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ORIGINAL RESEARCH PAPER

# Evaluation of municipal waste collection performance using operational data

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**ABSTRACT**

**BACKGROUND AND OBJECTIVES:** Developing countries' governments face challenges in municipal solid waste collection, such as rapidly increased volume of waste, physical and social obstacles to collection routes, or funding shortages. The lack of practical evaluation of the waste collection performance is considered a gap in improving the waste collection system in these countries. This study aims to assess the efficiency of current municipal solid waste collection by analyzing operational data that can help enhance the collection.
**METHODS:** The geographical information system and the geographical position system data of all active trucks were collected for 14 consecutive days using the digital map. Data on waste volume collected by trucks, waste volume at collection points, and operational time of trucks throughout a working day were collected by survey. The operational efficiency indicators, including the deadhead rate, waste collected per distance unit, stopping time rate, and costs, are estimated to evaluate the effectiveness of municipal solid waste collection services.
**FINDINGS:** The results indicate that solid waste collection efficiency of 1.67 tons/kilometers is low for high-density population areas. The deadheading rate of approximately 20 percent shows that the collection route operated by drivers is meandering and inefficient. Although using small trucks (6–7 tons) for transporting waste to landfills over a long distance is inefficient, small vehicles are used more than large ones. Ineffective utilization of transfer stations could lead to high idle time, accounting for approximately 37.6 percent of a collection trip. The regulated estimating method for transportation costs is not comprehensively developed, which may cause mistakes in choosing collection vehicles for operation and transfer station usage.
**CONCLUSION:** The research findings assess the performance and identify ineffective factors that require improvement of waste collection, aiming to enhance the solid waste management system. Waste collection routes of Hoan Kiem district must be designed using empirical data. The distance-based coefficients should be developed for all collection vehicles with different loading capacities to better estimate collection and transportation costs in Hanoi, helping decision-makers utilize the current transfer station more effectively and appropriately in choosing collection vehicles for operation.



NUMBER OF REFERENCES
31

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8

NUMBER OF TABLES
2

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## INTRODUCTION

In developing countries, waste management systems often struggle to provide effective collection services to urban populations (Shekdar, 2009). Ineffective urban waste collection practices can spread disease and adverse environmental and socio-economic impacts due to fuel consumption and pollutant emissions (Zsigraiova *et al.,* 2013). Collection accounted for a significant share of the waste management cost (Greco *et al.,* 2015), averaging between 50 percent (%) and 70% of the total system (Hannan *et al.,* 2020). Municipalities in developing countries have implemented numerous waste collection schemes. Urban areas cannot take advantage of these initiatives due to financial distress and limited resources (Soni, 2022). Guerrini *et al.* (2017) advocated that enhancing the efficiency of waste collection services must be prioritized for adequate financial support. Improving the performance of solid waste collection systems (WCS) is a major challenge for most developing countries. In developing cities, drivers were responsible for constructing the waste collection routes without considering the increasing demand. An efficient OCR is vital as cities expand due to urbanization (Hazra and Goel, 2009). Analyzing demand, performance analysis, and planning routes more effectively are necessary to meet this increasing demand. The performance analysis findings can help make decisions about corrective actions to improve performance to meet environmental needs, ensure public acceptance, encourage social participation, and inform investment decisions or other specific activities (Sulemana *et al.,* 2018). Urban waste collection rate has increased gradually in cities and provinces in Vietnam. It rose from 81% in 2010 to 92% in 2019 (Monre, 2020). Major cities, such as Ha Noi, Ho Chi Minh, and Da Nang, had relatively high urban solid waste collection rates of 99% and 100%. The secondary waste collection efficiency is inadequate, causing adverse effects, such as traffic problems, unpleasant odors, and litter on the road, affecting the sewage system. The rapid increase in the generated waste and continuous change in waste composition due to socio-economic development leads to confusion in operational practices. According to the National Status of the Environment Report (Monre, 2020), the solid waste composition showed a significant change due to the lifestyle of urban residents. Biodegradable organic matter in household waste dropped from a high rate of approximately 80–90% in the 2000s to 50–60% in 2015–2020. Recyclable materials, such as paper and plastic, including components challenging to handle, such as textile, leather, rubber, and low-valued plastic waste, tend to increase over the years (Hoang *et al.,* 2017; Pham *et al.,* 2021). Low-density waste in the composition leads to a relative increase in waste volume, affecting the WCS capacity and operational efficiencies. Current research on collection efficiency focused on evaluating the municipal solid waste (MSW) collection service performed by private companies and local governments. Salazar-Adams (2021) research reveals that private waste collection companies may outperform the government's efficiency. However, in terms of eco-efficiency in MSW collection service, Romano *et al.* (2020) demonstrated that publicly-owned waste operators tend to excel. In Vietnam, the number of publicly-owned waste collection operators surpasses that of private companies. Notably, the collection efficiency of both is subpar. Collection activities' performance analysis through operational data is more important than relying on operators' choices. Collection system optimization has gained significant attention as a research trend. Previous studies defined optimal collection routes by re-allocation of recycling stations (Le *et al.,* 2022); developed optimal routes to reduce costs and greenhouse gas emissions (Hannan *et al.,* 2020), minimizing the number of vehicles with transfer stations (Ghiani *et al.,* 2021), or maximizing waste volume collected (Son, 2014). A substantial amount of data input is needed to achieve accurate results using optimization models. This requirement necessitates data worthiness and timeliness, which lack in Vietnam. The problems in Vietnam are the lack of data and key performance indicators (KPIs) to assess the collection system. Literature assessed the KPIs of WCS, including the operational cost (Zsigraiova *et al.,* 2013), vehicles' traveled distances (Tavares *et al.,* 2009), and the number of trips (Kinobe *et al.,* 2015). The operational scheduling and routing of collection vehicles are often considered as leading causes of poor performance of the collection system, but these factors are less considered in previous literature. This shortcoming occurs in many developing cities, including Ha Noi City (HNC). Regarding waste collection in densely populated urban areas, such as the city center of HNC, operational time is critical in ensuring efficient and timely waste collection. The problem of traffic congestion during rush hour exacerbates the challenge of waste collection. Being efficient in the timely waste collection could help minimize traffic flow disruption. The operational time has been studied in previous literary works, yet these studies have been somewhat limited concerning its impact on enhancing the collection process. Operational time for each waste collection process, such as loading and unloading waste, moving, and off-route during operation, was not specified in the study of Le *et al.* (2021). The timely efficiency was evaluated in the study by Nguyen (2018) but did not consider factors affecting the running time, such as routes and distance from landfills and transfer stations. Weight collected per distance unit is a crucial measure for evaluating the efficacy of collection routes. It provides valuable insights into appropriate collection services based on area conditions, especially in high-density urban settlements (Nguyen, 2018). Other essential metrics for waste collection assessment are cost for collection and deadheading rate. The term 'deadheading' means the unnecessary distance traveled by collection trucks that do not collect trash. A high deadheading rate means more fuel, labor, and upkeep expenses with no income in return. Academic research tends to focus on the former (Salazar-Adams, 2021; Le *et al.,* 2022; Hannan *et al.,* 2020) and not consider the latter. An assessment of the rate of deadheading, accompanied by KPIs, such as weight collection per unit of routes and trucks, operational time, and cost analysis, can uncover potential strategies for improving the system. Previous studies have been found to overlook the issue of insufficient attention. A thorough analysis of these indicators and the factors that influence them is necessary to develop effective strategies for improvement. This study mainly aims to identify the primary factors that affect collection efficiency indicators and to devise strategies for enhancing WCS. This study was conducted in Hoan Kiem district (HKD), Ha Noi City, Vietnam in 2021.

## MATERIALS AND METHODS

Ha Noi is one of the most prominent cities in Vietnam with a population of 8.5 million people and plays a significant role in Vietnam's economy and culture. Like many rapidly growing cities, waste management in Ha Noi has become a critical issue in recent years (Monre, 2020).

### *Study area*

HKD is one of the famous tourist destinations in Ha Noi (Fig. 1). Located in the city's heart, this district is famous for its peaceful beauty and cultural significance, offering visitors a glimpse into its rich heritage. The district is the smallest district of Ha Noi City, with a population of approximately 140 thousand.

The waste collection in the old quarter district often faces problems due to the complexity of the urban, high-density population, the significant number of tourists, and the inappropriate waste collection routes (Phuong *et al.,* 2021). Fig. 2 shows the waste flow and collection method applied in HKD.

Although vehicles and facilities are adequate, slow waste transportation due to inefficient route design causes various difficulties for collection activities. The daily waste generation in HKD is approximately 250–300 tons (t), primarily from household, tourist, commercial, and public activities, and this amount of waste is transported to Nam Son landfill (NSL), which is 50 kilometers (km) from the city.

### *Survey and data collection*

The global position system (GPS) loggers attached to Ha Noi urban environment company (URENCO) collection vehicles record the coordinate data by time. The database is stored and processed in URENCO digital map system for management. The GPS data of operational trucks operating in HKD is collected for 14 consecutive days (May 16–29, 2021) via Ha Noi URENCO digital map system (Nordtest, 1995). With 11 collection trucks (including six 6-ton loads, two 7-ton, two 10-ton, and one 11-ton vehicles) operating in the area, the team could collect operational data of approximately 197 collection rides (197 samples) for processing and analyzing the efficiency of the WCS. Quantum global information system (QGIS) ver. 3.30.1 software was used to map collection routes with collection points. The collection points' geographic coordinates are collected from Ha Noi URENCO. Due to no collection route being designed, the collection route in each area is defined by survey team members based on the location of collection points, and the road segment drivers travel most to collect waste in that area. The volume of waste in collection points and waiting time at collection points were observed

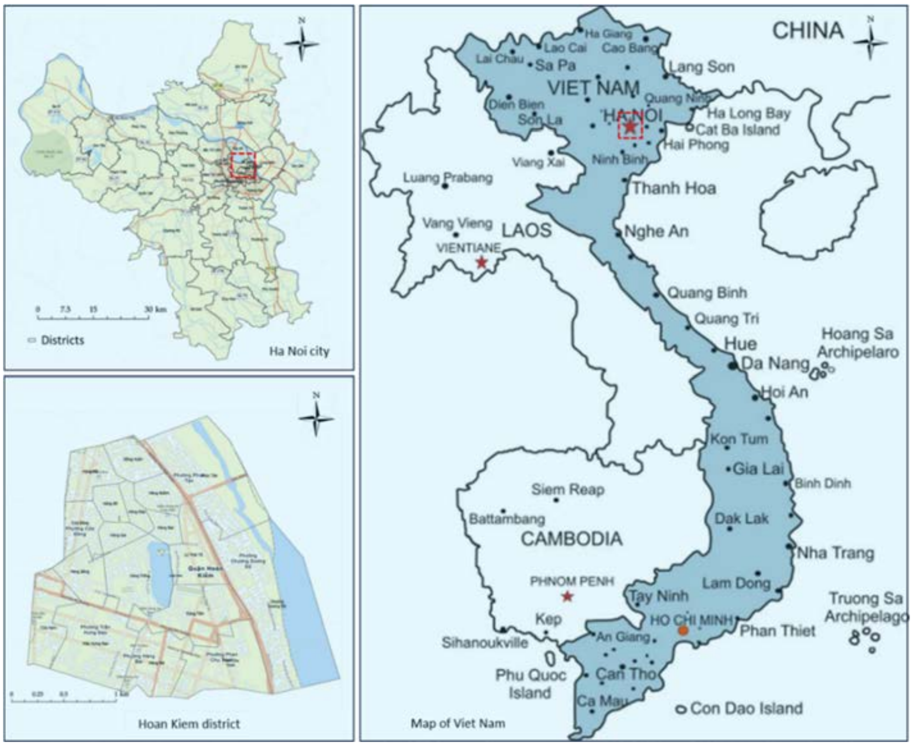


Fig. 1: Geographic location of the study area HKD, Ha Noi City, Vietnam


Fig. 2: Methods for collecting waste in HKD

by the field survey team in the collection points during the survey period. The collection cost for each trip was estimated and provided by URENCO as secondary data. The explanation of indicators, input data, and collection methods is presented in Table 1.

*Data analysis*

Several indicators evaluate the collection operation's effectiveness in this study. Firstly, the effectiveness of the collection route and vehicle usage in the related tour is evaluated by the rate of waste collected amount per moving distance of collection trucks. This indicator is popular in comparing collection methods (Nguyen, 2018). In this study, indicator $E_1$ (Eq. 1) assesses the route operated by collection drivers in each area while the indicator $E_2$ (Eq. 2) evaluates the effectiveness of using collection vehicle types for the whole trip. The effectiveness of

Table 1: Factors and indicators for assessing the performance of the collection route

| No. | Input data and indicators | Denotes | Units | Explanation and determination |
|---|---|---|---|---|
| 1 | | $i,j,k$ | | Denote the collection truck, route, and vehicle type |
| 2 | Number of sample | $n^j$<br>$n_k$ | | The number of trucks collecting waste on route *j*, and the number of collection trucks type *k* |
| 3 | Length of total collection trip | $Q_{i,j}$ | Km | The total length of the trip (from garage to landfill and go back to garage) that the collection truck *i* collecting waste on route *j*. The data is collected from recorded data in the digital map of URENCO based on the registered plate of vehicles and time. |
| 4 | Operational time | $T_i$ | minute (min) | The operational time of a collection truck *i* for one trip. The data is collected from URENCO digital map. |
| 5 | Stopping time | $T_i^s$ | min | The total stopping time of collection truck *i* during the operation. Survey team members collect and calculate the data by tracking vehicle *i* on each trip on URENCO digital map. |
| 6 | The length of the collection route | $D_j$ | km | The length of route *j* traveled by collection trucks from the first collection point to the last. $D_j$ is determined based on the digital map after survey team members create the collection route. |
| 7 | The length of the deadhead | $D_j^h$ | km | The total segment length of that collection vehicle traveled more than once in route *j* without waste collection. $D_j^h$ was defined by survey team members based on the movement of the collection truck in the collection route map. |
| 8 | Collected waste amount of a vehicle in one trip | $M_i$ | t | The amount of waste that the collection truck *i* collected in one route. Data of $M_i$ are collected from recorded data of weighbridge in NSL according to the registered plate of vehicles and the time the vehicle arrived |
| 9 | The efficiency of the collection route | $E_0^j$ | t/km | The rate of the waste amount per distance of the collection route *j* inside the city |
| 10 | The route efficiency of collection vehicles (truck types) | $E_1^k$ | t/km | The rate of the waste amount that trucks type *k* (small and large) transport over the distance of the collection route*s* |
| 11 | The trip efficiency of the collection vehicles (truck types) | $E_2^k$ | t/km | The rate of the waste amount that trucks type *k* (small and large) transport over the distance of the collection trips |
| 12 | The indicator for deadheading rate assessment | $E_3$ | % | The percentage of the deadheading segment length and the length of the collection route (Mcbride, 1982) |
| 13 | The indicator for time usage effectiveness assessment | $E_4$ | % | The percentage of stopping time over operational time |

route *j* was calculated using Eq. 1 (Nguyen, 2018).

$$E_0^j = \frac{\sum_i \frac{M_{i,j}}{D_j}}{n_j} \quad (1)$$

The effectiveness of trucks type *k* was calculated using Eq. 2 (The current study result).

$$E_1^k = \frac{\sum_{i,j} \frac{M_{i,j,k}}{D_{j,k}}}{n_k} \quad (2)$$

The effectiveness of collection vehicles for the whole tour was calculated using Eq. 3 (The current study result).

$$E_2^k = \frac{\sum_{i,j} \frac{M_{i,j,k}}{Q_{i,j,k}}}{n_k} \quad (3)$$

The deadhead indicator presents the proportion of ineffective road segments applied to evaluate the collection route drivers' superiority based on their experience with city traffic and area conditions. A higher deadhead rate indicates the current collection route is meandering and inefficient. The deadheading rate was calculated using Eq. 4 (Cortés *et al.,* 2011).

$$E_3 = \frac{D_j^h}{D_j} \times 100 \quad (4)$$

The indicator of collection time usage evaluates the ratio of stopped time (including waste collection time) to the total operating time of the collection vehicle. A higher ratio indicates a longer idle time for the vehicle. A high ratio implies that the vehicle has to stop frequently during its operation, and the utilization of the collection vehicle's operation time along the route is inefficient. Stopping time can be affected by the local traffic condition or the road characteristics in downtown areas. The time usage effectiveness was calculated using Eq. 5 (The current study result).

$$E_4 = \frac{T_i^s}{T_i} \times 100 \quad (5)$$

## RESULTS AND DISCUSSION

Fig. 3 presents the maps of collection routes for waste collection in each area in HKD, as re-created by GPS data of collection vehicles during the survey. The red lines present the actual moving pathway of collection vehicles from the garage to collection areas, and the blue lines describe the route for collecting waste in assigned areas, defined by collection points in the areas and the highest moving frequency of collection vehicles.

The collection routes are not properly planned; the drivers choose the optimal route based on their experience and understanding of traffic conditions in the collection area. The collection routes in Hang Bai, Tran Hung Dao, and Cua Nam vary among collection trips. The drivers' unstable routes made the management and operation difficult, especially in assessing the effectiveness of waste collection activities. Analyzing and assessing collection activities' efficiency is impossible when drivers operate different routes time by time. Thus, the current collection face difficulties in improvement due to a lack of assessment data. Determination of route collection maps helps estimate the length, deadheading rates, and route efficiency.

### *Efficiency of collection routes*

Table 2 presents the daily data of collection routes, cost and efficiency, and the rate of truck types used for each route defined in the maps. Based on the created maps, the average length of a waste collection route is 5.3 km, with an average frequency of approximately 1.5 trips per day. The means of route efficiency of trucks is approximately 1.67 tons per kilometer (t/km), higher than Da Nang city (0.6–1.65 t/km) (Nguyen, 2018). The distance between the city and the disposal site is a key factor in collection efficiency. The routes with the highest effectiveness are Trang Tien, Tran Hung Dao, and Phan Chau Trinh, while those with the lowest effectiveness are Hang Dao, Le Van Linh, and Ly Thai To. Although the latter routes generate high volumes of waste, their collection efficiency is only approximately 1 t/km. Long-distance routes and dense populations decrease collection efficiency in these areas. The effectiveness of a route is also affected by the utilization of vehicles, as shown in this case study. Using larger vehicles can increase the amount of waste collected per distance unit and potentially increase collection costs. The cost column indicates the fee for collecting and transporting one ton of MSW from the city to the landfill for disposal, thereby representing the unit cost of a truck for this purpose.

### *The deadheading rates*

The high proportion of deadheading segments is attributed to the characteristics of the assigned area's terrain, road, and traffic conditions. One of the main factors is the inefficient routing and scheduling of waste collection trucks. Poor route design can lead to long detours and backtracking, wasting time, fuel, and resources. The deadheading rate significantly impacts the effectiveness of waste collection routes, but it lacks attention in waste collection studies in Vietnam. Fig. 4 illustrates the deadheading rate of waste collection routes, indicating that the average deadheading rate is approximately 20%. The collection routes with the highest deadhead are Hang Bai (50%) and Le Van Linh (30%). Due to its low deadheading rate, the Trang Tien route is the most efficient moving distance. The box plot reveals several outliers for the Bach Dang, Cua Nam, Hang Dao, Hang Bai, and Ly Thai To routes, indicating that collection vehicles traveled differently on each trip due to drivers' choices, increasing deadheading rates. The deadheading rate in waste collection routes got little attention in previous literature, and other Vietnamese cities' information on the deadheading

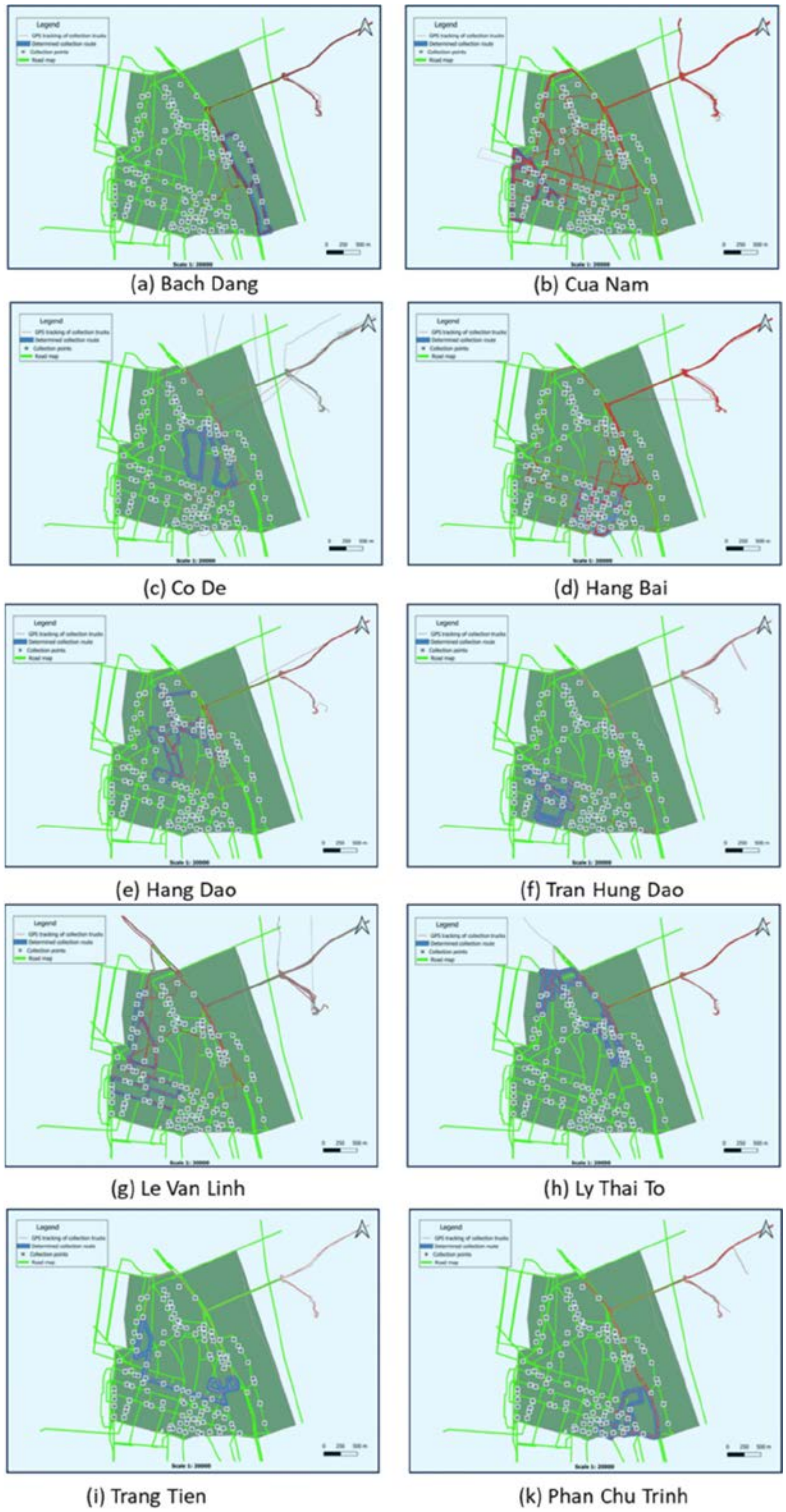


Fig. 3: Waste collection routes of HKD. The red and orange line shows the actual moving of collection vehicles, while the blue lines show the collection route in different areas. Handcart icons and their address present the collection points

Table 2: Data and parameters of collection routes in Hoan Kiem

| Route | $D_j$ (km) | Efficiency $E_0^j$ (t/km) | Daily collected (t/day) | Cost (VND/t) | Frequency (trips/day) | Percentage of 6 and 7-ton trucks (%) |
|---|---|---|---|---|---|---|
| Trang Tien | 4.4 | 2.53 | 3.2 | 271,850 | 0.3 | 0 |
| Tran Hung Dao | 4.2 | 2.82 | 12.7 | 268,681 | 1.1 | 0 |
| Phan Chau Trinh | 4.9 | 2.47 | 10.4 | 271,226 | 0.9 | 8 |
| Ly Thai To | 7.2 | 1.00 | 13.4 | 244,622 | 1.9 | 100 |
| Le Van Linh | 7.8 | 1.30 | 31.1 | 250,027 | 3.1 | 50 |
| Hang Dao | 7.9 | 0.98 | 13.2 | 247,020 | 1.7 | 100 |
| Hang Bai | 4.6 | 1.71 | 11.7 | 249,875 | 1.5 | 95 |
| Cua Nam | 3.8 | 1.98 | 12.5 | 262,147 | 1.6 | 100 |
| Co De | 4.3 | 1.79 | 4.4 | 257,808 | 0.6 | 100 |
| Bach Dang | 3.7 | 2.14 | 12.3 | 248,039 | 1.6 | 100 |
| Average | 5.3 | 1.67 | 12.5 | 257,130 | 1.4 | 65 |

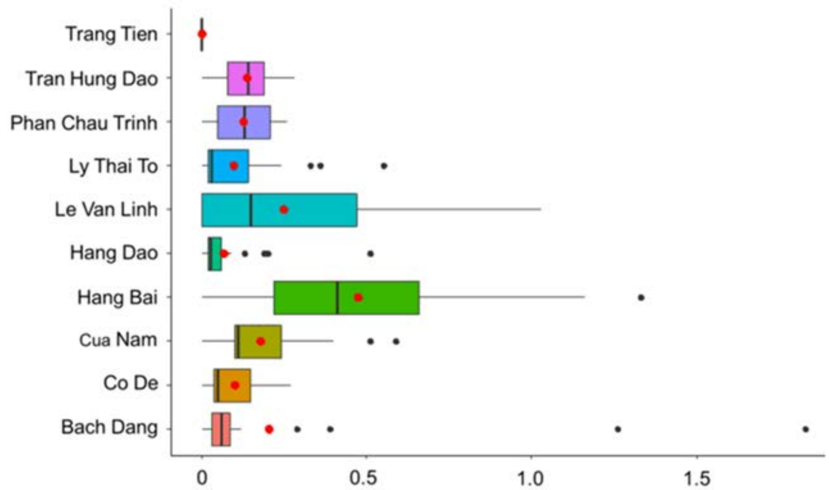


Fig. 4: The deadheading rate of collection routes

rate of waste collection routes is unavailable.

To reduce deadheading rates in waste collection routes, waste collection companies can invest in better route optimization and scheduling software to optimize routes based on real-time data on waste generation patterns (Ramos *et al.,* 2018). Various optimization methods are successfully applied to optimize collection systems, such as variable routing optimization (Hannan *et al.,* 2020); GIS approaches (Tavares *et al.,* 2009), mixed integer programming (Bhambulkar and Khedikar, 2011) or Integer Linear Programming (Ghiani *et al.,* 2021). In addition to optimizing routes and schedules, URENCO can undertake alternative waste collection methods, such as on-demand or subscription-based collection services, that can reduce deadheading rates by aligning collection schedules with waste generation amount more effectively. Such approaches can also provide more flexible and customized waste collection services to businesses and households with home businesses, leading to higher customer satisfaction and loyalty.

*The efficiency of collection vehicles*

Fig. 5 shows the result of effectiveness indicators $E_1$ and $E_2$ in assessing the effectiveness of truck usage for collection inside and outside the city center. The mean collection efficiency of vehicles over the trip is approximately 0.1 t/km, relatively lower than in Hoi An City (0.5 t/km) (Le *et al.,* 2021).

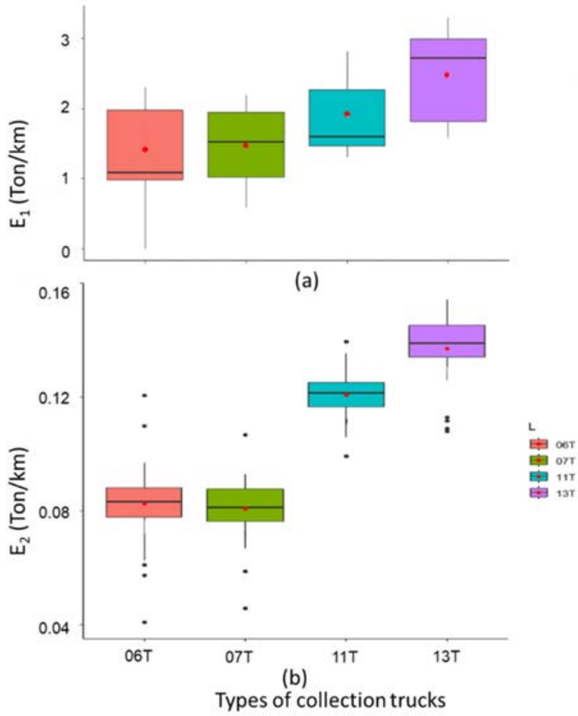


Fig. 5: The collection vehicles' effectiveness assessment

The variance in the efficiency of route collection across various vehicle types (from 1.5–2.1) (Fig. 5a) is considerably smaller than that of the efficiency of the trip (from 0.08–0.13) (Fig. 5b). These results indicate that small collection trucks (6-ton and 7-ton) are more effective for short trips, and big trucks (11-tons and 13-tons) are suitable for long trips. Using small trucks for transporting waste to landfills over a long distance is inefficient. To enhance the effectiveness of WCS, small trucks for the direct transportation of waste to NSL should be reduced, and a transfer station should rather be utilized (Worrell and Vesilind, 2010).

*Collection time*

Fig. 6 assessed the time usage efficiency of each vehicle used for transportation. On average, an entire collection trip took approximately 291 min (approximately 6 hours), and the stopping time is approximately 108 min (approximately 2 hours), accounting for approximately 37.6% of the traveled time. The operation and stopping times are significantly varied, while the total distance of collection trips is constant, approximately 93 km. Le *et al.* (2021) recent study discovered that the average cumulative operational hours for each type of vehicle across four working shifts in Hoi An City is approximately 3 hours. Vehicles can operate on four shifts per day. Shorter transportation distances result in better efficient use of vehicles, while longer distances pose challenges in controlling operational time (Nguyen, 2018). Implementing a waste transfer station presents an optimal solution to the time inefficiencies the vehicles face.

Fig. 7 illustrates the correlation between waste volume collected by a vehicle ($M_i$) and the stopping time of each vehicle. The correlation coefficient is 0.22, indicating that the stopping time of vehicles is not affected by the amount of loading waste. This result is consistent with a previous study by Nguyen (2018). The field observation results showed that the average loading time of small and large vehicles, considered part of stopping time in this study, is approximately 45 and 70 minutes (min). The unknown-reason stopping time is approximately 40–60 min, accounting for 13–20% of the overall collection time of vehicles, considered as

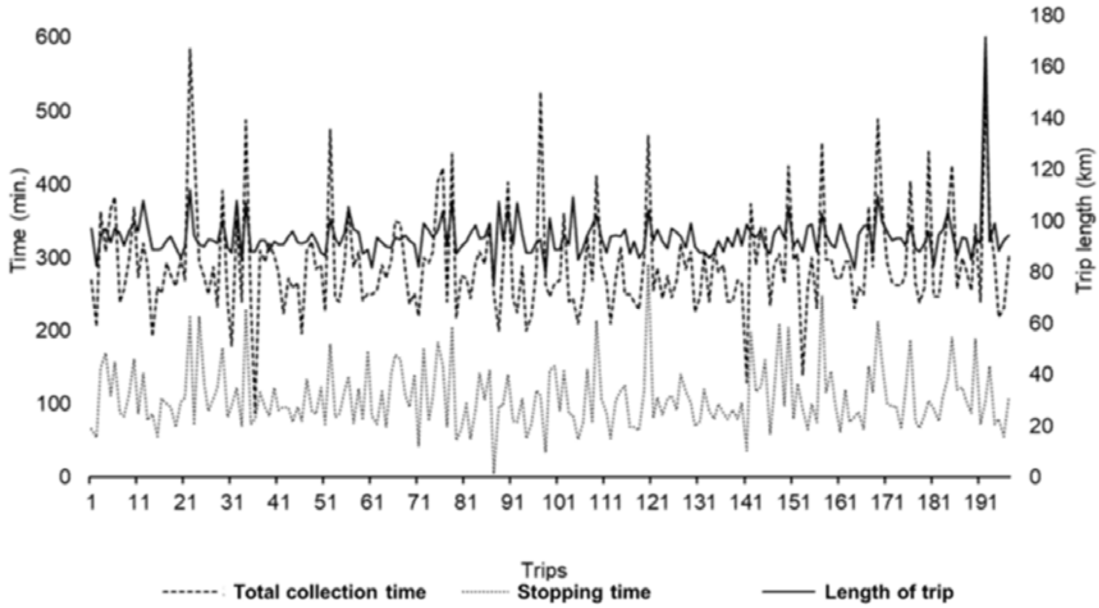


Fig. 6: Time usage of different collection trips

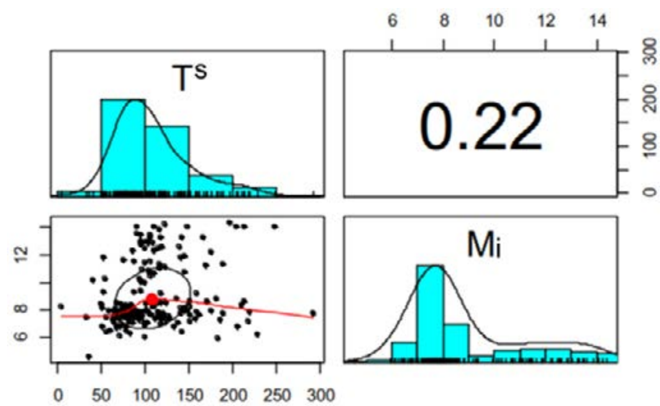


Fig. 7: Correlation of stopping time and loading waste of vehicle.

off-route factors. This result is consistent with the off-route factors defined in the study of Tchobanoglous *et al.* (1993), which varies from 10– 40% of collection time, and a rate of 15% is the representative off-route factor for most operations. This study indicates that the drivers made efficient use of their time while gathering and carrying waste despite working a six-hours-extended shift.

Despite the Lam Du transfer station located approximately 5 km from the city center, it is not being utilized to transform small collection trucks into large vehicles (Ghiani *et al.,* 2021). Fig. 8 shows the cost for collection and the number of trips using small vehicles (7 t maximum loading capacity) and using large vehicles (13 t maximum loading capacity). The unit costs for transporting one t of waste using small compressor trucks are cheaper than that for large ones. URENCO Hanoi uses small trucks for transporting waste to landfills more frequently. It can be explained by the collection

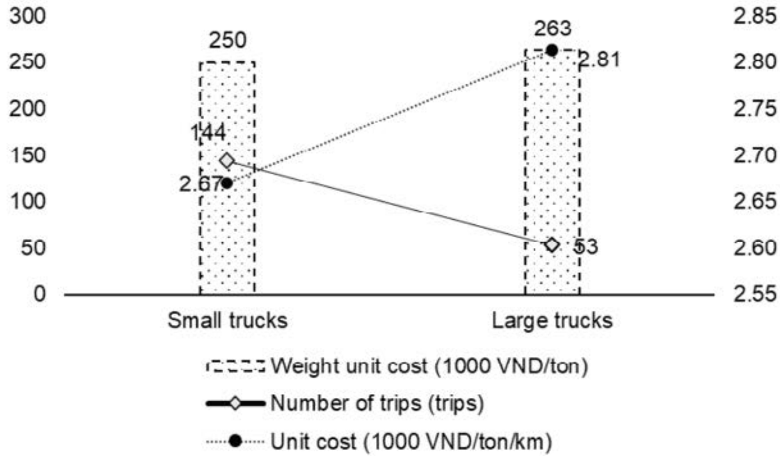


Fig. 8: Collection cost

cost estimates method regulated by the decision 30/2020/QĐ-UBND on Nov 26th, 2020, on issuing procedures, standards, and cost estimation for environmental sanitation maintenance in Ha Noi City (HPC, 2020). The method applied the same distance-based adjustment coefficients for labor and equipment costs for all vehicles. The unit cost of small trucks is always lower than that of big trucks. This study result contrasts prior studies of waste transfer stations (Ouano, 1983) and the theory for estimating transportation cost (Worrell and Vesilind, 2010), indicating that the slope of unit cost per weight of small trucks is greater than that of large trucks. The unit cost per t per km of small trucks should be greater than that of large ones (Ouano, 1983). Since the large vehicle unit cost is higher than the small vehicle unit cost, the transfer station is inappropriate in Ha Noi. It requires developing the distance-based adjustment coefficients appropriate for different truck capacities to improve the cost-estimating method of waste transportation.

## CONCLUSION

The study investigated HKD's secondary collection system through operational data and four KPIs. The analysis of these indicators has revealed the interdependence of these factors and their consequential impact on the overall operation of the collection system. Notably, this research pioneers analyzing and evaluating the deadheading rate indicator. The result indicates that the existing collection routes, established by drivers based on their experience with local traffic, are meandering and ineffective. The mean deadheading rate is relatively high, at approximately 20%. Hang Bai route exhibits the highest deadheading of approximately 50%. The mean collection efficiency of vehicles throughout the trip, estimated to be approximately 0.1 t/km, is relatively low compared to other cities in Vietnam. The mean operational time of a collection trip is approximately 6 hours, and the driver must work a prolonged shift. The collection system requires more workers and trucks due to the long operational time. The study also shows that the transportation cost estimation method is inappropriate when applying the same distance coefficient for small and big trucks. It can also explain the ineffective utilization of transfer stations and the relatively high operational time and long transportation distance in HKD. After analyzing the collection efficiency indicators and the contributing factors, the primary strategies for enhancing efficiency have been identified. Following the initiative to promote scientific-based decision-making in Vietnam, it is recommended that a study be conducted to determine the distance factors for waste transportation trucks of varying types. The results should then be disseminated and discussed with relevant authorities. Precise calculations and collection cost projections can efficiently utilize collection vehicles and transfer stations. Next, vehicle routing should be re-designed to reduce the deadheading rate and optimize waste collection. By illuminating these strategies, communities and URENCO could better manage and streamline their waste management processes, leading to more sustainable and environmentally friendly practices.

## AUTHOR CONTRIBUTIONS

G.M. Hoang, the corresponding author, has contributed to planning the research, interpreting results and preparing the manuscript. T.D. Nguyen conducted secondary data collection and reviewed, commented, and edited the manuscript., H.T.T. Ung conducted survey and and N.T.L. Le caried out data analysis.

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## CONFLICT OF INTEREST

The author declares that there is no conflict of interest regarding the publication of this manuscript. In addition, the ethical issues, including plagiarism, informed consent, misconduct, data fabrication and/or falsification, double publication and/or submission, and redundancy, have been ultimately observed by the authors.

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## ABBREVIATIONS

| | |
|---|---|
| *%* | Percent |
| $D_j$ | Distance of collection route |
| $D_j^h$ | Distance of deadhead |
| $E_0$ | Efficiency of collection route |
| $E_1$ | Route efficiency of collection trucks |
| $E_2$ | Trip efficiency of collection trucks |
| $E_3$ | Percentage of deadheading length |
| $E_4$ | Percentage of stopping time |
| *GIS* | Global information system |
| *GPS* | Global position system |
| *HKD* | Hoan Kiem district |
| *km* | kilometers |
| $M_i$ | Amount of waste that a collection truck collected |
| *min.* | minutes |
| *MSW* | Municipal solid waste |
| *min* | minute |
| *NSL* | Nam Son landfill |
| OCR | operational collection route |
| $Q_{i,J}$ | The total distance of the collection trip |
| *QGIS* | Quantum GIS |
| *t* | Ton |
| $T_i$ | Operational time |
| $T_i^s$ | Stopping time |
| *URENCO* | Urban environment company |
| *WCS* | waste collection systems |

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