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CASE STUDY

Optimization of solid waste collection system in a tourism destination

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ABSTRACT

BACKGROUND AND OBJECTIVES: Prior to the COVID-19 pandemic, Hoi An City was one of the most famous tourist destinations in the world. This led to a rapid increase in solid waste generation, leading to problems and challenges in solid waste collection and management. This problem is also being experienced by other developing countries of the world. Despite the existence of established waste management strategies, targets set for the collection of recyclable waste have not been met. This study introduces solutions to the problems and challenges faced by the waste management sector in Hoi An city and other developing countries. This study aimed to i) optimize the map of the recovery recycling stations in an urban community, ii) develop an effective solid waste collection system, and iii) provide management tools to enhance recycling activities, contributing to improving waste management in Hoi An city.

METHODS: The RRSs were integrated into a solid waste collection system in the urban communities of Hoi An City, were conducted through location-allocation analysis in a geographic information system environment. Routing problems of carts were solved in the combination of the rescheduling of existing solid waste collection activities in the study site. The economic evaluation by scenarios was also calculated for ten years to assess the feasibility of scenarios.

FINDINGS: Thirty-four locations were identified and optimized to accommodate the RRSs and new collection routes. The distances travelled and working time increased in proportion to the increase in waste separation effectiveness. Waste separation is vital to the effectiveness of the new solid waste collection system. The optimal solid waste practice model (in scenarios 2 and 4) revealed the positive results in improving the solid waste collection system, operating economy, and local adaptation.

CONCLUSION: This study redesigned the solid waste collection system to solve the current problems in the tourism destination of Hoi An city. This study contributed as a case study of integrating urban recovery recycling stations into optimizing a solid waste collection system in a tourism destination. Introducing strict waste separation was the pivotal first step in systematically upgrading the solid waste collection system in Hoi An City. This study's findings provide government officials and service providers with methods that can be applied to solve the problems faced by Hoi An city's existing solid waste collection and management system.

NUMBER OF REFERENCES	NUMBER OF FIGURES	NUMBER OF TABLES
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INTRODUCTION

The urgency for enhancements to the solid waste collection system (SWCS) has arisen due to the boom in the tourism industry. An increase in tourist numbers over recent years has brought about many environmental problems, specifically an increase in solid waste generation (Zambrano-Monserrate *et al.,* 2021). The upsurge in solid waste generation has increased the challenges faced in the solid waste management (SWM) of governments globally (Sharma, 2016). Hoi An City is categorized as a UNESCO World Heritage Site (Giang *et al.,* 2017). The upsurge in tourism-related activities has resulted in a dramatic increase in solid waste generation in Hoi An City (Song Toan *et al.*, 2018). This is the biggest challenge faced by SWM in Hoi An City. Solid waste collection (SWC) is one of the most critical components of an SWM system, accounting for between 50% and 90% cost of SWM (Das and Bhattacharyya, 2015). The SWCS in the tourism destination of Hoi An city (TDoHAC) has been facing many problems, namely illegal SWC that is not in line with current laws and procedures (Cuong *et al.*, 2021), improper gathering waste practices, and comingling separated solid waste (Song Toan *et al.*, 2019). The enhancement of the SWCS in TDoHAC was an urgency for tourism activities and sustainable development. Currently, the SWM national strategies in developing countries are focused on enhancing the recycling system towards a sound-material cycle society (Sharma Kapil and Jain, 2019). In Vietnam, solid waste is required to be separated into recyclable waste, food waste, and other waste by the new national environmental protection law (NASRV, 2020). Moreover, the adjustment of the national strategy for integrated management of solid waste also highlighted that SWM must consider the life cycle of solid waste from generation to final treatment (PMSRV, 2018). Despite the strategies towards the reversed logistic system for recyclable waste, the implementations in the developing countries have not achieved the expected results and faced many problems. The informal recycling system in developing countries may not be efficient in recovery and recycling (Zhu *et al.*, 2021). In Vietnam, about 10% of total domestic waste was recycled (The World Bank, 2018). A significant amount of recyclable waste was detected at the landfills (Song Toan *et al.*, 2021). The recycling activities are operated by the informal and private sectors, which are the scavengers, waste pickers, and junk shop collectors. Despite the vital role of the informal sector (Tong *et al.*, 2021), the operation of informal systems, particularly in developing countries, normally contributed to local pollutants (Bali Swain *et al.*, 2020). The informal recyclers usually adopted outdated technologies and improperly managed pollutants, leading to the environmental pollution of air, soil, and water (Yang *et al.*, 2018). The operation of informal sectors conflicts with the environmental goals of the government. So, the transition from informal to formal recycling system is inevitable. The integration of informal sectors into formal SWM system can enhance the management practices to ensure environmental protection in a systematic approach. This integration can also help local authorities in actualizing the strategies of SWM on waste separation and integrated SWM. The transition from the informal to the formal recycling system may lead to a restructuring of the municipal SWM system, whereby a redesign of the integrated collection system is inevitable. In this study, the Recycling Recovery Systems (RRSs) will be established to collect recyclable materials from resident areas. The integrated collection system is also studied and optimized. The changes were intentionally made to the entire system by integrating RRSs with the aim to formalize the reversed logistic system. Moreover, the optimization of collection routes falls typically under the umbrella of vehicle routing problem (VRP) and arc routing problem (ARP). ARP is used to SWC in case the solid waste is discharged along a street segment. ARP is considered as Capacitated ARP if there is a vehicle capacity constraint (Wøhlk, 2008). CARP is proven to be an NP-hardness (Nondeterministic Polynomial time-hardness) problem that requires many resources to solve (Liu *et al.*, 2021). The counterpart of ARP is VRP, which solves problems of SWC for truck fleets to travel between depots and collection points. This problem also falls into capacitated VRP if routing is constrained (Longo *et al.*, 2006). The optimization of collection routes of TDoHAC was conducted under the umbrella of VRP due to the existence of solving tool integrated into geographic information system (GIS) software. It is undeniable that SWM has spatial nature. Thus, taking advantage of new technologies, namely GIS, should be prioritized. GIS is a popular tool in environment-related studies. There are many GIS applications used for optimization in SWM. TransCAD and ArcGIS have been the two most popular tools for optimization (Murray, 2021). ArcGIS Network Analyst (ANA) was applied for the optimization of SWCS. A study used ANA to analyze SWC and create optimal vehicle routes in three waste collection scenarios in Sfax, Tunisia. Thanks to ELECTRE III method, this study suggested an efficient and environmentally-friendly scenario for SWC (Amal *et al.*, 2020). ANA was also used to optimize the collection routes of dustbins in Vellore city, India. The method for choosing the transfer station was the median center following various design factors to minimize Euclidean distance. The optimized routes showed a reduction of 59.12% in traveled distances (Lella *et al.*, 2017). In Vietnam, a study conducted optimization of SWC with a focus on interrelationships between parameters in a dual-phase SWCS. A GIS-based dual-phase model was built, and total system cost was estimated in Hai Phong city, Vietnam. The model showed a 13.76% reduction in travel distance (Hoang Lan *et al.*, 2018). Another study proposed a model for optimizing municipal SWC in a static context and a dynamic context using GIS analysis, equation-based modeling, and agent-based modeling in Ha Giang city, Vietnam. The results showed a reduction in cost by 11.3% (Khanh *et al.*, 2017). Above-mentioning studies have strongly optimized the distances and time of collection routes without much concerning the waste separation program. This study designed and planned SWCS of TDoHAC based on the existing SWCS in considering its problems and challenges, especially solid waste separation program. The applications of ANA into optimizing SWC in Vietnam and Hoi An city were still limited. This would be the first effort to apply ANA to the optimization of SWCS in Hoi An city, Vietnam. Moreover, integrating the RRSs system into SWCS was considered a comprehensive solution for actualizing the SWM strategies and targets of collecting recyclable waste. This study integrated the collection of recyclable waste through urban RRSs into the official SWM system. This can be suggested as the first research to consider integrating informal recyclable waste collection into the official SWM system regarding optimization of SWCS in Vietnam and among developing countries. The aims of the current study was an effort to i) optimize the map of the recovery recycling stations (RRSs) in an urban community, ii) develop the solid waste collection system, and iii) provide management tools to enhance recycling activities and improve waste management in Hoi An city.

MATERIALS AND METHODS

Hoi An city is a famous tourist city in the central of Vietnam (Fig. 1). The downtown in the city's centre is the core tourism destination which attracts about 5,000 tourists per day. The tourist activities cause the high density of waste generation in the tourism area by 15 ton/km^2 (Song Toan *et al.*, 2019), which has brung many negative impacts on the environment and landscape of the world cultural heritage site.

The main component of solid waste in TDoHAC was kitchen waste, accounting for 46.8% of total waste generation. Tissue, garden waste, and plastic bags were also the significant components with 11.54%, 8.68%, and 7.84%, respectively. The other waste were glass (1.83%), incombustible waste (1.56%), combustible waste (1.13%), textile (2.88%), rubber (0.84%), leather (1.34%), as well as wood and bamboo (1.7%). Notably, the proportion of recyclable waste was 12.85%, including metal (1.16%), paper (3.79%), cardboard (3.9%), plastic (2.95%), and PET (1.05%) (Song Toan *et al.*, 2019). These types of waste were recyclable and valuable, which were usually sold to junk shops. Thus, the solid waste from TDoHAC illustrated a high potential for recycling. However, only a small amount of recyclable waste was collected by waste workers in TDoHAC, while the remaining large amount of recyclable waste was mainly collected by the informal sector (Song Toan *et al.*, 2019). This study made an effort to integrate the activities of the informal sector into formal SWM. Regarding SWCS, waste is collected daily by carts and trucks, two primary vehicles for SWC in TDoHAC. Carts are also used for collecting waste from street sweeping. There are two meeting points for carts, where carts gather to meet compaction trucks. The capacity of compaction trucks ranges from 6 to 9 m^3. There were four main sessions of SWC, Early morning, Morning, Afternoon, and Evening. The majority of the workload was conducted in the morning. The

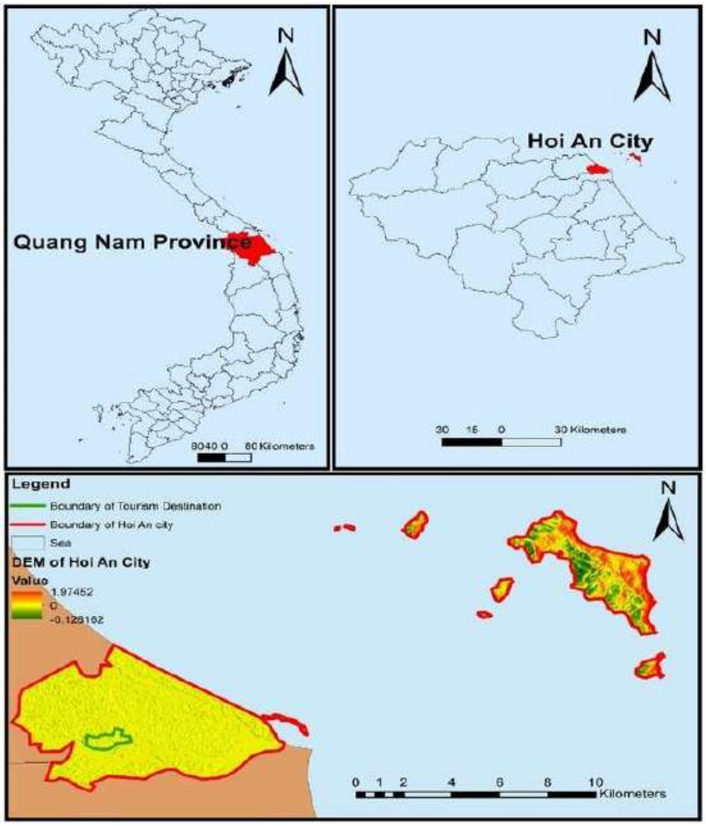


Fig. 1: Geographic location of the study area and topographic conditions of Hoi An city in Vietnam

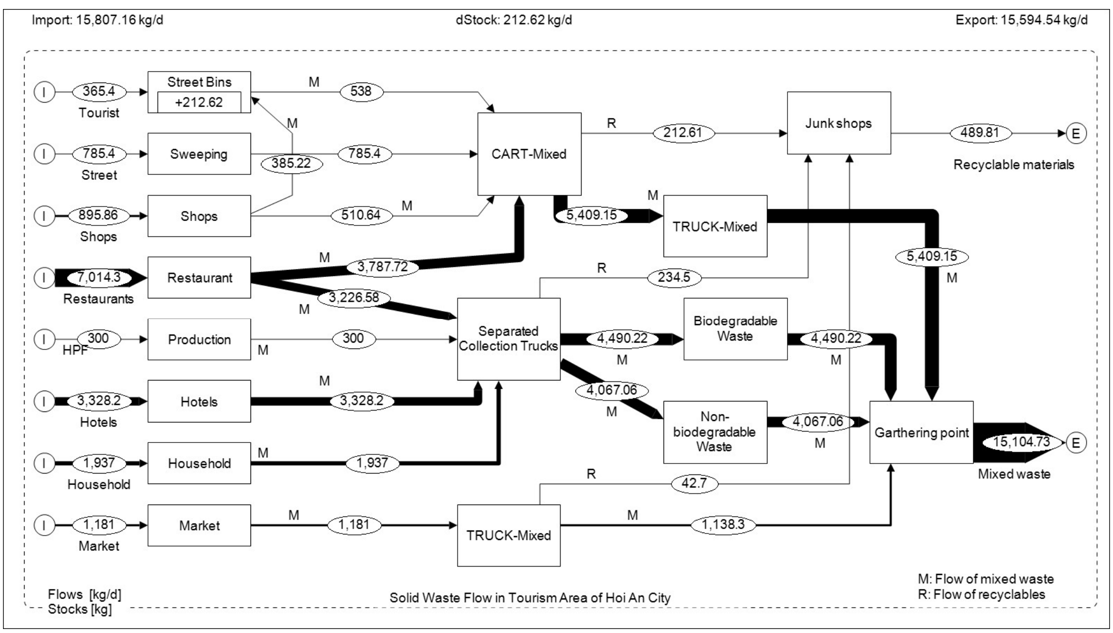


Fig. 2: The S0 (existing solid waste collection in TDoHAC) (Song Toan *et al.*, 2019)

amount of solid waste generated was 15,807.16 kg, and the amount of solid waste storage in TDoHAC was 212.62 kg (Fig. 2). Solid waste was mingled and discharged at a landfill or waste treatment facilities.

There were problems in the current SWCS. The separated waste was mixed before being transferred to waste treatment facilities due to no distinct routes for collecting separated solid waste. Solid waste was also illegally discharged into carts and trucks. The biodegradable waste, which harms tourism activities, was only collected every two days. The business sectors showed no enthusiasm for storing biodegradable waste, so that they illegally discharged biodegradable waste into carts or trucks on Tuesday, Thursday, and Saturday. Regulation on time of waste gathering (5:00 AM – 6:00 AM) was commonly violated because citizens gathered waste along the street right after the end of business activities, causing adverse effects on urban aesthetics and tourism activities (Cuong *et al.*, 2021). This led to an urge to optimize SWCS in TDoHAC.

The planned scenarios for solid waste collection

The planned scenarios (S) were found based on two concepts of minimization (S1 and S2) and optimization (S3 and S4). Four scenarios were constructed to address existing problems of SWCS in TDoHAC. The construction of these scenarios also considered new procedures about solid waste separation at source and the existing condition of waste treatment facilities of Hoi An city. Solid waste in Hoi An city is separated into recyclable waste and mixed waste (S1 and S2) as well as recyclable waste, combustible waste, and bio-degradable waste (S3 and S4). Despite concepts and scenarios, the municipal separation and collection of recyclable materials were compulsory due to Vietnamese strategies. This denoted the intense relationships between scenarios and national strategies on SWM.

Fig. 3 shows the waste flow of S1 and S2. The appearances of CART-Rec and RRSs were showed and no waste was stored. Solid waste was separated into recyclable waste and mixed waste. Moreover, the time for curbside collection of trucks were changed to start at approximately 0:15 AM. The amount of recyclable waste increased from 489.91 kg (S0) to 1028.58 kg (S1) and 1579.49 kg (S2). S1 and S2 addressed the problems of existing SWCS. No waste stored and daily collection of bio-degradable waste in TDoHAC can satisfy the demand of business sectors. Distinct routes for collecting recyclable waste meant that there would be no mixture of separated waste. The time frame for SWC was changed to meet the requirements of tourism activities.

Fig. 4 denotes the flow of solid waste for S3 and S4. No waste was kept in TDoHAC, being similar to S1 and S2. S3 and S4 were constructed for the increase in waste separation effectiveness. The SWCS in these two scenarios was more complex compared to other scenarios. There were appearances of CART-Com (carts for combustible waste collection), CART-2 Compartments (carts for sweeping in S3 and S4 in addition to CART-Rec. The trucks were distinctly used for collecting biodegradable waste (TRUCK-Bio), combustible waste (TRUCK-Com), and recyclable waste (TRUCK-Rec). Moreover, the time frames for curbside collection of trucks (biodegradable waste and combustible waste) were also changed, from 0:15 AM to 5:00 AM.

Process of optimization

This research was conducted in three main stages: preparing GIS data, Creating network datasets, and Using ANA to analyze the results (Fig. 5).

Stage 1: Preparing GIS data

This study is performed from December 14, 2019, until March 7, 2020, to collect the spatial data related to SWC in TDoHAC using 747A+ GPS Trip Recorders (Cuong *et al.*, 2021). Population information was collected by document review (Song Toan *et al.*, 2019). Slope and elevation data are not integrated into the model due to the plain research area (Fig. 1).

Stage 2: Creating network dataset

Firstly, the study manually chose the locations for candidate RRSs due to the below criteria.

- Existing locations of bins
- The governmental procedures must be satisfied
- The distances between locations are not larger than 250 meters (Zamorano *et al.*, 2009)
- RRSs must not impede citizens' commuting (Zamorano *et al.*, 2009)
- RRSs should be located in the passable roads (Zamorano *et al.*, 2009)

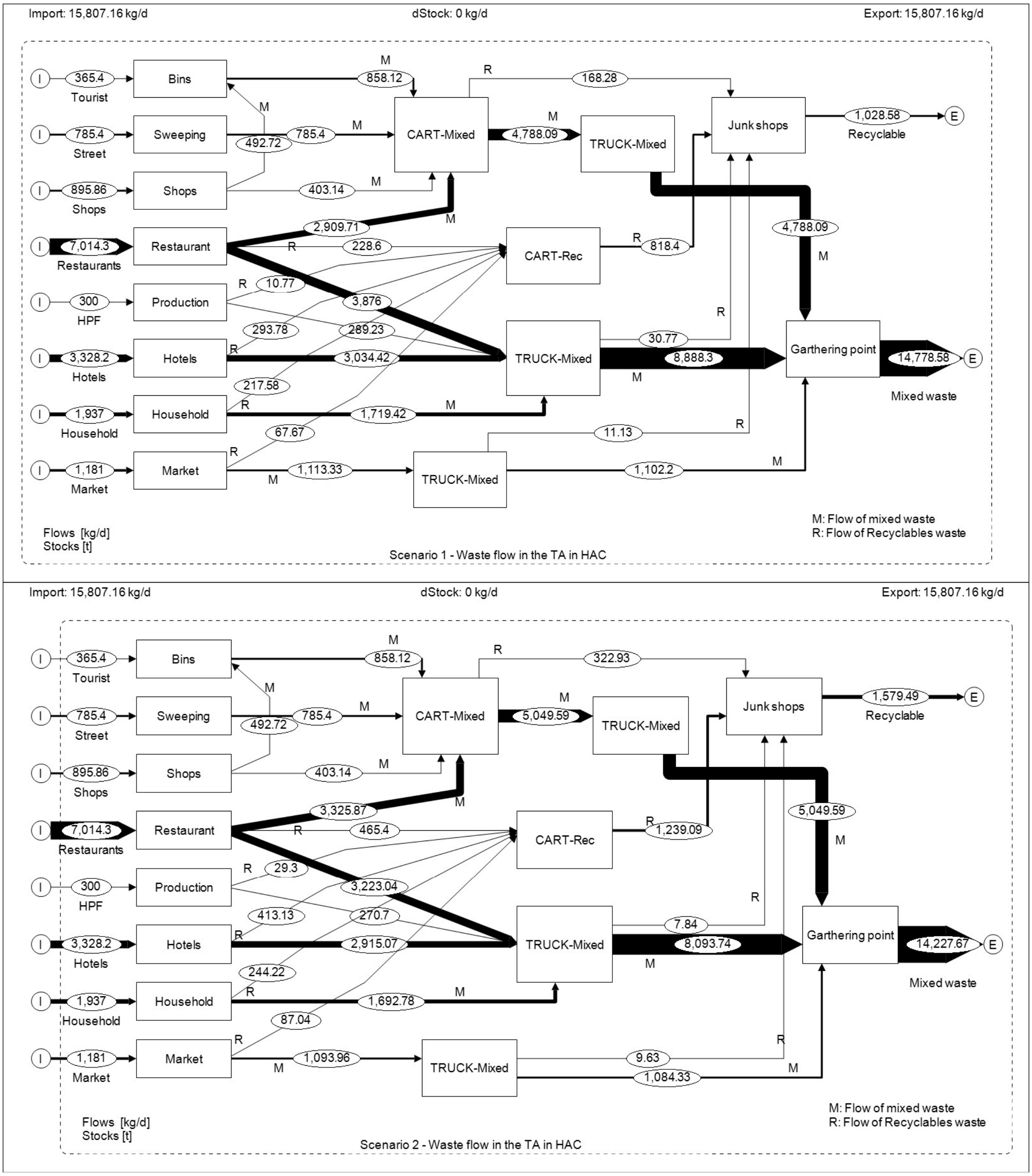


Fig. 3: Waste flow of S1 and S2

- RRSs must ensure the minimum distance from the demographic unit (DU) to the nearest bins (Pires *et al.*, 2018)
- The service area of RRSs must be maximized

At the end of this stage, the locations of the candidate RRSs were then used for location-allocation analysis in the following stages.

The second part is about routes for combustible waste collection by carts. Results of surveys denoted that the total amount of waste collected was similar among the existing four main routes of compaction

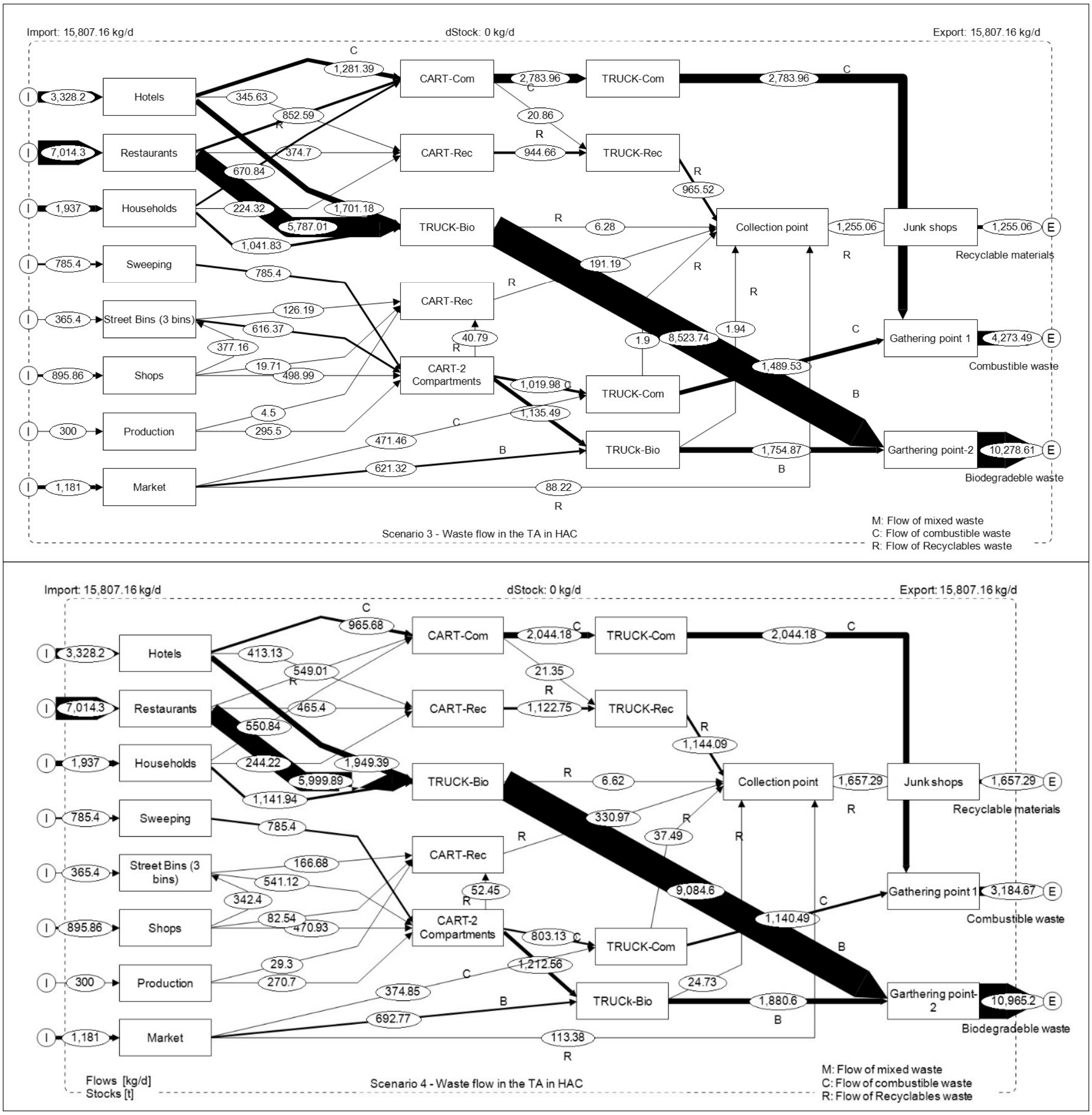


Fig. 4: Waste flow of S3 and S4

trucks. Thus new routes for combustible SWC by carts were built based on these routes. However, these routes were the curbside collection in densely populated areas. Thus optimization of the combustible SWC falls under the umbrella of ARP. The ARP was converted into VRP based on available conversion between ARP and VRP (Baldacci and Maniezzo, 2006). Line data was converted into point data, with the distance between points being five meters.

Stage 3: Using ANA to analyze the results

ANA solved VRP of compaction trucks and carts as well as optimized locations and numbers of RRSs. Handy carts started and ended at the parking areas. However, vehicles must be empty before coming

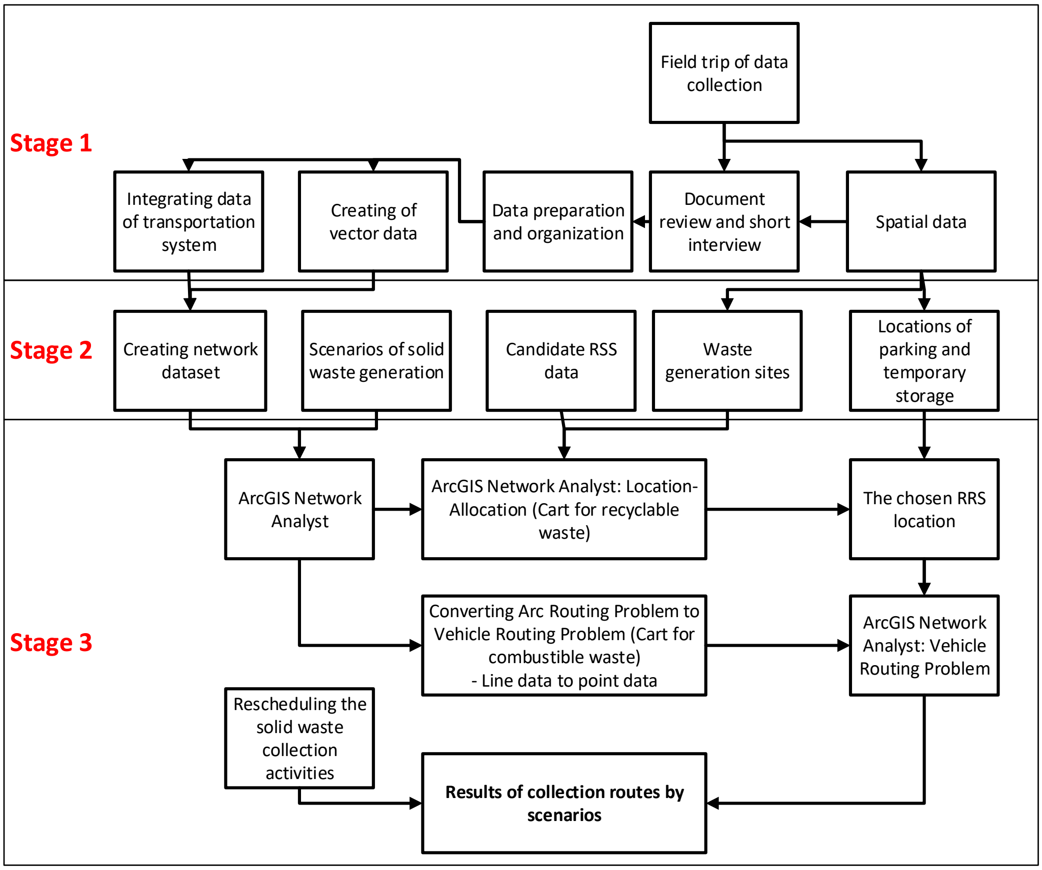


Fig. 5: The process of method applied

back to parking areas. This was not supported in ANA so that this problem was solved in two steps.

Step 1: The carts started at the parking area and collected waste from stations. Then, they moved to meeting points to discharge the waste. The average speed chosen was 3 km/h.

Step 2: The carts came back to the parking area from meeting points. The starting points were meeting points, while the endpoint was the parking area. The average speed chosen was 5 km/h (1.389 m/s) (Cavagna *et al.*, 1983).

Rescheduling existing SWCS was also conducted in this stage. The time frames of four compaction trucks (curbside collection) were changed to early morning. The routes of sweeping, compaction trucks (curbside collection) remained unchanged.

Economic assessment by scenarios

The cost-benefit analysis was calculated in ten years. The salary in the early morning was duplicated due to regulations on labour (GSRV, 2015). The average salary of drivers and workers was about 217 USD/month. 30.4 was the average number of days in a month. Moreover, the financial loss of SWM was about 17,007 USD/year (Song Toan *et al.*, 2019).

The economic benefits of applying new SWCS by scenarios were calculated using Eq. 1.

$$EB = B_{RW} + MRW - (IV + MR + OC_{Truck} + OC_{Cart}) \quad (1)$$

The money from selling recyclable waste was calculated using Eq. 2.

$$B_{RW} = A_{RW} . P_{RW} \quad (2)$$

Where;

B_{RW}: money from selling recyclable waste (USD).

A_{RW}: estimated amount of recyclable waste by scenarios
P_{RW}: the price of the recyclable waste

Prices were 634 USD/ton for metals, 95 USD/ton for plastics, and 90 USD/ton for paper (HAPWC, 2017). Metal, sellable plastics, and paper accounted for 1.16%, 4%, and 7.69% of waste generation in TDoHAC (Song Toan *et al.*, 2019). Thus the average price for recyclable waste was 141 USD. Fluctuation in the price of recyclable waste was assumed insignificant during the three years.

The money gained from reducing waste to landfill were calculated using Eq. 3.

$$MRW = RW + CW + BW \quad (3)$$

Where;
MRW: money gained from reducing waste to landfill
RW: money gained from reducing recyclable waste to landfill
CW: money gained from reducing combustible waste to landfill
BW: money gained from reducing biodegradable waste to landfill

The initial investments for RRS and CART-2 Compartments were calculated using Eq. 4.

$$IV = IV_{RRS} + IV_{Cart} \quad (4)$$

Where;
IV: Initial investment for RRS and CART-2 Compartments
IV_{RRS}: Initial investment for RRS (130 USD/RRS)
IV_{Cart}: Initial investment for CART-2 Compartments (130 USD/cart)

The costs for maintenance and repairing for RRS and CART-2 Compartments were calculated using Eq. 5.

$$MR = MR_{RRS} + MR_{Cart} \quad (5)$$

Where;
MR: Maintenance and repairing cost for RRS and CART-2 Compartments
MR_{RRS}: Maintenance and repairing cost for RRS
MR_{Cart}: Maintenance and repairing cost for CART-2 Compartments

The standard repair and maintenance rates of an RRS or a two-compartment cart were 15% per year (Hoang Lan *et al.*, 2018)

The operational costs for truck fleets were calculated using Eq. 6.

$$OC_{Truck} = Fuel + S_{Driver} + S_{W\_Truck} \quad (6)$$

Where;
OC_{Truck}: Operational costs for truck fleets
Fuel: Cost for additional distances that truck traveled (0.84 USD/km) (Hoang Lan *et al.*, 2018)
S_{Driver}: Salary for drivers
S_{W_Truck}: Salary for workers followed trucks

The operational costs for CART-Rec and CART-2 Compartments were calculated using Eq. 7.

$$OC_{Cart} = S_{W\_Rec} + S_{W\_2Com} \quad (7)$$

OC_{Cart}: Operational cost for CART-Rec and CART-2 Compartments
S_{W_Rec}: Salary for workers driving CART-Rec
S_{W_2Com}: Salary for workers driving CART-2 Compartments

RESULTS AND DISCUSSION

A total of 204 candidates were chosen for location-allocation analysis. Table 1 illustrates the results of the location-allocation analysis. The

Table 1: Results of location-allocation analysis for choosing RRS locations

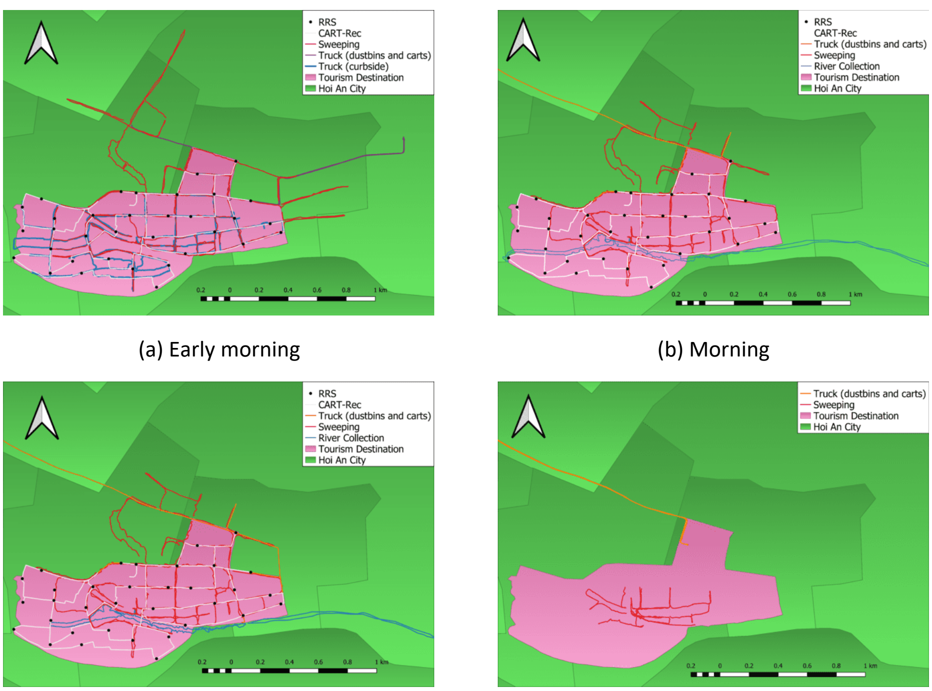
Content of analysis	Maximum walking distance			
	100 m	150 m	180 m	200 m
Number of RRS	93	49	34	31
Number of Demographic Unit (DU)	8045	8045	8045	8045
Number of DU covered	7608	7980	8037	8037
Percentage of coverage (%)	94.57%	99.19%	99.90%	99.90%

numbers of RRS had inverse relationships with maximum walking distance and the number of DU covered. The number of RRSs decreased from 93 to 31 when the maximum walking distance increased from 100 meters to 200 meters as well as the number of DU covered increased from 7608 to 8037. TDoHAC is a crowded area with tourism activities so that the number of RRS must be minimized. Operational cost proportionally relates to the fluctuation in the number of dustbins or transfer stations (Höke and Yalcinkaya, 2020). The percentage of DU used designated dumping was reduced to 55.2% if the distance from DU to dumping sites was more than 200 m, and an increase of 1% in the distance led to a rise of 0.48% in improperly discharging waste (Wang *et al.*, 2018). The maximum distance of 180 m was chosen for the subsequent analysis of CART-Rec. This maximum distance was also 20 m larger than the optimal results of the city of Mashhad (Erfani *et al.*, 2017). The bins in the Mashhad were for mixed waste so that the maximum distance of 180 m would be over the requirement of the number of bins. However, in Hoi An city, RRSs were designed for recyclable material, in which the amount of waste would be far lesser. Moreover, the maximum distance of 180 m meat that the number of RRSs can be reduced compared to 150 m. Thus, a maximum distance of 180 m was chosen for TDoHAC due to existing local conditions.

The optimized collection routes by scenarios

Figs. 6, 7, 8, and 9 show that the SWCS was gradually more complex, from S1 to S4. The RRSs and collection routes of recyclable waste appeared in S1 (Fig. 6). The study integrated the system of RRSs and created collection routes for Cart-Rec in all four scenarios. This was an effort to make the collection of recyclable waste official in TDoHAC. Fig. 8 denoted the appearance of routes for combustible waste. The increase in the variety of vehicles for SWC was also denoted from S1 to S4 (Figs. 6, 7, 8, and 9).

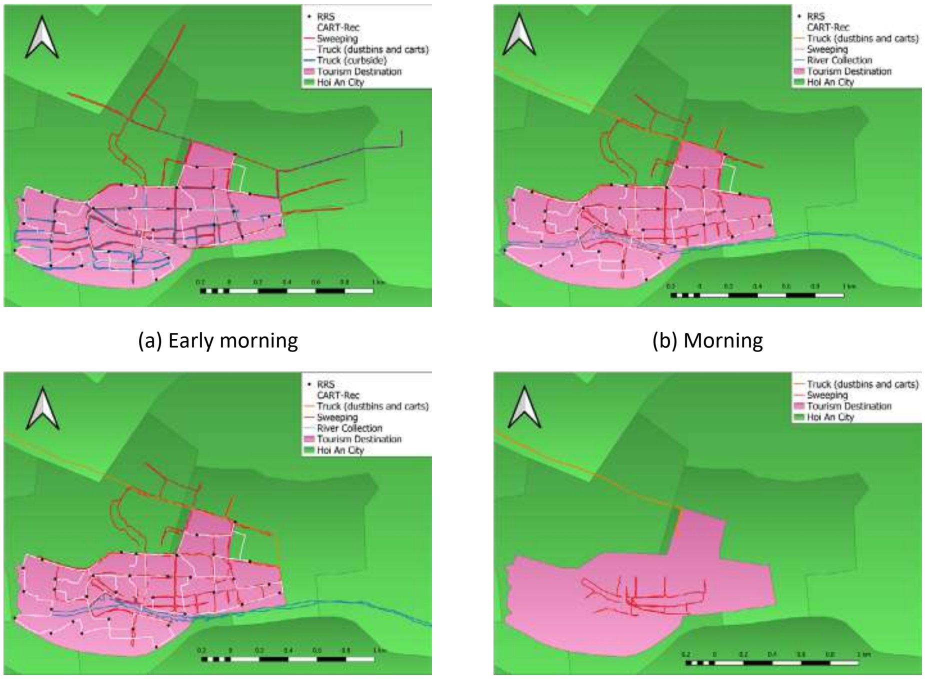
The new collection routes can combat existing problems and challenges of the current SWCS in TDoHAC. Firstly, the solid was not stored in the TDoHAC. Solid waste was collected three times



(a) Early morning (b) Morning

(c) Afternoon (d) Evening

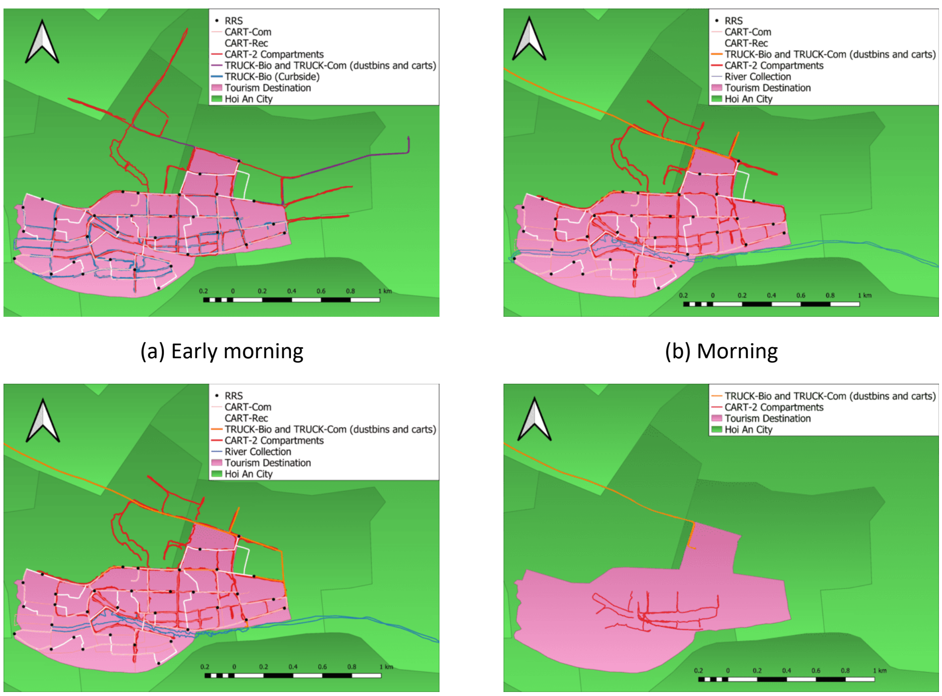
Fig. 6: Collection route of S1



(a) Early morning (b) Morning

(c) Afternoon (d) Evening

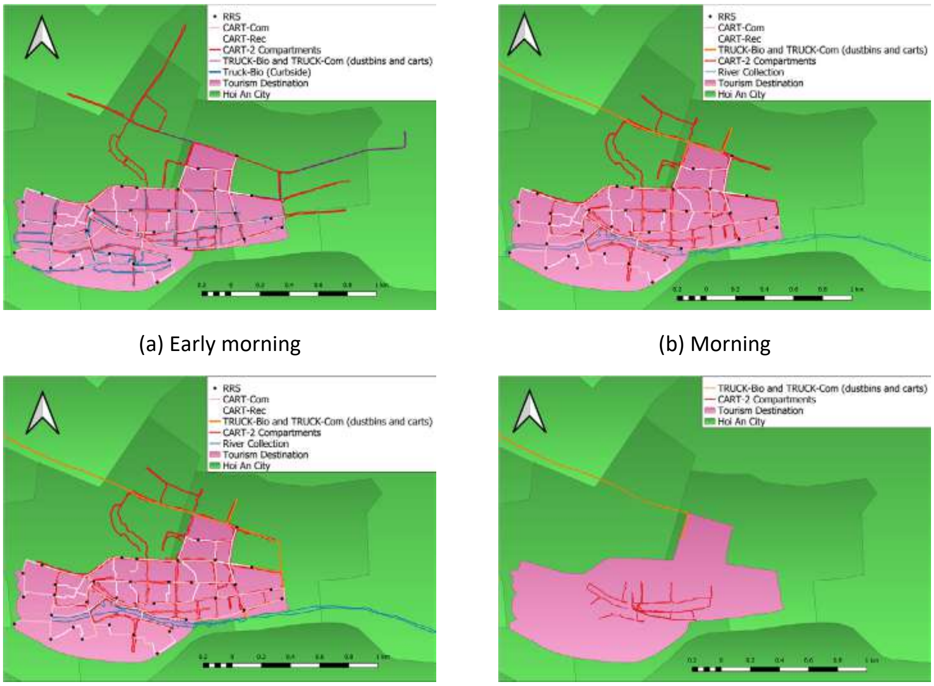
Fig. 7: Collection route of S2



(a) Early morning (b) Morning

(c) Afternoon (d) Evening

Fig. 8: Collection route of S3



(a) Early morning

(b) Morning

(c) Afternoon

(d) Evening

Fig. 9: Collection route of S4

a day, meeting the demand of business sectors of no waste storage. This satisfied the demand from business sectors in the study site. The TDoHAC was in a high density of ancient buildings with small areas so that the solid waste storage in the study site was not welcomed. The new collection system solved the demand of business sectors. Secondly, the citizens' belief in solid waste separation program will be boosted. The current SWC practices of mixing waste after being separated led to the citizens' doubt on solid waste separation program. Regarding new collection system, there were different routes for the collection of separated waste in TDoHAC. The appearance of distinct routes would limit the commingling of separated waste. Thirdly, the new procedures for conducting solid waste separation were fulfilled. Solid waste was separated into two types in the minimization concept and three types in the optimization concept. This ultimately met the requirements of new Vietnamese regulations and strategies on SWM. Fourthly, the new SWCS can also minimize the risk of illegal collection due to rescheduling time frames and frequencies of SWC. The changes in the timeframes for the curbside collection by trucks to early morning also solved the existing improper waste gathering practices since the solid waste was soonly collected right after the end of business activities. Finally, the collection routes for urban RRSs system were created and optimized. The foundation of urban RRSs system was the first step for integrating the informal sector into the SWM. Thus, the optimized routes ensured the operation of these RRSs.

Table 2 illustrates information on SWCS by scenarios. Distance and time proportionally increased with the complexity of scenarios and the effectiveness of waste separation. Distance and time were largest in S4 that waste separation was most effectively conducted. Distance traveled by truck increased from 83.98 km (S0, S1, S2) to 89.7 km (S3, S4). In contrast, working time increased by three hours between S0, S1, S2, and S3, S4. Regarding carts, the total distance traveled increased from 160.82 km (S0) to 191.07 km (S1), 193.36 km (S2), 280.90 km (S3), and 290.98 km (S4) while working time increased from 172.89 hours (S0) to 174.99

Table 2: The information for the solid waste collection by scenarios

Content of analysis		S0		S1		S2		S3		S4	
		Truck	Cart	Truck	Cart	Truck	Cart	Truck	Cart	Truck	Cart
Distance (km/day)		83.98	160.82	83.98	191.07	83.98	193.36	89.77	280.90	89.77	290.98
Time (hour/day)		13.52	172.89	13.52	174.99	13.52	178.94	16.59	207.25	16.59	210.40
Labour (person/day)	Driver	4		4		4		5		5	
	Worker (Truck)	8		8		8		8		8	
	Worker (Cart)		52		63		65		81		83
Truck (trip/day)		8		8		8		11		11	
Traditional Cart (trip/day)			59		61		64		24		27
Two-compartment cart (trip/day)									52		52
Number of truck		5		5		5		5		5	
Number of traditional carts used			38		34		35		12		13
Number of two-compartment carts used									31		31

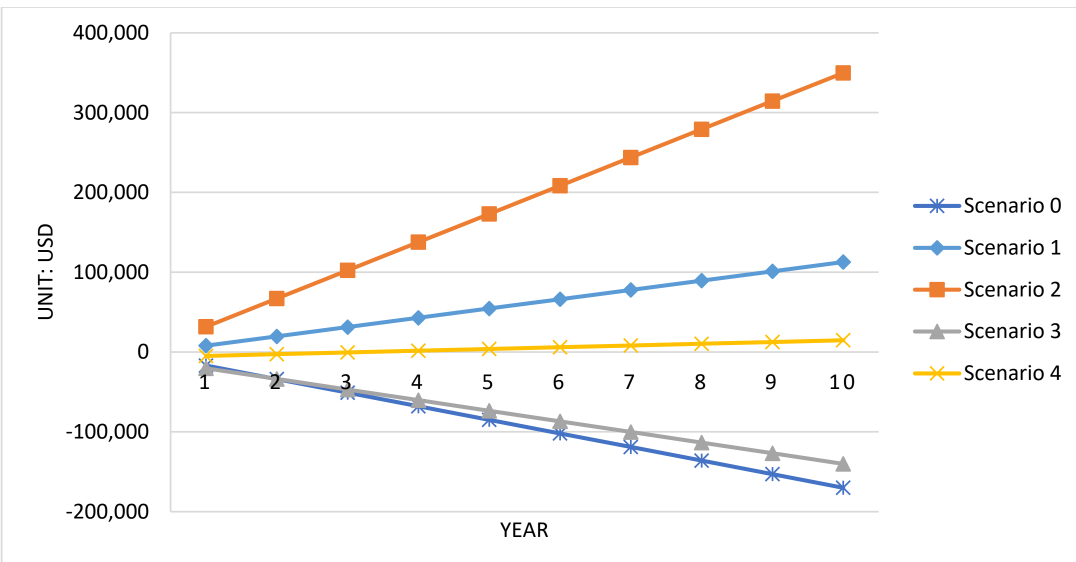


Fig. 10: Economic assessment by scenarios

hours (S1), 178.94 hours (S2), 207.25 hours (S3), and 210.40 hours (S4). The number of trips of carts increased approximately 30%, from 59 trips (S0) to 76 trips (S3) and 79 trips (S4). This increase was due to recyclable waste and combustible waste collection by traditional carts. The largest number of trips for carts in S3 and S4 belonged to the two-compartment carts, 52 trips a day. The combustible waste was also collected in sweeping (S3 and S4), leading to the change from traditional carts to two-compartment carts. The number of carts used fluctuated from 38 carts used in S0 to 34, 35 carts in S1 and S2 as well as 43 and 44 carts in S3 and S4. While traditional carts were popularly used in S1 (38 carts), S2 (34 carts), and S3 (35 carts), the two-compartment carts were dominantly used in S3 and S4, with 31 two-compartment carts in each scenario. The increase in complexity and numbers of new collection routes also led to a need for more workers and drivers and enhanced the management skills of the service provider's staff. In general, the implementation of new collection systems required more resources. The workload, working time, traveled distances, and the number of workers increased primarily in S2 and S4. The economic benefits of applying new collection systems would be the driving force for the service provider (Fig. 10). Moreover, the strategies and regulations on SWM were achieved. Thus, the tradeoffs for the changes would be acceptable.

Economic assessment by scenarios

Fig. 10 denotes the economic assessment by scenarios in TDoHAC. S2 marked the financial gain, while S0 (existing SWCS) indicated the highest financial loss in ten years. S0 showed the financial problems of the existing SWCS. Illegal SWC led to financial loss and detriments to the environment by increasing the amount of mixed waste discharged at the landfill. As a result, the enhancement of SWCS was an urgent need for TDoHAC. The effectiveness of waste separation illustrated a critical role in enhancing the SWCS. Regarding the minimization concept, the economic gain from conducting the new SWCS of S2 was approximately three times larger than S1. The recyclable waste in S2 was about 1.6 tons/day, while that of S1 was only about 1 ton/day. This was the explanation for the differences in financial gain between S1 and S2. In terms of optimization concept, the effectiveness of solid waste separation again showed a critical role. In S3, the financial gain was highly negative at -140,139 USD compared to S4 with 14,675 USD after ten years (higher effectiveness of solid waste separation at source). In S3 and S4, solid waste was separated into three types, namely recyclable waste, combustible waste, and biodegradable waste. A variety of waste types meant that the operational costs would increase due to the collection of combustible waste. However, the financial gain of S4 was positive despite the adverse financial gain in the initial three years. Additionally, the financial gain did not consider the benefits of selling compost produced from biodegradable waste due to its high economic value (Limon and Villarino, 2020). This showed that the optimization of SWCS was economically feasible; if any, the effectiveness of solid waste separation fulfilled the expectations of scenarios. These results were also similar to another study on the cost efficiency of selective collection. The cities conducting selective collection were more cost-efficient in spite of higher costs escalating (Campos-Alba *et al.,* 2021).

The cooperation of citizens and business sectors plays a vital role in the success of waste separation program and the implementation of a new collection system (Weekes *et al.*, 2021). The effectiveness and implementation of solid waste separation at source in Vietnam were the most serve problems (Lien *et al.*, 2021). Fortunately, citizens showed a positive attitude towards running the waste separation at source program if the separated waste could be collected daily (Song Toan *et al.*, 2019).

CONCLUSION

This study redesigned the SWCS due to the planned scenarios of SWM practice. The current problems of SWCS in TDoHAC were addressed. ANA was used to define new routes for CART-Rec, CART-Com, trucks and identify the optimal locations of 34 RRSs. The integration of new urban RRSs was analyzed and illustrated through the optimized process. The maximum distance of 180 m was chosen due to the constraints of social behaviours and requirements of tourism activities in TDoHAC. Thus 34 urban RRSs were identified and located in TDoHAC as the recovering facilities for recyclable waste. The establishment of RRSs was considered as the first effort to formalize activities of the informal sector in Hoi An city. ANA solved routing problems of carts and trucks in TDoHAC. The collecting distances and working time increased with effectiveness in waste separation. Total collecting distance by truck increased from 83.98 km (S0, S1, S2) to 89.7 km (S3, S4) while working time by truck increased by three hours between the group of S0, S1, S2 and the group of S3, S4. Regarding carts, total distance traveled increased from 160.82 km (S0), to 191.07 km (S1), 193.36 km (S2), 280.90 km (S3), and 290.98 km (S4) while working time increased from 172.89 hours (S0) to 174.99 hours (S1), 178.94 hours (S2), 207.25

hours (S3), and 210.40 hours (S4). The economic assessment results showed the positive results of applying the new collection system. S2 and S4 indicated the benefits of 349,652 USD and 14,675 USD after ten years. However, the effectiveness of solid waste separation was the precursor to the success of applying the novel collection systems. The failure in solid waste separation would also lead to unsuccess in improving the solid waste collection system. S3 showed a loss of 140,139 USD after ten years of application. Future studies should focus more on improving the effectiveness of solid waste separation at soure, which would be the challenge of many developing countries in the world. Governmental officials and service providers benefit from the findings on strategically managing SWCS to boost the effectiveness and efficiency of SWCS in Hoi An city. The two concepts of minimization (S1 and S2) and optimization (S3 and S4) and their tradeoffs were clearly illustrated to officers and managers in Hoi An city. Moreover, the concept of converting the informal sector into the formal sector would also be the solution for achieving the national strategies on SWM, especially the collection of recyclable waste towards the sound-material cycle society. This study contributed as a case study of the application of ANA and the integration of urban recovery recycling stations into the optimization of SWCS for a tourism destination. The novelty of this research was the integration of the informal sector into the SWM system to formalize the operation of recyclable collection in a systematic view. Despite the national strategies of developing countries towards a sound-material cycle society, the holistic practices have not been well mentioned and researched. This study was an effort to actualize the SWM strategies and national targets of collecting recyclable waste of developing countries towards a sound-material cycle society.

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CONFLICT OF INTEREST

The authors declare no potential conflict of interest regarding the publication of this work. In addition, the ethical issues including plagiarism, informed consent, misconduct, data fabrication and, or falsification, double publication and, or submission, and redundancy have been completely witnessed by the authors.

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PUBLISHER'S NOTE

ABBREVIATIONS

%	Percentage
3Rs	Reduce, reuse, and recycle
AM	After midnight
ANA	ArcGIS network analyst
ARP	Arc routing problem
CART-2 Compartments	Carts for sweeping in S3 and S4
CART-Com	Carts for collection combustible waste
CART-Rec	Carts for collecting recyclable carts
COVID-19	Coronavirus disease

DU	Demographic unit
Eq.	Equation
Fig	Figure
GIS	Geographic information system
GPS	Global positioning system
GSRV	Government of the Socialist Republic of Viet Nam
HAPWC	Hoi An Public Works Joint Stock Company
hour/day	Hour per day
kg	Kilogram
km	Kilometer
km/day	Kilometer per day
km/h	Kilometer per hour
km^2	Square kilometer
m	Meter
m/s	Meter per second
m^3	Cubic meter
NASRV	National Assembly of Socialist Republic of Viet Nam
NP-hardness	Nondeterministic Polynomial time-hardness
person/day	Person per day
PM	Past morning
PMSRV	Prime Minister of the Socialist Republic of Viet Nam
RRSs	Recyclable Recovering Stations
S	Scenario
SWC	Solid waste collection
SWCS	Solid waste collection system
SWM	Solid waste management
TDoHAC	The tourism destination of Hoi An city
trip/day	Trip per day
TRUCK-Bio	Trucks for collecting biodegradable waste
TRUCK-Com	Trucks for collecting combustible waste
TRUCK-Rec	Trucks for collecting recyclable waste
UNESCO	The United Nations Educational, Scientific and Cultural Organization
USA	The United States
USD	The United States dollar
USD/cart	United States dollar per cart
USD/km	United States dollar per kilometre
USD/month	United States dollar per month
USD/RRS	United States dollar per recyclable recovering station
USD/ton	United States dollar per ton
USD/year	United States dollar per year
VRP	Vehicle routing problem

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