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Optimalization Of Solid Waste Transportation In Geger District, Madiun

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Graphical Abstract

Abstract
This study aims to evaluate the performance of the solid waste transportation system in Geger District and determine the required transportation capacity to improve service coverage. The research involved the collection of primary and secondary data, including waste generation rates, transportation routes, and fleet characteristics (type, capacity, service area, and quantity). Fielad observations were conducted to quantity waste accumulation at temporary disposal sites, while fleet operational duration was analyzed through direct vehicle tracking. The performance assessment indicates that the current waste collection and transportation coverage is only 7.45%, demonstrating a significant gap between service capacity and waste generation. Operational analysis reveals inefficiencies in fleet utilization and routing. System optimization was conducted by estimating the required number of transportation units based on waste generation and service demand. Furthermore, a SWOT analysis was applied to formulate strategic improvements. The results suggest that enhancing fleet capacity, optimizing operational schedules, and improving TPS infrastructure are critical to increasing system performance. These findings provide a technical basis for developing a more efficient and sustainable solid waste transportation system in Geger District.

Keywords: Madiun, Optimalization, Solid waste, Strategy

1. INTRODUCTION

In 2023, Geger District, Madiun Regency, generated approximately 26,566 kg of municipal solid waste per day. However, the existing transportation capacity is limited to about 3,985 m³/day, resulting in a service coverage of only 7.69%. This low performance is due to the limited number of transportation trips (ritation) and fleet capacity. Waste is transported to the Kaliabu Landfill in Mejayan District using five arm roll trucks, each with a capacity of 6 m³. This condition is far below the target set by the Regional Waste Management Policy and Strategy (JAKSTRADA) of Madiun Regency (2018–2025), which aims to achieve 70% service coverage. Therefore, significant improvements in the waste transportation sector are urgently required.

In solid waste management systems, transportation plays a critical role in transferring waste from sources or temporary disposal sites to final disposal sites [1], [2]. The performance of waste transportation systems is influenced by multiple factors, including accessibility, transportation mode, trip frequency, travel time, routing patterns, and service coverage [3]–[5]. As waste generation increases, the complexity of transportation systems also rises, requiring more efficient operational planning [6], [7]. Key factors affecting system performance include waste volume, vehicle type, travel distance, labor requirements and operational time efficiency [8], [9].

From an economic perspective, transportation costs can account for up to 70% of total waste management expenditures, highlighting the importance of optimizing system efficiency [10], [11].

Optimization of the waste transportation system in Geger District is therefore essential to improve service performance within existing resource constraints. Route optimization and operational adjustments must consider both effectiveness and efficiency [12], [13]. In addition, long-term planning is needed to anticipate future waste generation. This study evaluates transportation needs over a 10-year projection period under three scenarios: (1) no waste reduction, (2) optimal waste reduction, and (3) gradual waste reduction. These scenarios are used to assess how waste reduction strategies influence transportation demand and service performance.

This research focuses on optimizing the existing waste transportation system and estimating future transportation requirements in Geger District, which consists of 19 villages. The area is characterized by relatively high population density and intensive socio-economic activities, supported by various public facilities, making waste transportation a critical component of environmental management. Currently, the district is served by four temporary disposal sites locations-Pagotan Market, Kaibon Village, Segaran Housing, and Sangen Housing, which are insufficient to accommodate the total waste generated. Limited transportation frequency and low public awareness further contribute to poor temporary disposal sites conditions. Therefore, this study aims to evaluate the current waste transportation system, analyze transportation needs, and formulate effective strategies to improve service performance in Geger District up to 2033.

2. METHOD

Geger District is in Madiun Regency and borders Madiun City to the north, Dagangan District to the east, Dolopo District to the south, and Kebonsari District to the west. This study focuses on evaluating the solid waste transportation system through field observations of five arm roll truck units operating in the area. Operational data, including transportation duration, loading–unloading time, and off-route or idle time, were collected using direct measurement with a stopwatch.

2.1. Data Collection Methods

Primary data were collected through direct observation and measurement, following national standards [14], [15]. The observations included existing field conditions, transportation routes, and operational characteristics of the waste transportation system using the Hauled Container System (HCS). Secondary data were obtained from relevant institutions, including the Geger District Office and the Environmental Agency of Madiun Regency. These data include fleet characteristics (type, capacity, number of units), service coverage areas, transportation route maps, and waste generation data.

2.2. Data Analysis Methods

The collected data was processed and organized into tabular form to facilitate analysis. Operational performance was evaluated based on transportation duration, trip frequency, and service coverage. The analysis focused on identifying inefficiencies in fleet utilization and estimating the required transportation capacity to improve system performance.

2.3. Determination of Transportation Strategies Using SWOT Analysis

Strategic recommendations were developed using SWOT analysis by identifying internal factors (strengths and weaknesses) and external factors (opportunities and threats). Each factor was assigned a weight and score to determine its relative importance. The total scores were then used to position the existing transportation system within the SWOT matrix quadrant. Based on this positioning, appropriate strategies were formulated to improve the effectiveness and sustainability of the waste transportation system. Considerations from experts/respondents used as the basis for the SWOT analysis include the Head of the Waste and Hazardous and Toxic Materials Division of the Madiun Regency Environmental Service, the Sub-Coordinator of Waste Processing at the Madiun Regency Environmental Service, the foreman of the temporary waste storage facility in the Geger area, and several garbage truck drivers.

3. RESULTS AND DISCUSSION

3.1. Existing Conditions of Waste Transportation

Equations Solid waste management in Madiun Regency is administered by the Environmental Agency, covering residential areas and public facilities. Waste transportation operations in Geger District are conducted daily from 05:00 to 13:00 (±8 hours), with flexible adjustments based on field conditions. The system is served by five transportation units (Table 1), predominantly arm roll trucks, in accordance with [16], [17]. The relatively long distance between temporary disposal sites and the Kaliabu landfill makes the use of arm roll trucks appropriate for improving transportation efficiency. However, operational frequency varies significantly, with some fleets completing two trips per day while others operate only one to two trips per week. Field observations conducted over seven consecutive days indicate that the average volume of waste transported to the landfill is approximately 17.47 m^3/day, whereas total waste generation reaches 234.65 m^3/day. This results in a service coverage of only 7.45%, indicating a substantial gap between waste generation and transportation capacity. Percentage source rubbish based on results weighing from temporary disposal sites to landfill is presented in Table 2.

The system applies to a HCS, where full containers at temporary disposal sites are exchanged with empty ones and transported to the landfill in a continuous cycle. Route tracking using GPS My Tracks shows that transportation routes mainly pass through major roads connecting Madiun-Surabaya, influencing travel time and vehicle speed (Table 3 and Table 4). The average operational time per trip is approximately 3 hours, with less than 0.5 hours of idle time (Table 5 and Table 6). Given the current one-trip-per-day pattern, vehicles operate only 3–4 hours daily, indicating underutilization. Furthermore, the off-route factor exceeds 0.15 [18], [19], suggesting inefficiencies and the need to increase trip frequency.

Table 1. Fleet routes

License plate number	Service area	Area type	Amount of rent/week
AE9007FP	Pagotan Market	Public facilities	3
AE8956FP	Pagotan Market	Public facilities	3
AE8576FP	Pagotan Market	Public facilities	5
AE8308FP	Kaibon Village	Settlement	2
AE8957FP	Segaran Housing Sangen Housing	Settlement	1

Table 2. Sources Rubbish based on polling stations

Polling station	Waste volume total intake (m^3)	Average (m^3/day)	Percentage source of rubbish (%)
Pagotan Market	87.40	12.49	71.49
Kaibon Village	21.20	3.02	17.31
Segaran Housing	7.00	1.00	5.73
Sangen Housing	6.70	0.96	5.48
	122.30	17.47	100.00

Table 3. Waste transportation routes

License plate number	Route
AE9007FP	TPA - TPS Pagotan Market - TPA
AE8956FP	TPA - TPS Pagotan Market - TPA
AE8576FP	TPA - TPS Pagotan Market - TPA
AE8308FP	Kaibon Village – TPA
AE8957FP	TPA - TPS Segaran Housing – TPA TPA - TPS Sangen Housing – TPA

Table 4. Distance of each waste transport trip

License plate number	Ritation	Average distance (km/ritation)
AE9007FP	Poll-TPS Pagotan Market -TPA	66.2
AE8956FP	Poll-TPS Pagotan Market -TPA	66.2
AE8576FP	Poll-TPS Pagotan Market -TPA	66.2
AE8308FP	Poll-TPS Kaibon Village -TPA	57.6
AE8957FP	Poll-TPS Segaran Housing -TPA Poll-TPS Sangen Housing -TPA	64.6

Table 5. Total time for each trip

License plate number	Service Area	Time (hour/time)		Total time (hour/time)
		Effective	Rest	
AE9007FP	Pagotan Market	3.32	0.5	3.82
AE8956FP	Pagotan Market	3.26	0.5	3.76
AE8576FP	Pagotan Market	3.16	0.5	3.66
AE8308FP	Kaibon Village	3.30	0.5	3.80
AE8957FP	Segaran Housing Sangen Housing	3.42	0.5	3.92

Table 6. Total remaining off route time (W) for each trip

License plate number	Polling Station Name	Time (hour/time)		Remaining time (hour/time)
		Working hours	Ritation	
AE9007FP	Pagotan Market	8	3.82	4.18
AE8956FP	Pagotan Market	8	3.76	4.24
AE8576FP	Pagotan Market	8	3.69	4.31
AE8308FP	Kaibon Village	8	3.79	4.21
AE8957FP	Segaran Housing Sangen Housing	8	3.91	4.09

3.2. Transportation System Optimization

Optimization was performed by evaluating remaining travel distance and available working time [20]. If operational time and distance allowed, the number of daily trips (ritation) was increased; otherwise, adjustments were made to maintain compliance with the 8-hour working limit. The analysis reveals that most fleets still have the capacity for optimization, except for the unit operating at Pagotan Market, which already achieves a service level of 128.50% and serves areas beyond Geger District. Increasing the number of trips for underutilized fleets-particularly those serving temporary disposal sites of Kaibon Village, Segaran Housing, and Sangen Housing-proved effective. After optimization, these fleets were able to perform up to two trips per day. This improvement increased service coverage by 8.62%, raising the overall transportation service level from 7.45% to 16.07% (Table 7). These findings demonstrate that optimizing operational scheduling can significantly enhance system performance without immediate infrastructure expansion.

Table 7. Additional waste transportation trips

License plate number	Polling Station Name	Optimization		Rubbish transported		
		Before (irritation)	After (irritation)	Before (m^3/week)	After (m^3/week)	After (m^3/day)
AE8308FP	Kaibon Village	2	10	21.2	106	15.14
AE8957FP	Segaran Housing Sangen Housing	1	6	7.0	42	6

3.3. Solid Waste Generation and Composition

Waste composition and generation data were analyzed based on [15] to support mass balance calculations and long-term planning. Material Flow Analysis (MFA) was applied to project waste generation up to 2033 (Table 8) under two scenarios: optimal conditions and gradual reduction [21]. The analysis incorporates waste composition percentages and recovery factors (RF) to estimate future waste flows. The results highlight the importance of integrating waste reduction and recovery strategies into transportation planning to reduce system burden and improve overall efficiency (Table 9, Table 10, Table 11, Figure 1, and Figure 2).

Table 8. Total time for each trip

Facility	License plate number	Number (people)		Generation (m^3/day)	
		Year		Year	
		2023	2033	2023	2033
Rubbish domestic	-	64,650	70,850	234.66	245.19
Facility education	8,266			1.24	3.72
Facility health	80			0.32	0.96
Market facilities	3,000			1.5	3.00

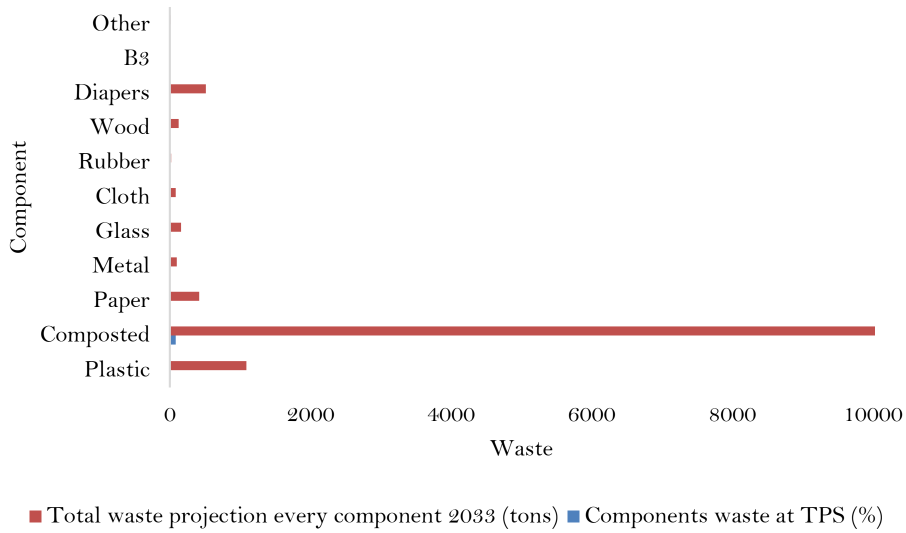

Figure 1. Total waste projection

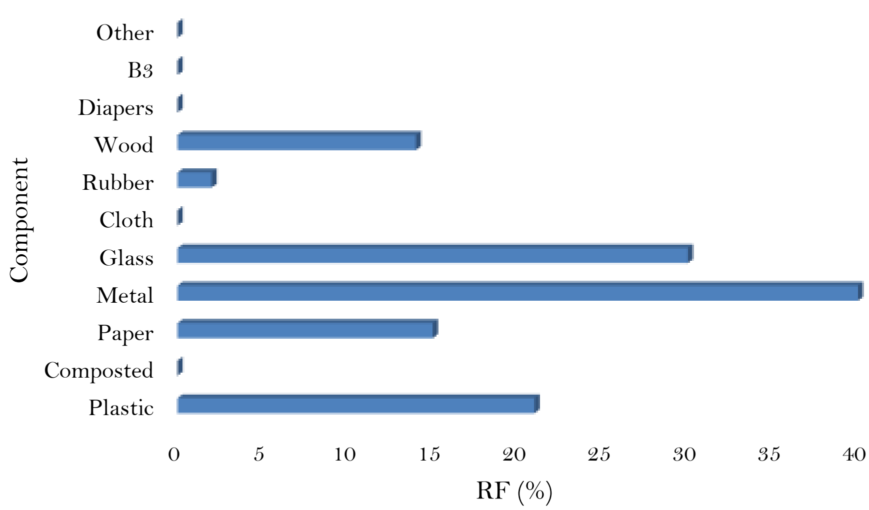

Figure 2. RF values

Table 10. Generation of rubbish with optimum reduction

Year	Total waste served	Total waste reduced						Total waste reduced	Total waste thrown away to the landfill
		Plastic	Paper	Metal	Glass	Wood	Rubber		
		8.58%	3.28%	0.75%	1.25%	0.98%	3.28%	(tons/year)	(tons/year)
		21%	15%	40%	30%	14%	20%		
2023	975.26	17.57	4.80	2.93	3.66	1.34	0.64	30.93	944
2024	979.55	17.65	4.82	2.94	3.67	1.34	0.64	31.07	948
2025	983.86	17.73	4.84	2.95	3.69	1.35	0.65	31.20	953
2026	988.19	17.81	4.86	2.96	3.71	1.36	0.65	31.34	957
2027	992.54	17.88	4.88	2.98	3.72	1.36	0.65	31.48	961
2028	996.91	17.96	4.90	2.99	3.74	1.37	0.65	31.62	965
2029	1,001.29	18.04	4.93	3.00	3.75	1.37	0.66	31.76	970
2030	1,005.70	18.12	4.95	3.02	3.77	1.38	0.66	31.90	974
2031	1,010.12	18.20	4.97	3.03	3.79	1.39	0.66	32.04	978
2032	1,014.57	18.28	4.99	3.04	3.80	1.39	0.67	32.18	982

2033	1,019.03	18.36	5.01	3.06	3.82	1.40	0.67	32.32	987
Total	10,967.02	197.6	53.96	32.90	41.13	15.05	7.19	347.83	10,619

Table 11. Generation of rubbish with reduction gradually

Year	Total waste served	Presentation reduction rubbish gradually	Total waste reduced (tons/ year)	Total waste reduced						Total waste reduced (tons/year)	Total waste thrown away to the landfill (tons/year)
				Plastic	Paper	Metal	Glass	Wood	Rubber		
				8.58%	3.28%	0.75%	1.25%	0.98%	3.28%		
				2.1%	1.5%	40%	30%	14%	20%		
2023	975.26	0%	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	975.26
2024	979.55	2%	19.59	0.35	0.10	0.06	0.07	0.03	0.01	0.62	978.93
2025	83.86	4%	39.35	0.71	0.19	0.12	0.15	0.05	0.03	1.25	982.61
2026	988.19	6%	59.29	1.07	0.29	0.18	0.22	0.08	0.04	1.88	986.31
2027	992.54	8%	79.40	1.43	0.39	0.24	0.30	0.11	0.05	2.52	990.02
2028	996.91	10%	99.69	1.80	0.49	0.30	0.37	0.14	0.07	3.16	993.75
2029	1,001.29	12%	120.15	2.16	0.59	0.36	0.45	0.16	0.08	3.81	997.48
2030	1,005.70	14%	140.80	2.54	0.69	0.42	0.53	0.19	0.09	4.47	1,001.23
2031	1,010.12	16%	161.62	2.91	0.80	0.48	0.61	0.22	0.11	5.13	1,004.99
2032	1,014.57	18%	182.62	3.29	0.90	0.55	0.68	0.25	0.12	5.79	1,008.78
2033	1,019.03	20%	203.81	3.67	1.00	0.61	0.76	0.28	0.13	6.46	1,012.57
Total	10,967.02	-	1,106.32	19.93	5.44	3.32	4.15	1.52	0.73	35.09	10,931.93

3.4. Optimization Strategy for Waste Transportation System

To enhance system performance, strategic planning was conducted using SWOT analysis. The results identify several key strategies [22], [23]:

1. Human Resource Development, strengthening personnel capacity through training and education in waste management to improve operational performance.
2. Workforce Welfare Improvement, providing fair wages aligned with the regional minimum wage and additional incentives to increase motivation and productivity.
3. Stakeholder Collaboration, enhancing partnerships with third parties through Corporate Social Responsibility (CSR) programs to support funding for temporary disposal sites development and fleet procurement.
4. Monitoring and Evaluation, implementing regular performance monitoring of temporary disposal sites operations and transportation systems to ensure continuous improvement.
5. Infrastructure and Fleet Improvement, rejuvenating transportation fleets and upgrading temporary disposal sites facilities to increase transportation frequency and service coverage.

Overall, these strategies emphasize that improving operational efficiency, strengthening institutional capacity, and upgrading infrastructure are essential to achieving a more effective and sustainable waste transportation system in Geger District [24], [25].

4. CONCLUSION

The performance of the waste transportation system in Geger District can be significantly improved by optimizing fleet operations, particularly through increasing the number of daily trips for arm roll trucks. The implementation of two trips per day at Kaibon Village temporary disposal sites and one additional trip at Segaran Housing and Sangen Housing temporary disposal sites has proven effective in enhancing service coverage. Future projections for 2033 under three scenarios: no reduction, optimal reduction, and gradual reduction, indicate annual waste generation of 1,019.03 tons/year, 986.71 tons/year, and 1,012.57 tons/year, respectively. These results suggest that waste reduction strategies can contribute to lowering transportation demand and fleet requirements. Key recommendations include improving and expanding temporary dumping site facilities and supporting infrastructure to enhance operational efficiency and service performance.

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