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Efficient Waste Categorization And Collection Station F Allocation To Reduce Operational Costs

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Abstract

The purpose of the study is to make effective waste management for sustainable urban development, particularly in rapidly growing cities like Rajshahi City Corporation, where inadequate infrastructure and inefficient practices have led to environmental pollution and economic burdens. This research addresses these challenges by proposing a comprehensive waste management framework focused on waste categorization and cost reduction strategies. The study employs a multi-stage methodology, beginning with waste characterization through data collection and analysis using Excel. Subsequently, plastic and compostable waste are sorted and composted, with Google Maps integration utilized to optimize transportation routes. Finally, Mixed Integer Linear Programming (MILP) is applied to minimize overall waste management costs. Analysis of the results reveals a daily net profit of 649,140 BDT, indicating the economic viability of the proposed waste management approach. By leveraging technology, cities can overcome waste management challenges and advance their sustainability agendas. Overall, this research provides valuable insights into the potential benefits of adopting innovative waste management practices in urban contexts, offering a pathway towards cleaner, healthier, and more sustainable cities.

Keywords
Waste Categorization, Cost Reduction, Mixed Integer Linear Programming (MILP), Sustainability Financial Efficiency.

1. Introduction
The field of waste management has gained increasing attention due to its profound impact on environmental sustainability, public health, and economic welfare. As the global population continues to grow and urbanization accelerates, the challenges surrounding waste management have become more complex and urgent. Historically, waste management has followed a linear model, where resources are extracted, used, and then discarded, leading to environmental degradation and resource depletion. However, this paradigm has given way to a more holistic approach, known as the circular economy, which aims to minimize waste generation and maximize resource efficiency. Zorpas (2020) developed research on "Strategy development in the framework of waste management" which encapsulates this shift, emphasizing the need to align waste management practices with circular economy principles. Presently, waste management is confronted with a plethora of challenges, many of which are exacerbated by rapid urbanization and changing consumption patterns. Zhang (2019) developed "Barriers to Smart Waste Management for a Circular Economy in China" which underscores the hurdles faced in adopting advanced technologies, such as IoT and AI, for waste management. Colvero (2018) developed the "Use of a geographic information system to find areas for locating" which underscores the significance of appropriate site selection for waste disposal facilities to mitigate these adverse effects.

Presently, the challenge lies in adhering to legal restrictions and ensuring site selection. Construction and demolition waste management (CDWM) poses another pressing challenge, particularly in rapidly developing nations like China and the USA. Aslam (2020) developed a review on "Review of Construction and Demolition Waste Management in China" which highlights the need to address circular economy principles, regulatory compliance, and stakeholder engagement. The COVID-19 pandemic has also cast a spotlight on waste management challenges. Hantoko (2021) developed "Challenges and Practices on Waste Management and disposal" which addresses waste generation, particularly medical and infectious waste, during the pandemic. This situation underscores the urgency of adapting waste management practices to unforeseen crises. Presently, the field faces challenges such as inadequate technological adoption, improper waste disposal practices, and crises like the COVID-19 pandemic. However, the studies highlighted in this review collectively emphasize the need for comprehensive strategies, stakeholder engagement, technology integration, and regulatory improvements to address these challenges and pave the way for a sustainable waste management future.

1.1 Objectives

The objectives of study are to categorize different types of waste and to minimize the total cost.

2. Literature Review

Guerrero (2013) conducted the challenges of solid waste management in cities, focusing on increasing waste generation, high costs, limited understanding, and inadequate data. Colvero (2018) employs GIS and legal analysis to identify suitable areas for municipal solid waste (MSW) landfill construction in Goiás State, Brazil. Jadhav (2018) addresses the municipal solid waste management challenge in Aurangabad, India, utilizing mixed integer linear programming (MILP). The waste-to-wealth initiative addresses solid waste management challenges in developing nations, emphasizing the economic potential of recycling. The study characterizes waste generated at Covenant University, highlighting significant amounts of recyclable materials. It underscores the importance of waste characterization for effective management (Olukanni 2018). Zhang (2019) examined smart waste management for a circular economy. IoT, big data, and AI are highlighted as pivotal technologies. However, limited practical implementation and stakeholder engagement hinder real-world impact. Singh and Dipti (2019) advocate the 4R principle for waste management. Oa (2019) introduces an Environmental Impact Assessment (EIA) model for soil remediation in South Korea. Esparza (2020) presents a comprehensive review of food waste (FW) and fruit and vegetable waste (FVW) management. Zorpas (2020) addressed waste management strategies within the context of environmental, social, and economic concerns.

Aslam (2020) examined construction and demolition waste management (CDWM) practices in the USA and China. Maulidati1 (2020) developed the method of sorting plastic bottles-waste. Different types of plastic bottle waste are similar although they are made of various plastic materials. Adu (2020) employs the challenges of lack of waste sorting in health facilities, the consequences of mixing infectious Waste, and inconsistent color-coding waste containers. Batur (2020) shows challenges in long-term municipal solid waste management (MSWM) through a mixed integer linear programming (MILP) model. The study underscores the need for scientifically driven waste management solutions amid environmental, economic, and social constraints, highlighting optimization models' potential in decision-making (Hoanga 2020). Hantoko (2021) underscores the need for improved waste management practices and offers short, mid, and long-term responses for sustainable waste management during similar crises. Rangga (2022) developed The Solid Waste and Public Cleansing Management Act (SWPCMA) 2007 was introduced to improve waste management, yet challenges persist. Optimal transportation planning is crucial for cost-effective waste management policies in rapidly growing urban areas (Barma 2022).

Table 1. Previous work in waste management for sustainability

Author	Waste Categorization	Quantification	Segregation	Layout design of Collection Station	Layout design of Landfill	Advanced Technology	Location Allocation of Bin	Required bin Calculation	Cost of bin placement
Aslam (2020)	✓		✓						
Colvero (2018)	✓	✓							
Guerrero (2013)	✓				✓				
Josfirin (2022)	✓					✓			
Maulidatil (2020)	✓						✓	✓	

Table 1 shows the previous work in waste management for the sustainability of the environment. In the present condition, no author has taken the consideration of cost of bin placement in wards. Also, they have not given any calculation of the required bin needed in a ward. The layout of the STS is not designed which is needed for effective waste handling.

Table 2. Previous work in waste management

Author	Method	System Component					Location allocation	Distance measurement
		Source	Collection Station	Treatment Plant	Plastic Sorting	Landfill		
Badran (2005)	MILP	✓	✓	✓	✓	✓		Linear
Jadhav (2018)	MILP	✓	✓	✓		✓		Linear
Hoanga (2020)	MILP	✓	✓	✓				Linear
Xia (2022)	MILP	✓	✓	✓	✓	✓		Linear
Mirnezami (2020)	MILP	✓	✓			✓		Linear
Batur (2020)	MILP	✓	✓			✓		Linear
Esparza (2021)	MILP	✓		✓				Linear
Maulidatil (2021)	barcode scanning				✓			
Rangga (2022)	Cost benefit analysis	✓		✓				Linear
Singh (2019)	MILP		✓		✓	✓		Linear

Table 2 shows the previous work in waste management where mixed integer linear programming is used, and all distances are considered in a linear system. No stations of the waste flow are allocated.

3. Methods

The study addresses waste management challenges in Rajshahi City Corporation through a systematic approach. Data on waste generation and composition is collected and analyzed using Excel. Google Maps aids in mapping transportation routes, while MATLAB solves a MILP model for cost-benefit analysis. Strategic placement of Plastic Sorting

Centers (PSCC), Sorting Transfer Stations (STS), and Landfill sites ensures efficient waste sorting, transfer, and disposal. Sensitivity analysis validates the model's robustness.

3.1 Model Formulation

In Rajshahi City Corporation, inefficient waste management practices create a pressing environmental challenge. The absence of proper waste separation techniques leads to diverse waste types, including plastic, organic, and hazardous materials. This results in heightened pollution levels, posing significant health hazards. Moreover, the lack of designated disposal sites exacerbates the problem, as waste often finds its way to unauthorized dumping areas. The model implementation plan for waste management in Rajshahi City Corporation involves strategically placing Plastic Sorting Centers (PSCC), Sorting Transfer Stations (STS), and Landfill sites. This layout optimizes waste sorting and disposal logistics. Each PSCC is strategically located within the city's three thanas for efficient plastic separation. STS serves as intermediate hubs for waste transfer, ensuring streamlined transportation to designated Landfill sites.

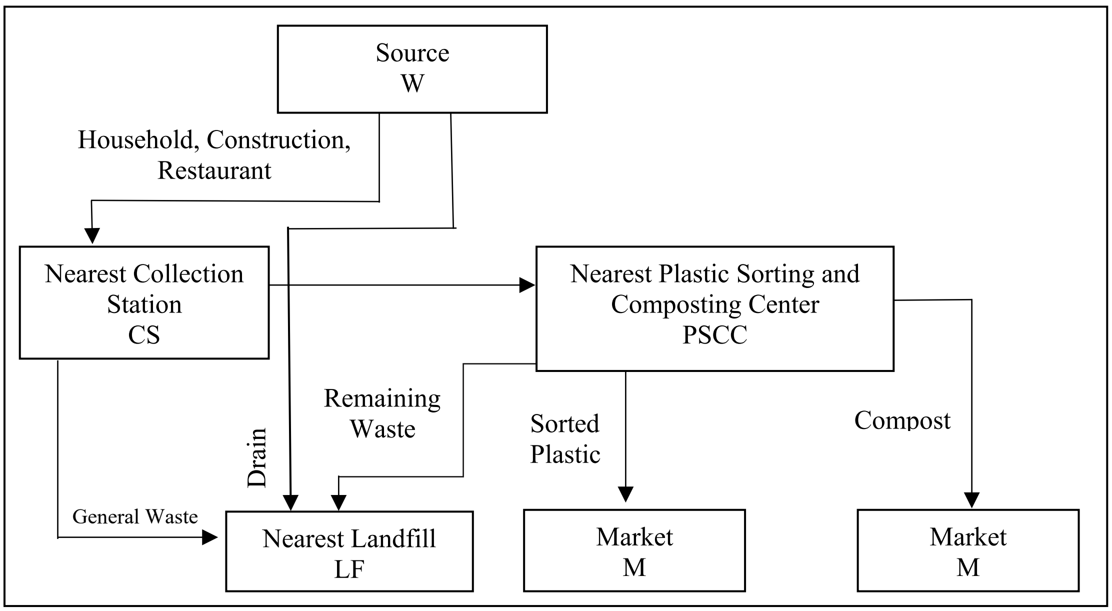

Figure 1. Waste flow system of the model

Model Assumptions

- The thana-wise population have been divided by the wards to obtain the ward-wise population.
- There are no plastic sorting and composting centers in Rajshahi City Corporation. Three plastic sorting and composting centers are assumed that are placed in three thanas.
- There is only one landfill but one more landfill has been granted. So, these two landfills have been considered.
- The variable cost of the plastic sorting and composting center is assumed.
- The transportation costs from the plastic sorting center and composting center to the industry are assumed.

Variables

QWij = amount (in tons) of daily solid waste transferred from Ward i to STS j (i = 1..., I; j = 1..., J)
QSTSCjk = amount (in tons) of daily solid waste to be transferred from STS/OWCS j to Composting Center k (j = 1..., J; k = 1..., K)
QSTSLjl = amount (in tons) of daily solid waste to be removed from STS/OWCS j to Landfill l (j = 1..., J; l = 1..., L)
QSTSPjp = amount (in tons) of daily Plastic to be removed from STS/OWCS j to Plastic Sorting Center (j = 1..., J; p = 1..., P)
QDWLil = amount (in tons) of daily drain waste to be transferred from Ward i to Landfill j (i = 1..., I; l = 1..., L)
QCpkl = amount (in tons) of daily solid waste to be transferred from Plastic Sorting and Composting Center k to Landfill l (pkl = 1..., PKL; l = 1..., L)

QPSCMpm = Plastic (in tons) delivered from plastic sorting center p to Market (p = 1..., P; m= 1..., M)
QCMkm = amount of Compost (in tons) delivered from Composting center p to market m
(p = 1..., P; m= 1..., M)
Dj = 1 if STS is to be set up in a Ward j (j = 1..., J)
Xij = 1 if Ward i is assigned to STS/OWCS j, 0 otherwise.
Yjk = 1 if STS/OWCS j is assigned to Composting Center k, 0 otherwise.
Zjl = 1 if STS j is assigned to landfill l, 0 otherwise.
Cjk = 1 if STS j is assigned to Composting Center k, 0 otherwise
Sjp = 1 if STS/OWCS j is assigned to Plastic Sorting Center p, 0 otherwise.
Wpkl = 1 if Composting Center k is assigned to landfill l, 0 otherwise.

Parameters

CSTSj = daily capacity of the STS/OWCS.
CCk = daily capacity of the Composting Center.
CPSCp = daily capacity of the Plastic Sorting Center.
CLl = daily capacity of the Landfill.
FBi = fixed cost of placing the bin represents the daily fixed cost.
FSTSj = fixed cost of the STS/OWCS represents the daily fixed cost.
FCk = fixed cost of the composting plant represents the daily fixed cost.
FPSCp = fixed cost of the Plastic Sorting Center represents the daily fixed cost.
FLl = fixed cost of the landfill represents the daily fixed cost
VSTSj = variable cost of the STS/OWCS represents the daily variable cost.
VCk = variable cost of the Composting Center represents the daily variable cost.
VPSCp = variable cost of the Plastic Sorting Center represents the daily variable cost.
VLl = variable cost of the Landfill represents the daily variable cost.
TWij = transportation cost of 1 ton of waste from the Ward i to the STS/OWCS j
(i = 1..., I; j = 1..., J)
TSTSCjk = transportation cost of 1 ton of waste from the STS/OWCS j to the Composting Center k (j = 1..., J; k = 1..., K)
TSTSPjp = transportation cost of 1 ton of waste from the STS/OWCS j to the Plastic Sorting Center k (j = 1..., J; k = 1..., K)
TDWLij = transportation cost of 1 ton of drain waste from the Ward i to landfill l
(i = 1..., I; l = 1..., L)
TCpkl = transportation cost of 1 ton of waste from the plastic sorting and composting plant k to the landfill l (k = 1..., K; l = 1..., L)
TPSCMpm = Transportation cost per ton of plastic from plastic sorting center to market
(p=1…, P) (m=1…., M)
T = number of STS and OWCS
DRi = amount of daily waste of drain generated at Ward i
AMC = daily administrative cost
SVC = daily supervisory cost
SC = daily sweeper Cost
Rt = Rate of 1ton Plastic is sold to the industry
Ct = Rate of 1ton Compost is sold to the industry
WCF = Fee for daily waste collection

Objective Function 1:

$$\begin{aligned}\text{Minimize } Z_1 = {} & \sum_{j=1}^{J} FSTS_j D_j + \sum_{k=1}^{K} FC_k + \sum_{l=1}^{L} FL_l + \sum_{p=1}^{P} FPSC_p + \sum_{i=1}^{I} FB_i + \sum_{j=1}^{J} VSTS_j + \sum_{k=1}^{K} VC_k + \sum_{p=1}^{P} VPSC_p \\ & + \sum_{l=1}^{L} VL_l + \sum_{j=1}^{J}\sum_{i=1}^{I} TW_{ij}\ QW_{ij}\, X_{ij} + \sum_{k=1}^{K}\sum_{j=1}^{J} TSTSC_{jk}\ QSTSC_{jk}\, Y_{jk} \\ & + \sum_{j=1}^{J}\sum_{l=1}^{L} TSTSL_{jl}\ QSTSL_{jl}\, Z_{jl} + \sum_{pk=1}^{PK}\sum_{l=1}^{L} TC_{pkl}\ QC_{pkl}\ W_{pkl} + \sum_{m=1}^{M}\sum_{p=1}^{P} TPSCM_{pm}\, QPSCM_{pm} \\ & + \sum_{m=1}^{M}\sum_{c=1}^{C} TCM_{km}\, QCM_{km} + \sum_{i=1}^{I}\sum_{l=1}^{L} TDWL_{il}\ QDWL_{il} + \sum_{m=1}^{M}\sum_{p=1}^{P} TPSCM_{pm}\, QPSCM_{pm} \\ & + \sum_{d}^{D} AMC + \sum_{d}^{D} SVC + \sum_{i}^{I}\sum_{d}^{D} SC\end{aligned}$$

Objective Function 2:

$$\text{Maximize, } Z_2 = \sum_{n=1}^{N}\sum_{p=1}^{P} QPSC_{pm}\, R_t + \sum_{n=1}^{N}\sum_{c=1}^{C} QC_{cn}\, Ct + \sum_{i}^{I} WCF$$

Constraints:

$X_{ij} \in \{0,1\}, \forall i \in i$ (4.1)

$X_{ij} = 1$ for the Ward i where distance ij is minimum for each i (4.2)

$X_{ij} = 1$ for the Ward i where there is a STS/OWCS (4.3)

$X_{ij} = 0$ for the other STS/OWCS (4.4)

$Y_{jk} \in \{0,1\}, \forall j \in J$ (4.5)

$Y_{jk} = 1$ for the composting center k where distance jk is minimum for each j (4.6)
$Y_{jk} = 0$ for the other composting center (4.7)
$S_{jp} \in \{0,1\}, \forall j \in J$ (4.8)
$S_{jp} = 1$ for the Plastic Sorting center p where distance jp is minimum for each j (4.9)
$S_{jp} = 0$ for the other plastic sorting center. (4.10)
$Z_{jl} \in \{0,1\}, \forall j \in J$ (4.11)
$Z_{jl} = 1$ for the landfill l where distance jl is minimum for each j (4.12)
$Z_{jl} = 0$ for the other landfill (4.13)
$W_{pkl} \in \{0,1\}, \forall j \in J$ (4.14)
$W_{pkl} = 1$ for the landfill l where distance pkl is minimum for each pk (4.15)
$W_{pkl} = 0$ for the other landfill (4.16)
$\sum_{j=1}^{J} QW_{ij} \leq G_i$ for i = (1…, I) (4.17)
$\sum_{i=1}^{I} QW_{ij} \leq CSTS_j$ for j = (1…, J) (4.18)
$\sum_{j=1}^{J} QSTSC_{jk} \leq CC_k$ for k = (1…, K) (4.19)
$\sum_{j=1}^{J} QSTSP_{jp} \leq CPSC_p$ for p = (1…, P) (4.20)
$QW_{ij} \geq 0$; $QSTS_{jk} \geq 0$; $QSTSL_{jl} \geq 0$; $QC_{pkl} \geq 0$ for i = 1…, I; j = 1…, J; k = 1…, K; l = 1…, L (4.21)
$D_j = \{0,1\}$ for j = 1…, J (4.22)
$\sum_{i}^{I} QDWL_{il} <= CL_l$ (4.23)

4. Data Collection

In the data collection phase, primary data was obtained directly from key stakeholders involved in waste management, namely the Rajshahi City Corporation, the Poribohon transportation service, and local waste collectors. These stakeholders provided comprehensive datasets essential for analyzing and understanding the dynamics of waste management within the area of study.

4.1 Data Analysis

After acquiring the requisite data, we proceeded to calculate the parameters based on the gathered information. With 30 wards comprising the Rajshahi City Corporation, these wards were designated as the primary sources of waste generation. In Rajshahi City Corporation, 298 tons of waste is collected daily. The ward-wise waste generation has been determined by the population living in a ward. Of collected waste, 15% waste can be recycled, and 45% waste can be composted. The remaining waste will be delivered directly to the landfill.

Table 3**.** Transportation cost from STS/OWCS to Plastic Sorting Center

Stations	Distance from STS/OWCS to Plastic Sorting Center			General Waste goes to PSC	Fuel cost			Transportation cost/ton		
	PSC 1	PSC 2	PSC 3		PSC 1	PSC 2	PSC 3	PSC 1	PSC 2	PSC 3
STS_1	2.5	6.6	10.2	1.55	25	65	100	29	55	78
STS_2	1.65	2.8	6.2	3.09	32	55	121	24	31	53
STS_3	1.4	5.1	7.3	1.55	14	50	72	22	45	59
STS_4	0.3	3.8	8.3	1.55	3	37	81	15	37	65
STS_5	2.2	3.7	5.9	1.55	22	36	58	27	36	50
STS_6	3.16	3.3	5.3	1.55	31	32	52	33	34	47
STS_7	2.4	2.35	5.78	3.68	56	55	135	30	30	51
STS_8	4.4	2.29	4.3	4.41	123	64	120	44	31	43
STS_9	2.2	3	6.7	1.47	20	28	62	27	32	55
STS_10	4.8	1.5	6.2	2.94	89	28	115	44	23	52
STS_11	4.6	0.9	5.1	2.94	86	17	95	42	19	46
STS_12	4.2	1.6	3.9	2.21	59	22	55	39	22	37
STS_13	4.9	2.3	3.2	0.74	23	11	15	51	35	40
STS_14	6	2.8	3.3	1.49	57	26	31	51	31	34

STS_15	7.7	5.1	0.16	0.74	36	24	1	68	52	21
OWCS_1	0.73	4.9	8.9	3.09	14	96	174	18	45	70
OWCS_2	2.8	3	5.7	0.74	13	14	27	37	39	56
OWCS_3	5.7	2.8	2.67	4.43	160	79	75	52	34	33
OWCS_4	6.6	4	1.4	2.14	89	54	19	54	38	21
OWCS_5	8.7	6.1	1.4	2.88	159	111	26	68	52	22

Table 3 shows the transportation cost from STS/OWCS to plastic sorting centers. Waste can go the PSC 1, PSC 2, and PSC 3. Waste will go to that PSC where transportation cost is minimum.

Table 4. Transportation cost from STS/OWCS to Composting Center

Stations	Distance from STS/OWCS to Composting Center			General Waste goes to PSC	Fuel cost			Transportation cost/ton		
	C_k 1	C_k 2	C_k 3		C_k 1	C_k 2	C_k 3	C_k 1	C_k 2	C_k 3
STS_1	2.5	6.6	10.2	4.64	73	194	300	32	59	81
STS_2	1.65	2.8	6.2	9.28	97	165	364	40	47	68
STS_3	1.4	5.1	7.3	4.64	41	150	215	26	49	63
STS_4	0.3	3.8	8.3	4.64	9	112	244	19	41	69
STS_5	2.2	3.7	5.9	4.64	65	109	173	31	40	54
STS_6	3.16	3.3	5.3	4.64	93	97	156	37	38	50
STS_7	2.4	2.35	5.78	11.03	168	164	404	49	49	71
STS_8	4.4	2.29	4.3	13.23	369	192	360	69	55	68
STS_9	2.2	3	6.7	4.41	61	84	187	30	35	59
STS_10	4.8	1.5	6.2	8.82	268	84	346	58	37	67
STS_11	4.6	0.9	5.1	8.82	257	50	285	57	34	60
STS_12	4.2	1.6	3.9	6.62	176	67	164	48	32	47
STS_13	4.9	2.3	3.2	2.21	69	32	45	44	27	33
STS_14	6	2.8	3.3	4.46	169	79	93	54	34	37
STS_15	7.7	5.1	0.16	2.23	109	72	2	61	45	13
OWCS_1	0.73	4.9	8.9	9.28	43	288	523	34	60	86
OWCS_2	2.8	3	5.7	2.21	39	42	80	30	32	49
OWCS_3	5.7	2.8	2.67	13.28	479	235	225	77	59	58
OWCS_4	6.6	4	1.4	6.42	268	163	57	63	47	30
OWCS_5	8.7	6.1	1.4	8.65	477	334	77	83	66	36

Table 4 shows the transportation cost from STS/OWCS to composting centers. Waste can go the Ck 1, CK 2, and CK 3. Waste will go to that CK where transportation cost is minimum.

Table 5. Transportation cost from STS/OWCS to Landfill

Stations	Distance from STS/OWCS to Landfill		General Waste goes to Landfill	Fuel cost		Transportation cost/ton	
	LF1	LF2		LF1	LF2	LF1	LF2
STS_1	6	9.2	4.12	157	240	54	74
STS_2	4.1	7.2	4.12	107	188	41	61
STS_3	6.2	9.4	4.12	162	245	55	75
STS_4	4.7	8.5	4.12	123	222	45	69
STS_5	5.2	8.4	4.12	136	219	49	69
STS_6	5.7	8.3	4.12	149	217	52	68
STS_7	4.8	7.4	4.12	125	193	46	62
STS_8	6.9	7.6	4.12	180	198	59	64
STS_9	3.2	6.3	4.12	83	164	36	55
STS_10	4.5	4.3	3.92	112	107	44	42

STS_11	4.5	4.9	3.92	112	122	44	46
STS_12	6.7	6.6	3.92	166	164	57	57
STS_13	7.5	5.9	3.92	186	146	63	52
STS_14	6.1	4.5	3.92	151	112	54	44
STS_15	9.4	7.8	3.92	233	194	75	65
OWCS_1	4.9	8.1	3.92	122	201	46	66
OWCS_2	5.1	8	3.92	127	199	47	66
OWCS_3	7.9	7.3	3.92	196	181	65	61
OWCS_4	8.3	6.7	3.92	206	166	68	57
OWCS_5	10.5	8.9	3.92	261	221	82	71

Table 5 shows the transportation cost of STS/OWCS to landfills. Waste can go the LF1, and LF2. Waste will go to that LF where transportation cost is minimum.

Table 6.Transportation cost from Plastic Sorting and Composting Center to Landfill

PSCC	**Landfill**		**General Waste goes to Landfill**	**Fuel cost**		**Transportation cost/ton**	
	LF1	**LF2**		**LF1**	**LF2**	**LF1**	**LF2**
PSCC 1	5.6	8.7	16.94	601	933	87	107
PSCC 2	6.1	6	23.92	924	909	111	110
PSCC 3	9.6	8	17.27	1050	875	113	103

Table 6 shows the transportation cost of plastic sorting and composting centers to landfills. Waste can go the LF 1, and LF 2. Waste will go to that LF where transportation cost is minimum.

Waste Categorization

The total amount of waste generated daily in Rajshahi City is 350 metric ton. Out of the total generated waste, 298 metric tons are collected daily, reflecting the efficiency of the waste collection system.

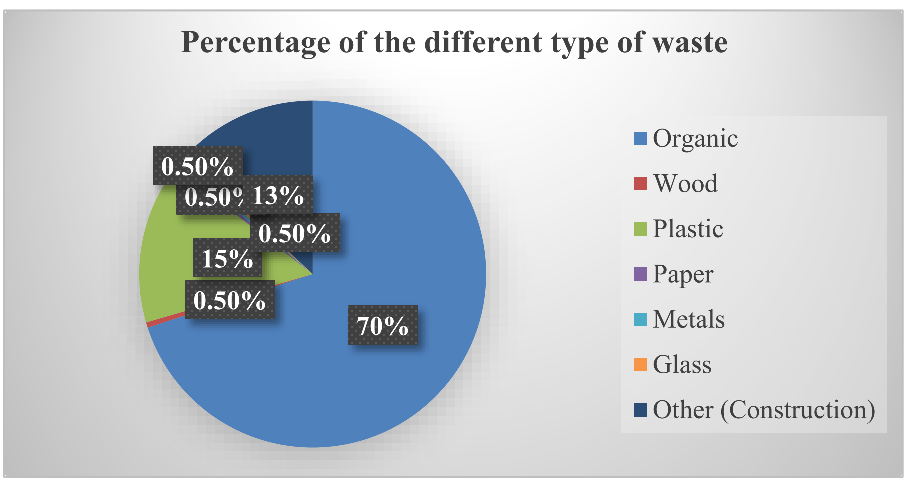

Figure 2. Percentage of different types of waste

Fig 2 shows the percentage of different types of waste. Organic Waste (70%) Constitutes the largest proportion of the total waste, organic waste accounts for approximately 70%. Wood Waste (0.50%) represents a small percentage of the total waste, accounting for only 0.50%. Approximately 1.49 metric tons of wood waste are generated daily. Plastic Waste (15%) constitutes a significant portion of the waste stream and the daily amount is approximately 44.7 metric tons. Paper Waste (0.50%) represents 0.50%. Approximately 1.49 metric tons of paper waste are generated daily. Metals Waste (0.50%) accounts for a small fraction of the total waste, comprising 0.50%and the daily amount is approximately 1.49 metric tons. Glass Waste (0.50%) constitutes a minor portion of the waste stream. Other (Construction) Waste (13%), primarily construction waste, represents a notable percentage of the total waste, accounting for 13%. Daily, approximately 38.74 metric tons of construction waste are generated.

Table 7. Percentage of different types of waste

Total Waste (ton)	**Percentage of General Waste**	**Percentage of Recyclable Waste**	**Percentage of Compostable Waste**
298	62.49 %	9.38 %	28.12%

Table 7 shows the percentage of different types of waste that are generated in Rajshahi City Corporation.

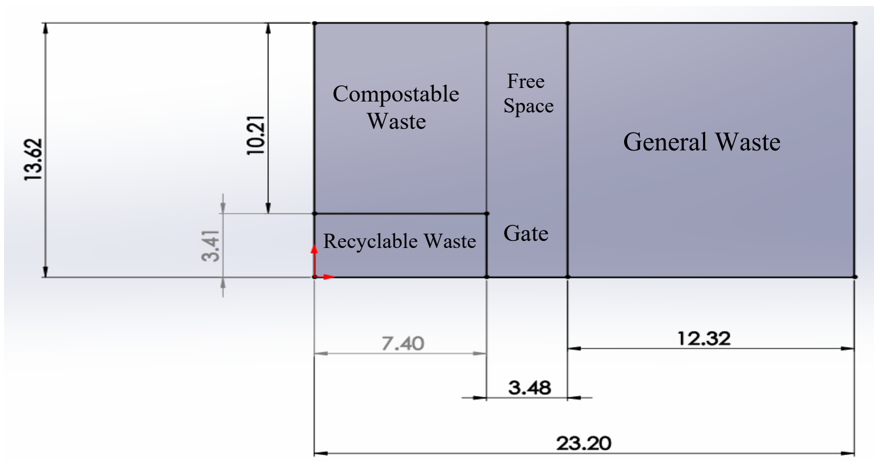

Figure 3. 2D view of the Secondary transfer station

Fig 3 shows the 2D view of secondary transfer station. We have designed the station based on the percentage of different types of waste. The layout of the can be divided into three sections for three types of waste. This will helpful for waste loading and unloading.

5. Results and Discussion

The result analysis has revealed that the waste management approach is generating a net profit of 649,140 BDT daily, derived from a total revenue of 1,180,000 BDT and a total cost of 530,860 BDT. This indicates a significant financial benefit, illustrating the economic viability of the proposed strategy. This financial surplus underscore the potential for enhancing the overall financial sustainability of waste management operations in Rajshahi City. Furthermore, the positive financial outcome suggests the feasibility of scaling up the waste management approach and allocating resources to other essential municipal services.

5.1 Numerical Results

Net Profit = Total Revenue-Total Cost

Table 8. Total Profit Calculation

Total Revenue (BDT)	Total Cost (BDT)	Profit (BDT)
1,180,000	530,860	649,140

Table 8 shows the total revenue, total cost, and profit.

5.3 Proposed Improvements

Table 9. Comparison between two systems

System	Cost (BDT)	Profit (BDT)
No Allocation of Collection Station	1,000,000	0
Allocation of Collection Station	530,860	649,140

Table 9 shows the comparison between No Allocation of Collection Station and Allocation of Collection Station

5.4 Validation

Sensitivity analysis evaluates how changes in input variables affect model or system outputs. By systematically adjusting one factor while keeping others constant, it gauges the model's responsiveness and identifies key drivers of outcomes. In this study, the percentage change for the sensitivity analysis was considered -10% and 10%. The parameters subjected to this sensitivity analysis included.

Table 10. Effect of change in QWSTSij on total cost

Variable	Percentage change	Total cost
$QWSTS_{ij}$	10%	565970.46
	-10%	495747.83

Table 10 shows when the $QWSTS_{ij}$ (amount of daily solid waste transferred from ward i to STS) by 10% the total cost experienced an increase of approximately 6.61 percent and 10% decrease it remained is -6.61 percent.

Table 11. Effect of change in $QSTSC_{jk}$ on total cost

Variable	Percentage change	Total cost
$QSTSC_{jk}$	10%	531431.07
	-10%	530287.21

Table 11 shows when $QSTSC_{jk}$ (amount of daily solid waste transferred from STS to Composting center) by 10% the total cost experienced an increase of 0.11 percent and 10% decrease it remain is -0.11 percent.

Table 12. Effect of change in $QSTSP_{jp}$ on total cost

Variable	Percentage change	Total cost
$QSTSP_{jp}$	10%	530985.52
	-10%	530732.75

Table 12 shows when the $QSTSP_{jp}$ (amount of daily plastic to be transferred from STS to Plastic Sorting Center) by 10% the total cost experienced an increase of 0.02 percent and 10% decrease it remained is -0.02 percent.

Table 13. Effect of change in $QSTSL_{jl}$ on total cost

Variable	Percentage change	Total cost
$QSTSL_{jl}$	10%	531291.24
	-10%	530427.04

Table 13 shows when the $QSTSL_{jl}$ (amount of daily solid waste to be removed from STS to Landfill) by 10% the total cost experienced an increase of approximately 0.08 percent and 10% decrease it remained is -0.08 percent.

6. Conclusion

The proposed waste management strategy offers a compelling solution to the challenges confronting Rajshahi City. Through analysis, it's evident that this approach yields a noteworthy daily net profit of 649,140 BDT, showcasing its economic feasibility and potential for financial sustainability. This surplus not only covers operational expenses but also presents opportunities for investing in additional municipal services, thereby bolstering the city's developmental agenda. We have allocated the waste of different wards to specific STS or OWCS based on their transportation cost but have not considered the capacity of the STS or OWCS. If the capacity of one STS or OWCS exceeds, the remaining waste of a ward will go to the second nearest STS or OWCS where the transportation cost is minimum.

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