is chosen to evaluate the proposed model's effectiveness and efficiency.

Due to numerous factors, including the expansion of new environmental legislation, the emergence of social responsibility, and commercial interests, reverse logistics has recently received a great deal of attention. Reverse logistics has gained more attention over the past ten years due to declining natural resource and raw material reserves, rising production prices, issues with industrial waste landfills, and consumer products. This study suggests a municipal solid waste management network to save various expenses. In 2019, Pouriani and few created a bi-level mixed integer linear programming model that considers the setup expenses for dependable garbage collecting stations and the allocation of waste to different centers. A case study from Babol is used to assess the suggested paradigm. A case study from Babol, in the Iranian region of Mazandaran, is used to assess the suggested approach. According to the findings, collection stations are chosen in locations closer to their serviced areas, resulting in the best possible flow of garbage and goods. In contrast to using a multi-objective model, this approach takes hierarchy into account, which results in a more suitable analysis. This model demonstrates how choices made during the construction of the collection stations can have an impact on the various aspects of collection, transmission, and recycling. The problem should be seen in wider dimensions to be solved by heuristic techniques, they added, because cost parameters or conversion rates might be viewed as unknown.

It is insufficient to consider concerns of water supply, demand, disposal, and reuse separately when highlighting urban water problems. Only in the context of their interactions with the more extensive water system can innovatively water management systems and prospects for water reuse be evaluated effectively. A semiarid coastal city's future water supply, wastewater disposal, and reuse alternatives are determined for Beirut, Lebanon, using an integrated linear deterministic optimization model. According to the optimization model results, Beirut's most cost-effective alternative for meeting its urban nonportable and irrigation needs is the complete utilization of low-cost traditional sources. (Patrick et al., 2010)

Multiple processes engage in solid waste management, and each one's bad design has the potential to raise costs and pollute the environment. With a focus on systems based on mathematical programming and geographic information systems, Emmanuel(2018) reviewed papers in the area of applying optimization systems to the process of collecting solid trash. An objective function may be maximized or minimized using mathematical programming techniques to optimize a method, guarantee operational effectiveness, and function as decision support tools. However, when put into practice, they only offer partial answers and are unable to adequately address road network restrictions. This strategy makes it exceedingly difficult to take into account environmental contamination since the vehicle routing problem solution runs into enormous data processing restrictions. Studies should continue to concentrate on incorporating all network constraints, ecological pollution considerations, and the impact of land use changes on routing for increased efficiency of the vehicle routing systems.

Chapter 3: Methodology

3.1 Data collection

The Western Province accounts for roughly 60% of Sri Lanka's daily production of 7,000MT of solid trash. Each person creates between 0.1 and 0.4 kg of garbage every day, according to Dawoodbhoy (2021). According to the Waste Management Authority and the Central Environmental Authority, only half of the garbage produced is collected, transported, and treated. The majority of MSW management expenses are spent on waste collection and transportation. The present garbage collection and transportation technique entails collecting all rubbish from homes and transporting it by tractors along predetermined routes to the disposal facility. In the case study I, the daily garbage collection reports of the Dehiwala-Mount Lavinia Municipal Council in 2020 were the primary sources of secondary data on the amounts of rubbish that were collected and carried by date, by four tractors in September 2020, and their capabilities. Additionally, using the Dehivala-Mount Lavinia Municipal Council vehicle root maps, the distances in kilometers between the depot and the homes in the Ratmalana region were computed.

The inevitable byproduct of modernisation processes, according to Scanlan's 2007 description, is waste. Since its fast urbanization in the 1990s, Hong Kong, one of the most sophisticated cities in the world, has had to deal with a rising volume of rubbish (Chan, 1998). Recycling initiatives have been vigorously pushed in Hong Kong. In 2013 , 37% of municipal solid trash was recycled before being sent to landfills. According to the mathematical models based on the existing circumstances in Hong Kong, three landfills and two incinerators are provided. It is planned to put up two replacement truck warehouses each in Mong Kok and Yuen Long, as well as three garbage collection locations in Hung Hom, Tsuen Wan, and Sha Tin. Three garbage collection points and the transportation cost depending on the distance between each point were taken into account by the Environmental Protection Department (EPD) in Hong Kong's statement on the transportation system. Assumptions were established, and relevant data and statistics were analyzed to enable the creation of the mathematical model for municipal solid waste management in Hong Kong.

3.2 Materials, method & Linear programming model

Case study 1

The objective function of this linear programming model was to find the tour with the shortest distance. This study formulated the vehicle routing problem as an Integer Programming (IP) model with integer variables associated with each arc between locations (Households and the depot). The route optimization problem was solved using a linear programming model, and viable solutions were calculated using linear programming.

The case study I from Sri Lanka, by enhancing garbage collection and transportation operations in the Ratmalana area, linear programming techniques were used to reduce logistical costs, fossil fuel use, and emission output. This study's formulation of the vehicle routing issue used integer programming, with variables for each arc between households and the depot site being associated with integers.There were termanologies used which were N(Households), V(Vehicles), di(Demand of household), i Tv(Capacity of vehicle), v cij(Distance between node i and nodej)

The goal was to reduce the total distance that the vehicles traveled, where the mathematical model was explained as,

$$z = \sum_{v=1}^{V} \sum_{i=0}^{N} \sum_{j=0}^{N} c_{ij} c_{ij}^{v}$$

The constraints are given below

$$\sum_{1=i}^{N} \sum_{j=0}^{N} d_i x_{ijv} \leq T_i \ (v = 1,2, \dots, V) \dots (1)$$

$$\sum_{v=1}^{V} x_{ijv} = \ y_{ij}(i \neq j, \qquad i, j = 0,1, \dots, N) \dots (2)$$

$$\sum_{\substack{v=1 \\ j \neq i}}^{V} y_{ij} = \ 1(i = 1,2, \dots, N) \dots (3)$$

$$\sum_{\substack{v=1 \\ i \neq j}}^{V} y_{ij} = \ 1(j = 1,2, \dots, N) \dots (4)$$

$$\sum_{j=1}^{N} y_{0j} \, V \dots (5)$$

$$\sum_{i=1}^{N} y_{i0}\, V \ldots (6)$$

$$\sum_{\substack{j=0 \\ j\neq i}}^{V} x_{ijv} = \sum_{\substack{j=0 \\ j\neq i}}^{V} x_{jiv}\; (i = 1,2, \ldots , N; v = 1,2, \ldots V) \ldots (7)$$

$$u_i - u_j + (N + 1)y_{ij} \leq N\; (1 \leq i \neq j \leq N) \ldots (8)$$

The loading capacity of a single vehicle should be surpassed based on objective function (1). I and j can only be reached by one of the vehicles listed in (2). To gather the rubbish listed in (3) &, each thousand must be visited (4). In-use vehicle beginning and ending points are explained in numbers (5) and (6). (7) Denotes utilization of a large vehicle to enter and exit the residence. The circumstance in (8) prevents the formation of a sub tour.

To identify the best feasible solution study developed the Constraints as follows

- Each vehicle's loading capacity should not be exceeded
- Each arc can only be traversed by one vehicle
- Each house must be visited exactly once by one vehicle :
- If the vehicle is in use, it must begin and stop at the depot
- A vehicle that reaches a household must leave the same household
- Condition to stop the formulation of sub-tours:

Case study 2

For the development of integer linear programming and mixed integer programming, the following assumptions were made

- The waste collection point is assumed to be as close to the waste generation area as possible
- Waste classification is assumed to be done at the collection point, and only municipal solid waste is dumped into the system

- The system is assumed to be analyzed on a daily basis
- There is always a truck malfunction
- The transportation cost is determined based on a single journey, and the return trip is not taken into account.

i. The mathematical model using integer linear programming

This section outlines how the mathematical model was created using integer linear programming. In the study, indices were used to indicate the locations of the garbage collection point, the incinerator, the landfill, and the warehouse for replacement trucks, in that order. Several variables were taken into consideration, including the number of trips made from the waste collection point to the incinerator and landfill

- Number of trips made from the incinerator to the landfill;
- Number of trips made from the incinerator to the landfill;
- The number of vehicles required to transport waste to the incinerator and replacement truck warehouse
- whether to install the replacement truck warehouse,
- whether to install the incinerator
- The amount of waste transported from each location should be less than the capacity of a full-load truck.
- whether to make a landfill
- Amount of waste sent to an incinerator
- Amount of garbage contains in landfill
- Amount of all waste coming from all sources to a landfill
- Total number of a standard truck
- Total number of replacement truck

The purpose is to achieve the lowest possible cost for the municipal solid waste management system. It shows the total daily costs for waste management F1, which includes the costs for the incinerator and warehouse's construction, the costs for the incinerator and landfill's operation, and the costs for transportation between each of the two points. It also includes the costs for moving the replacement truck to the waste collection point and incinerator of F2, the costs for the truck of F3, and the profits from incinerator B.

The objective function F, to be minimized, is

$$F = F_1 + F_2 + F_3 - B$$

To identify the best feasible solution study developed the Constraints as follows

- The waste transported from each collection spot should equal the amount found at that node.
- The amount of waste sent from the incinerator to the landfill should be less than the bottom ash after the incineration process
- amount of debris carried to the incinerator and landfill should not be larger than the capacities of the incinerator and landfill, respectively
- The number of replacement trucks should be more significant than the breakdown rate
- The number of normal trucks should be higher than the replacement trucks.
- The daily truck traffic between two locations, excluding replacement trucks
- The number of replacement trucks needed every day in the waste management system

ii. The mathematical model using mixed integer programming

The mathematical model using mixed integer programming is based on the integer linear programming developed in the first approach .in addition to that, from using the indices and variables used in integer linear programming, new variables of "Tonnes transferred from waste collection point to the incinerator and landfill" and "Tonnes transferred from the incinerator to landfill "were developed to conduct the conduct mixed integer programming. Trash is monitored using a continuous variable, which yields more precise outcomes in terms of objective function, waste gathered, and income.

. The overall daily waste management costs of F_1 include the expenses related to investment and operational and transportation costs. The expenses regarding the use of the replacement truck, the truck cost, and the revenue from the incinerator are shown in F_2, F_3, and B, respectively.

The objective function F, to be minimized, is

$$F = F_1 + F_2 + F_3 - B$$

To identify the best feasible solution study developed the Constraints as follows

- The waste transported from each collection spot should equal the amount found at that node.
- The amount of waste sent from the incinerator to the landfill should be less than the bottom ash after the incineration process
- amount of debris carried to the incinerator and landfill should not be larger than the capacities of the incinerator and landfill, respectively
- The number of replacement trucks should be more significant than the breakdown rate
- Transferring waste between the landfill, incinerator and waste collection point should not exceed the capacity of the relevant waste collecting site.
- The amount of waste transported from each location should be less than the capacity of a full-load truck.

The number of replacement trucks needed every day in the waste management system

Chapter 4: Results

Case study 1

Based on the linear programming model, The proposed method has reduced the total traveling distance compared to the existing plan. The solution of the linear programming model reduces the distance by 31.23km per day, which impacts the cost of waste management and reduces labor and emission. According to the current practice, all four tractors are used to collect garbage along the six lanes, and the total distance coved by four vehicles is 86.26Km.

The mathematical model identified 25 nodes from the waste management Facility to waste collection spots for the four waste collection tractors, developed the LP mode, and solved it using Solver in MS Excel. The results are shown in Table 1.

Table 1:Route for vehicles A, B, C, and D (Joseph R. & Gunaratne M.D.N (2022))

Vehicle	**Route**	Distance (Km)
A	Depot-25	4.4
	25-24	0.43
	24-23	0.19
	23-22	1.51
	22-21	0.32
	2 1-20	0.95
	20-yard	2.3
	yard-Depot	5.4
	Total Distance (Km)	**15.5**
B	Depot-11	3.74
	11-10	0.32
	10-9	0.19
	9-8	0.27
	&-7	0.48
	7-6	0.17
	6-5	0.16
	5-4	0.35
	4-yard	2.4
	Total Distance (Km)	**8.08**

C	Depot-3	2.81
	3-2	0.64
	2-1	0.3
	I-yard	3.1
	yard-Depot	5.4
	Total distance (km)	**12.25**
D	Depot-19	4.3
	19-18	0.91
	18-17	0.1
	17-16	0.15
	16-15	0.22
	15-14	0.17
	14-13	0.34
	13-12	0.84
	12-yard	1.4
	yard-Depot	5.4
	Total distance (km)	**13.83**

Figure 1 shows routes for all four tractors obtained from LP Model. According to the results, the total traveling distance of all the vehicles is 55.06 Km

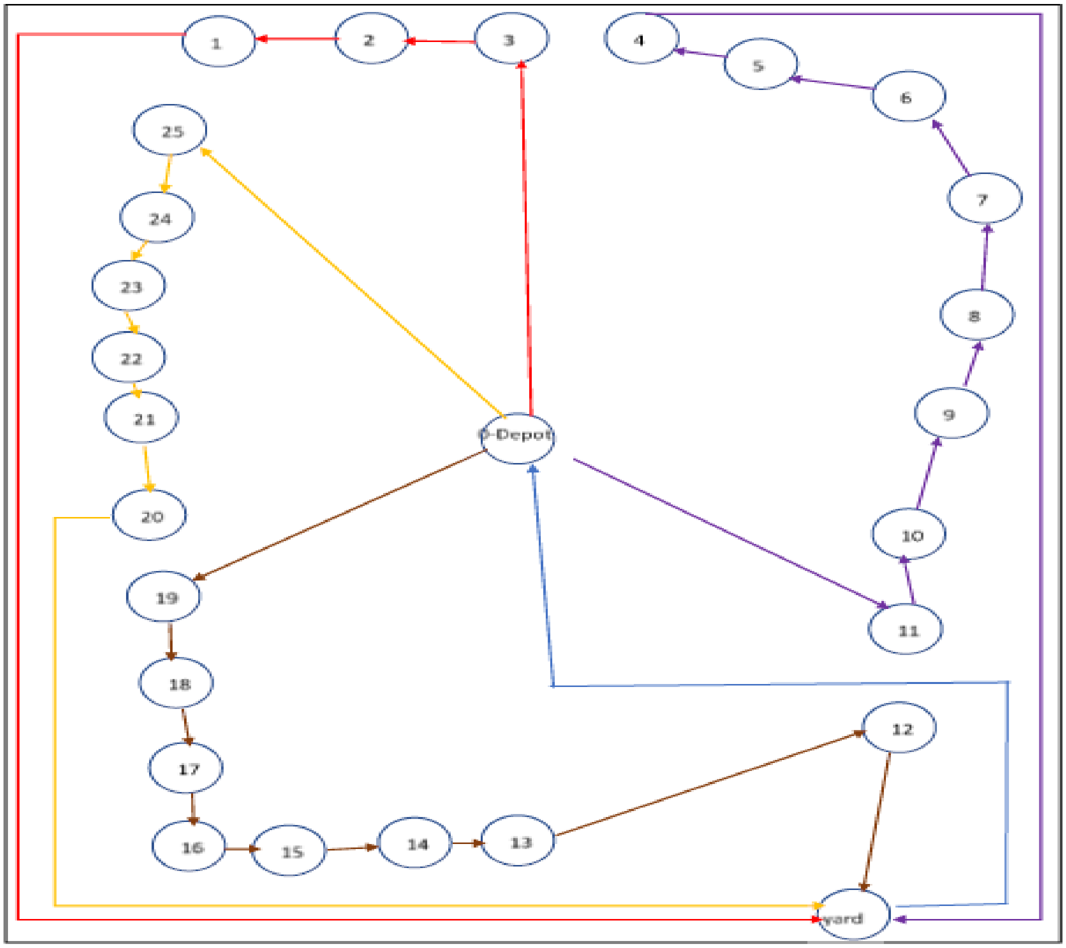

Figure 1: Routes for all tractors(Joseph R. & Gunaratne M.D.N (2022))

Case study 2

Case study 2 was based on a mathematical model which adopts integer linear programming and mixed integer programming. Therefore its results can be illustrated as,

i.) Results of the mathematical model using integer linear programming

The results of the mathematical model employing integer linear programming are summarised in Table 2. The system's daily cost is HK$248,883, which includes the construction of two incinerators in Shek Kwu Chau and Long Gang, as well as one warehouse for replacement trucks in Yuen Long.

According to the results, The system needs 115 regular trucks and ten backup trucks to provide transportation. When both incinerators are operating at full capacity, they can burn 3000 and 2000 tonnes of waste each day, respectively, for revenues of HK$3,960,000 and HK$1,920,000. The overall amount of waste to be dumped is 5504 tonnes, which is down roughly 42% from the original plan. Out of 4800 tonnes, only South East New Territories (SENT) landfill is operating close to capacity, at roughly 4536 tonnes. West New Territories (WENT) and North East New Territories (NENT)landfills have lots of room as a result. Given the result mentioned above and the fact that the landfill rate is significantly reduced, it can be decided to construct two incinerators and one storage for replacement trucks.

ii.) Results of the mathematical model using mixed integer programming

The system costs HK$247,144.5 per day when the mathematical model with mixed integer programming is used. The incinerators should be built at Shek Kwu Chau and Long Gang, and a replacement truck warehouse should be built at Yuen Long, according to a mathematical model. The incinerators are running nonstop. This case study supports the system with 100 regular trucks and eight trucks. Nine thousand five hundred tonnes of garbage were collected, and 5500 tonnes were dumped in landfills. While there are 4500 tonnes of waste in the SENT Landfill and 1000 tonnes in the WENT Landfill, the NENT Landfill will not accept any waste. An overview of the outcomes of the mathematical model employing mixed integer programming is shown in Table 2.

Table 2:Results of the mathematical model (Lee et al. (2016))

Mathematical Parameter	integer linear programming	mixed integer programming
Fraction of bottom ash of incinerator	0.2	0.2
The daily cost for the system (HKD)	248,883	247,145
Revenue for the incinerator at Shek Kwu (HKD)	3,960,000	3,960,000
Revenue for the incinerator at Long Gang (HKD)	1,920,000	1,920,000
Build the replacement truck warehouse at Mong Kok	NO	NO
Build the replacement truck warehouse at Yuen Long	YES	YES
The number of a normal truck	115	110
The number of replacement trucks	10	8
The amount to the incinerator at Shek Kwu (tonne)	3,000	3,000
The amount to the incinerator at Long Gang(tonne)	2,000	2,000
The total amount to incinerators (tonne)	5,000	5,000
The amount to landfill at WENT Landfill (tonne)	768	1,000
The amount to landfill at SENT Landfill (tonne)	4,536	4,500
The amount to landfill at NENT Landfill(tonne)	200	0
The total amount to landfills (tonne)	5,504	5,500
The amount in the waste collection point at Hung Hom(tonne)	3,000	3,000
The quantity in Tsuen Wan's garbage collecting point (tonne)	3000	3000
The quantity at Sha Tin's waste collection point	3504	3500
The total amount in waste collection (tonne)	9504	9500

Chapter 5: Conclusion

The most important one of these advantages is finding and utilizing the shortest path; thus, the organizations will gain tremendous savings. It is essential to have a useful design of a set of delivery or collection routes for the companies that have to deliver or collect goods. Benefits of implying optimization techniques in such industries are demonstrated through the project work. The objective is to reduce the distance and the total number of vehicles. However, the outcome may not meet both at the same time. The reason behind all of these trials is to minimize cost and get the best model to reduce time, fuel waste, and pollution. Modification and analysis are further due. It can be concluded that Linear Programming techniques are awfully hard to use for significant Vehicle Routing Problems. Also, a few computer software is available to solve such large-scale problems. There is an urgent need to develop a mathematical model to support decision-making regarding municipal solid waste management. few factors, such as environmental emission regulations, inventory costs, and normal-time-over-time operation, are neglected to simplify the mathematical model. Further measurements regarding particular parameters need to be conducted to improve the estimated data's accuracy.

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Reference

- Cheng, G. H., Huang, G. H., Li, Y. P., Cao, M. F., & Fan, Y. R. (2008). Planning of municipal solid waste management systems under dual uncertainties: A hybrid interval stochastic programming approach. Stochastic Environmental Research and Risk Assessment, 23(6), 707–720. https://doi.org/10.1007/s00477-008-0251-5
- Joseph R., & Gunaratne M.D.N. (2022). Optimization of waste collection and transportation in Ratmalana area in Sri Lanka. Proceedings of International Forestry and Environment Symposium, 26. https://doi.org/10.31357/fesympo.v26.5702
- Lee, C. K. M., Yeung, C. L., Xiong, Z. R., & Chung, S. H. (2016). A mathematical model for municipal solid waste management – A case study in Hong Kong. Waste Management, 58, 430–441. https://doi.org/10.1016/j.wasman.2016.06.017
- Mohammadi, M., Jämsä-Jounela, S.-L., & Harjunkoski, I. (2019). Optimal planning of Municipal Solid Waste Management Systems in an Integrated Supply Chain Network. Computers & Chemical Engineering, 123, 155–169. https://doi.org/10.1016/j.compchemeng.2018.12.022
- Najm, M. A., El-Fadel, M., Ayoub, G., El-Taha, M., & Al-Awar, F. (2002). An optimisation model for Regional Integrated Solid Waste Management I. Model formulation. Waste Management & Research: The Journal for a Sustainable Circular Economy, 20(1), 37–45. https://doi.org/10.1177/0734242x0202000105

- Cheng, G. H., Huang, G. H., Li, Y. P., Cao, M. F., & Fan, Y. R. (2008). Planning of municipal solid waste management systems under dual uncertainties: A hybrid interval stochastic programming approach. Stochastic Environmental Research and Risk Assessment, 23(6), 707–720. https://doi.org/10.1007/s00477-008-0251-5

- Joseph R., & Gunaratne M.D.N. (2022). Optimization of waste collection and transportation in Ratmalana area in Sri Lanka. Proceedings of International Forestry and Environment Symposium, 26. https://doi.org/10.31357/fesympo.v26.5702
- Lee, C. K. M., Yeung, C. L., Xiong, Z. R., & Chung, S. H. (2016). A mathematical model for municipal solid waste management – A case study in Hong Kong. Waste Management, 58, 430–441. https://doi.org/10.1016/j.wasman.2016.06.017
- Mohammadi, M., Jämsä-Jounela, S.-L., & Harjunkoski, I. (2019). Optimal planning of Municipal Solid Waste Management Systems in an Integrated Supply Chain Network. Computers & Chemical Engineering, 123, 155–169. https://doi.org/10.1016/j.compchemeng.2018.12.022
- Najm, M. A., El-Fadel, M., Ayoub, G., El-Taha, M., & Al-Awar, F. (2002). An optimisation model for Regional Integrated Solid Waste Management I. Model formulation. Waste Management & Research: The Journal for a Sustainable Circular Economy, 20(1), 37–45. https://doi.org/10.1177/0734242x0202000105