Generation of GIS Database for Optimization of Waste Transportation Route in Lien Chieu District, Da Nang City, Vietnam

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Abstract
The problem of timely collecting and transporting solid waste to the landfill sites in response to environmental pollution and urban beauty is an ongoing concern of many cities. The main objective of this research is to build a GIS database related to the municipal waste transportation in Lien Chieu District, Da Nang City. The traffic data including information about the route systems and their attributes were collected and standardized using the OpenStreetMap (OSM) application. Information about solid waste collection in Lien Chieu District was built based on the field surveys integrating with other referenced data sources. These data were processed in a GIS environment to prepare for waste transported optimization through Network Analyst method in ArcGIS software. The optimal waste transportation route proposed from this study can save the travel time and distance compared to the current route. Especially for the forklift trucks, the waste transported time is reduced by nearly 40 minutes, traveling distance is reduced by about 14 kilometers and the number of transportation trips is also saver compared to the current route. This improvement will increase the efficiency of the waste collection process and reduce environmental pollution. Results from this study can be widely applied for solid waste management in other metropolitan areas where suffering high pressure of population as well as municipal waste growth.

1. Introduction

Municipal solid waste is one of the top concerns in many countries around the world. In recent years, the high speed of economic development as well as urbanization process in Lien Chieu District, Da Nang City, Vietnam has resulted in the formation of many urbanized and residential zones. It is also observed that the amount of domestic waste is increasing along with the urban expansion and population growth (World Bank, 2018). Currently, Lien Chieu District is suffering about 160 tons of household waste per day and this amount of waste is forecasted about 280 tons per day by 2030. In order to enhance the environmental situation as well as the urban beauty, the rapid movement of garbage from gathering points to the landfill while ensuring the efficiency of collection and transportation is a problem that needs to be studied and resolved. Solid waste includes many different types such as domestic waste, industrial waste, medical waste, etc. In this study, the author focuses mainly on domestic waste (hereby can be called household waste). This is the type of waste that accounts for a major proportion in Da Nang City. In the waste management problem, Geographical Information System (GIS) is usually utilized for the following main purposes: identifying locations for construction of burial sites, managing the database of garbage disposal sites, setting up the routes for waste collection and transportation. GIS combined with other analytical methods can be used in finding the best places to build waste treatment centers. Shahabi et al., (2012) conducted a study on the application of GIS models to select waste treatment sites in urban areas in Saqqez City of Kurdistan Province in Northwestern Iran. Shrivastava and Nathawat (2003) also conducted a project about selection of potential waste disposal sites around Ranchi urban complex in India by remote sensing and GIS technology. Regarding the application of GIS in waste collection and transportation, there are several studies such as Tinmaz and Demir (2005), Apaydin and Gonullu (2007), Ahmed (2006), Malakahmad et al., (2013), Kallel et al., (2016), CPHEEO (2016).

Solid waste management comprises the generation, collection, transportation, treatment, and disposal of solid waste from a facility (Modak and Everett, 1996). The routing optimization problem in waste management has typically been addressed with different types of mathematical algorithms (O'Connor, 2013). This study was conducted with the goal of building a GIS database for the purpose of optimization of the household waste transportation route in Lien Chieu District, Da Nang City, Vietnam. These data include spatial and attribute information that can be applied for producing optimized routes for the waste trucks in a selected study area of Da Nang City. The spatial data which is mainly traffic data including information such as road name, speed, road type, etc were integrated with the waste gathering data containing information on location, collection time, collection volume and the data on landfill sites in order to generate the optimal transportation route for solid waste collection in Lien Chieu District. In addition, the data on waste transportation vehicles with information such as the location, loading capacity, etc were also applied in our model. Once the GIS database about the waste collection was generated, this research executed the network analysis in GIS environment to determine the optimal route for local waste transportation.

2. Methodology

2.1 Study Area and Current Situation of Solid Waste Management

The study area is Lien Chieu District which is a dynamic urban developing area of Da Nang City, Vietnam (Figure 1). This study area is also a hotspot of industrial as well as residential development. In accompany with the development process, the Lien Chieu District is also facing to a relatively large amount of solid waste. According to 2019 data, the average amount of garbage generating from Lien Chieu District is about 160 tons per day and is forecasted up to 280 tons per day by 2030 (Da Nang URENCO, 2019). The requirement is that all the generated waste must be collected and treated thoroughly, so that minimizing the environmental problems related to solid waste in this area. The waste collection in Lien Chieu District is following the common process in Da Nang City including three main methods which are door-to-door collection by tricycle, through fixed dustbin collection and directly collected by mini truck (Dang et al., 2018). Among the above mentioned methods, door-to-door collection by tricycle plays an important role with the collected volume of about 100 tons per day, occupied about 60 percent of the total amount of collected waste (Da Nang URENCO, 2019).

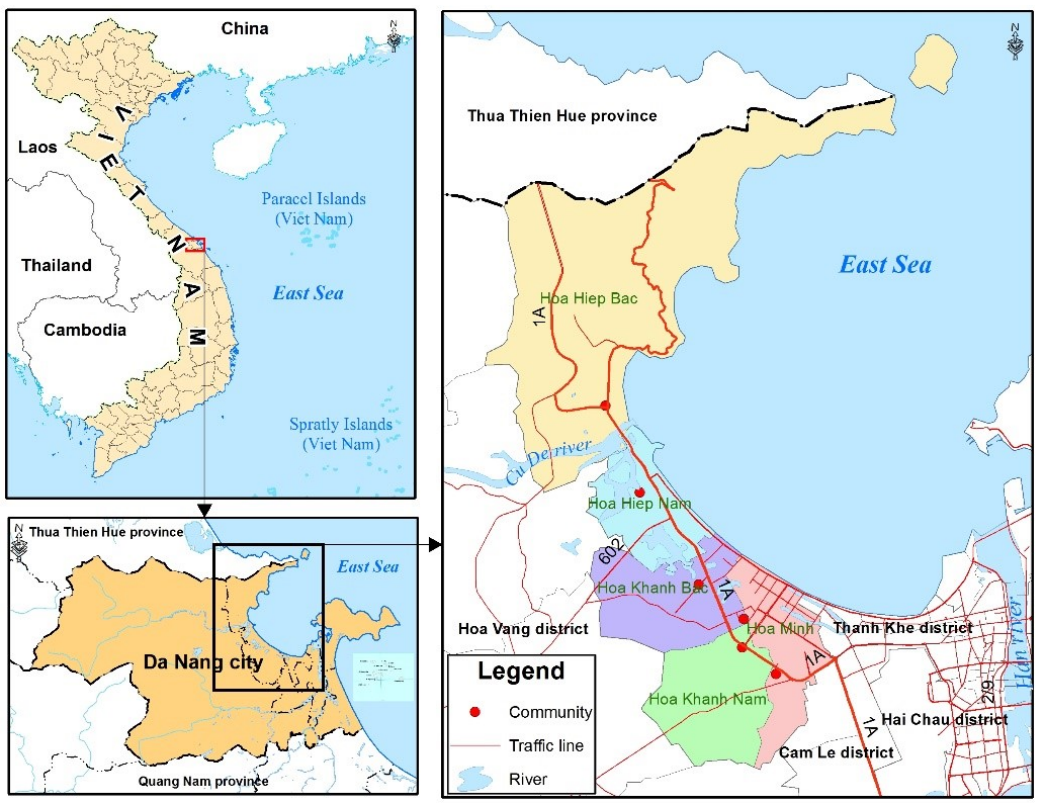


Figure 1: Location of study area

Regarding this collection method, there are totally 12 places of waste gathering points which have at least 2 bins of 660 liters that contribute to the total gathering volume about 123 bins of 660 liters (660L). Garbage from these places is collected directly by workers using the tricycles and transferred to the meeting points before being picked up by the forklift trucks. The amount of waste collected directly by mini truck is estimated about 50 tons per day, accounting about 30 percent of total waste amount of the District, and the remaining volume is collected through fixed dustbins.

The current waste transportation in Lien Chieu District is operated by two main companies, namely Da Nang Urban Environment Company (Da Nang URENCO) and Hanoi Urban Environment One Member Limited Company - Central Branch. Accordingly, the former company collects in three wards namely Hoa Minh, Hoa Khanh Nam and Hoa Khanh Bac with a total of 18 collected trips per day and the waste volume about 130 tons per day. The later one collects in two wards of Hoa Hiep Nam and Hoa Hiep Bac with 5 collected trips per day and the amount of garbage about 30 tons per day.

Regarding the waste transportation methods, there are two main methods in Lien Chieu District, which are based on forklift and compactor trucks. The former has the loading capacity of 9 tons and the later has the capacity of 4.5 tons. Since the compactor trucks have smaller loading capacity and size, it can collect only 25 percent of the total waste volume in Lien Chieu area. The remaining waste was collected and transported mainly by the forklift trucks which obtained 75 percent of the total collected waste volume of the study area. The authors had conducted tracking surveys of waste collection and transportation by using video camera recordings and GPS loggers, and collected the data on coordinates, transport locations (right, left or both sides of the road), transportation time, estimated waste volume, etc. These data are important sources for generating the solid waste GIS database and optimization of the waste transportation route for Lien Chieu District.

In order to improve the operational efficiency of waste collection and transportation, the generation and management of collected routes from that optimizing the waste transportation routes play an important role (Das and Bhattacharyya, 2015). It contributes to reducing the time and travel distance by vehicles, and hence improves the economic efficiency of waste collection as well as reduces the environmental pollution at the gathering points. This study focuses on building the optimal waste transportation route for forklift trucks which is the main vehicle using for waste collection in Lien Chieu District - Da Nang City.

2.2 Data Preparation

2.2.1 Preparation of traffic data

The OpenStreetMap data (*Openstreetmap.org*) which is a free and dynamic geospatial database was used to generate the traffic system map for Lien Chieu District, Da Nang City. The road data includes the following main information: road name, length, speed, type of road (one-way or two-way street). Data collected on OSM is presented in vector which are in different formats (point, line, area). They represent almost all spatial information about the real world. After collecting the road data from OSM, the study tried to extract the necessary traffic GIS data related to the construction of the waste transportation route such as roads, stops, obstacles, barriers, etc including both spatial and attribute information.

In addition, the traffic data collected from the local agencies was also utilized for validation of the road system. In this study, we extracted data related to traffic system of Da Nang City from the Department of Natural Resources and Environment and the Department of Transportation. Subsequently, the filed survey data was also investigated as a supplement traffic data for OpenStreetMap (OSM). The road data on OSM sometimes lacks information such as road name, road type, traffic signs, etc. Therefore, updating the OSM data using field survey data is an effective solution to prepare the completed road system for the determination of the waste transportation route.

2.2.2 Preparation of data on waste transportation

The data related to waste transportation includes the information on household waste, transportation vehicles and landfill sites. A field survey was conducted in the period from March 2020 to October 2020 in Lien Chieu area for generation of GIS database related to solid waste transportation (Figure 2). In order to generate the data on waste gathering points, we have tracked the information on the location and volume of garbage as well as the collected time at each point in the Lien Chieu District with the help of video camera (Figure 2a) and GPS logger (Figure 2b). The data on waste transport vehicles including the information on the type of vehicles, loading capacity and operating time were also investigated in this field work. In addition, the landfill data which is characterized by information about the location of the landfill was also surveyed, especially the information of Khanh Son landfill located in Hoa Khanh Nam Ward - Lien Chieu District - Da Nang City.

a. Setting camera on the forklift

b. GPS logger used for data collection

c. Waste collection of forklifts in Lien Chieu District

Figure 2: Field survey to collect data on waste transportation in Lien Chieu District

Waste collection and transportation in Da Nang City as well as in Vietnam has been generally done daily by the combination of manual door-to-door collection by tricycles, waste transfer at meeting points along the roadside, and transport by trucks going around the meeting points to pick up waste and carrying it to the landfill sites (Danang URENCO, 2019). However, the man-powered collection is slow-moving and consequently labour-intensive (Dang et al., 2018). Regarding the data collection and analysis on waste collection and transportation, some studies applied GPS (Global Positioning System) devices to get the tracking data on vehicles (O'Connor, 2013, Swapan and Bidyut, 2015 and Dang et al., 2018), and also analyzed the data by GIS software (Chalkias and Lasaridi, 2009, Tavares et al., 2009 and Yadav, 2013). This study has tried to improve the operation efficiency of waste collection and transportation in Lien Chieu District, Da Nang City using a Geographical Information System (GIS) approach. Results from field trip with the help of video camera and GPS logger has represented the current practice of solid waste collection and transportation in Lien Chieu District as explained below:

- Door-to-door collection by tricycle: the worker visits households from door to door to pick up the waste discharged at the side of the road by plastic bag or waste basket. The worker moves by tricycle with a dustbin, loads the waste into the dustbin, and carries it to a meeting point for transfer. At the meeting point, a forklift truck with the loading capacity around 11 tons will transfer the waste by turning over the dustbin, and transports it to the landfill site (Danang URENCO, 2019).
- Another method of waste collection in this area is door-to-door collection and transportation by compactor truck. The truck with a loading and compaction equipment visits households from door to door to pick up the waste discharged at the side of the road. While the driver keeps driving truck slowly, the collection workers follow the truck and load the waste directly into the truck (Dang et al., 2018). Since the compactor truck has smaller loading capacity than the forklift truck (only 4.5 tons), it can easy go through almost all the road types and conduct the door-to-door waste collection. After collected the waste, the compactor truck directly carries the waste to the landfill site without transfer.
- Besides, Lien Chieu District as well as Da Nang City used to practice the fixed time dustbin collection in the period from 2012 to 2018 as explained in Dang et al., 2018. However, due to limitation of the budget for this project, Da Nang City has stop this collection method since 2018 (according to Da Nang URENCO)

In the field trip, two camera including one attached on the waste truck and one attach on the motorbike following the target vehicle were used to record video about the operations of waste transportation route (Figure 2). The videos and images recorded from camera are the main data source for extracting the information about the waste collection time and estimated waste volume. The waste volume was estimated based on both using digital scale and video recording through calculation the number of dustbins and the percentage of waste loading.

In addition, the Garmin Oregon GPS logger was also used to collect the information about location of waste gathering points which is one of the input data for Network Analysis. Results from the field survey was processed and transformed to a GIS format which can support for generation of GIS database about municipal waste transportation in Lien Chieu District including the information on location of gathering points, waste volume at each point, type of vehicles, loading capacity and operating time. Details of these database are explained in the following sections.

2.3 Research Workflow

The research workflow for generation of GIS database and optimization of waste transportation route for Lien Chieu District, Da Nang City is shown in Figure 3. The data on household waste and traffic system after being collected were standardized in both spatial and attribute information. In order to validate the spatial road data, the Topology tool in ArcGIS was used to identify the geometrical errors. Regarding the attribute data, the missing information on OSM data has been updated by using the supplemented data such as data collected from local authorities or field surveyed data. Subsequently, an application namely Network Analysis, was executed in GIS environment to generate the map of the current waste transportation routes in Lien Chieu District.

ESRI's ArcGIS Network Analyst extension allows users to perform complex calculations to solve the vehicle routing problems. The program performs analysis over a network of connected edges and decides fleet routing, travel directions, closest facility, service area, and location allocation (O'Connor, 2013). In addition, the Network Analyst allows the user to dynamically model genuine network situations, and hence facilitates finding the optimal route that is very important in solid waste transportation (Malakahmad et al., 2013, Phailahan and Piyathamrongchai, 2018, Hasmantika and Maryono, 2018). Network Analysis is actually a tool to support fast and effective decision making for spatial analysis problems based on network systems such as: analyzing the shortest route, the optimal access, service delivery area, determining the nearest service facility, etc. Network Analyst allows simulation of complex real-world network models with limited conditions such as one-way roads, forbidden roads, limited speed, time, vehicle limitation and obstructions.

The standardized data is the required input for the Network Analysis method to solve the vehicle routing problem. In order to build a network, the necessary elements are network name, connection type, network node identification, height factor which is needed to be specified when the roads are flyovers or over-bridges. In fact, when viewed from above, the two roads have same position but due to the height difference, there is no intersection (for example, the Nga Ba Hue flyovers) that can cause troubles for the Network Analysis. Other parameters regarding the road properties includes the road conditions, speed limit, the road directions, one-way streets, turn restrictions, obstacles, etc. These conditions directly affect the results of routing optimization.

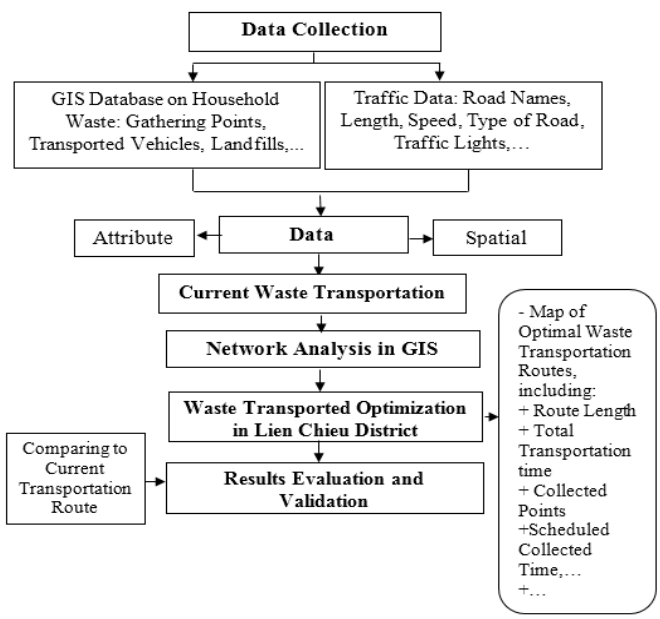


Figure 3: Study workflow on generation of GIS database for waste transportation in Lien Chieu District

Based on the GIS database on household waste and road system, the waste transportation route map in Lien Chieu District was generated with the help of Network Analysis tool. This map includes the following information: route length, total transport time, number of collection points on the route and expected collected time. In addition, the study also compares the proposed route with the current waste transportation one in the Lien Chieu area in order to adjust and decide the most reasonable route.

2.4 Generation of GIS Database for Waste Transportation

2.4.1 Generation of traffic data

This database is generated from OSM data combining with other supplemented data and transformed to the GIS format. The GIS database about traffic system in Lien Chieu District including both spatial and attribute dimensions has reflected adequately information for waste transportation in the study area (Table 1). However, the traffic data collected on OSM is sometimes still lacked of information about road name (Figure 4). Based on many different data sources such as Google Maps, field survey and data collected from local authorities, we updated and completed the spatial information for traffic data in Lien Chieu District, Da Nang City. The Data Management Tool in GIS with the help of Split line at vertices method has been used to separate the line into different segments for preparation of input data for Network Analysis. Beside the information on OSM such as road name, speed, road type, the attribute information of traffic data was also updated by integrating with various referenced data sources. Based on the information about length and speed, the study calculated the travel time for each different road segment. In addition, traffic light data was also investigated in this study. The road system downloaded from OSM usually does not include all traffic light locations in the Lien Chieu area. In this case, the field survey data has been used to update information about these barriers of the waste trucks for the study area. In addition, the time for passing the traffic light was also modified in order to meet the requirement for Network Analysis. In this simulation problem, suppose it take 30 seconds for a car to run through a traffic light.

Table 1: Table structure of traffic data

Field Name	Data_Type	Width	Description
Objectid	Object ID	10	Road_code
Highway	String	20	Road_Type
Name	String	40	Road_Name
Maxspeed	Double	20 (2)	Speed

Figure 4: Updating the traffic data using OpenStreetMap integrating with GIS
(the dash lines are lacked of road name and needed to be updated)

In the intersected locations such as the crossways, the vehicle will encounter 2 lights at the same place. Therefore, the travelled time will be doubled, so we need to split the time for the car passing through these points by 15 seconds. This modification can enhance the accuracy of estimated time for waste transportation in Network Analysis model.

2.4.2 GIS database for waste collection and transportation

Garbage data includes information about gathering points such as: the system of gathering locations, information of garbage trucks, landfill sites collected by field method. We have conducted a field survey to get information related to the waste collection such as order of points, type of bin, number of dustbins, estimated waste volume, collected time in the day, collected days of the week; transported location (on the right, left or both sides of the road), time to take garbage into the vehicle. In addition, we also investigate the information of waste trucks in this area such as: vehicle, loading capacity, transported time of the day, etc. Figure 5 shows the GIS database for determination of waste transportation route in Lien Chieu District that was generated from this study. It can be seen from Figure 5 that most of the waste gathering points are located on the main roads such as Ton Duc Thang, Nguyen Luong Bang, Nguyen Sinh Sac, Hoang Thi Loan, etc.

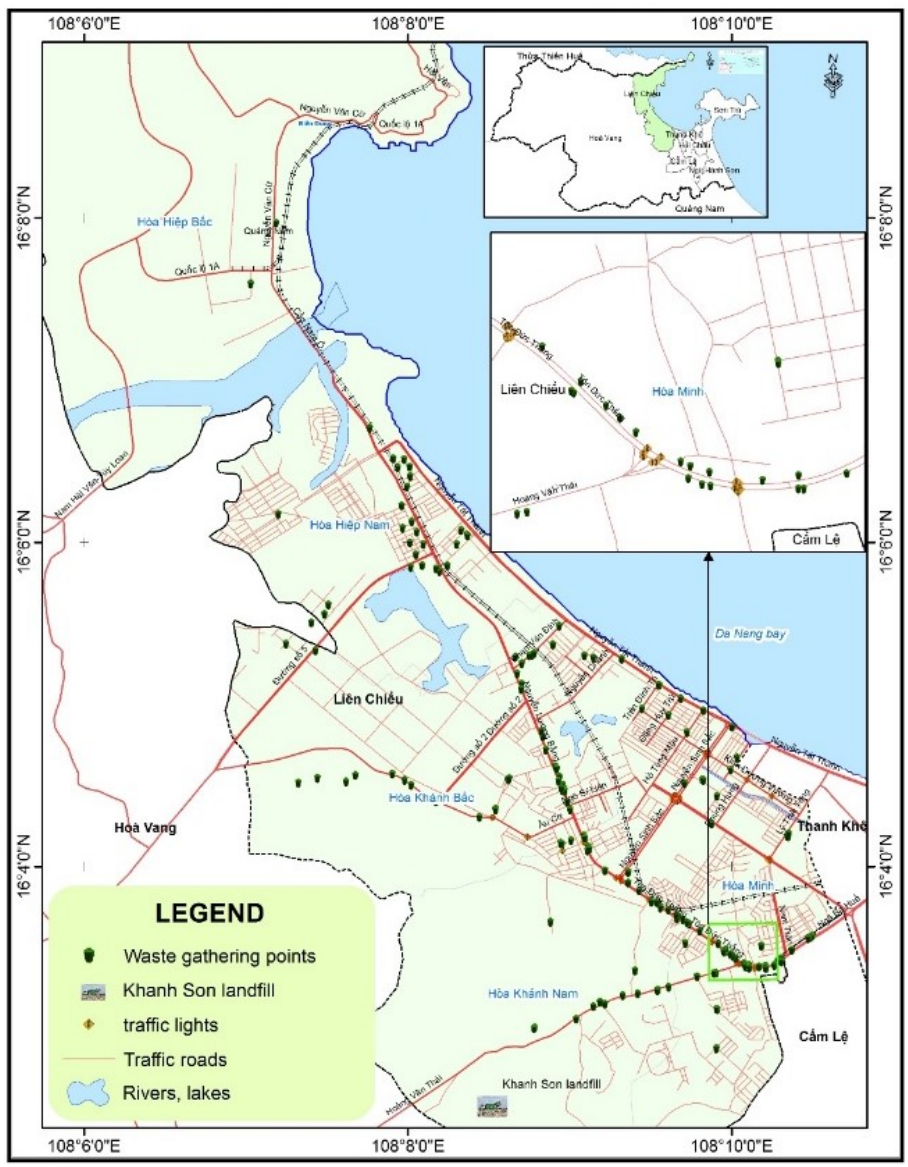


Figure 5: GIS database for building the waste transportation route in Lien Chieu District, Da Nang City

These gathering points are different in their capacities. The points with higher capacity are usually located at crossing areas such as crossway of Ton Duc Thang and Nguyen Sinh Sac Street, nearby Hoa Khanh market, 71 Lac Long Quan Street, nearby Phu Loc Water Treatment Station, etc. In some roads which are characterized by high population density, the compactor trucks can go through directly to collect the garbage. There are totally 53 waste bins of 240 liters (240L) capacity placed on Ton Duc Thang Street, 35 bins on Nguyen Luong Bang Street, 17 bins on Au Co and 13 bins located on Hoang Van Thai Street. Other routes have smaller number of dustbins. In case of 660 liters (660L) capacity, there are 19 bins located on Lac Long Quan Street, 20 bins on Ly Thai Tong Street, 16 bins placed on 4A Street in the area of Lien Chieu Industrial Park, 15 bins on Nguyen Sinh Sac Street, etc. In addition, in order to meet the demand of waste collection in Lien Chieu District, there are a number of hand pallet trucks (41 cars) and tricycle trucks (42 cars) being used for door-to-door collection.

2.5 Parameter Settings for Network Analysis to Determine the Waste Transportation Route

In this study, the waste transportation route was generated using the Network Analyst which is an extension in ArcGIS software that provides network-based spatial analysis including routing, travel directions, closest facility and service area analysis (Malakahmad et al., 2013). There have been several studies on application of Network Analysis in waste transportation optimization (Malakahmad et al., 2013, Phailahan and Piyathamrongchai, 2018 and Hasmantika and Maryono, 2018), however the results are still limited due to the parameter setting up problem. This study experiences the method of using Network Analysis in generation of waste transportation route in Lien Chieu District, and proposed the optimal waste collection route.

After obtaining the data related to network analysis, the study focused on setting up the parameters for Network Analyst application in ArcGIS software, including the following key information: Orders (information about gathering points), Depots (information about the vehicle characteristics), Routes (information about transportation routes), Break (information about break time if any), Route Zones (information about the transporting area), Specialties (information about special points on the transportation route), Barriers (information about obstacles on the road including points, lines or polygons), etc.

The data about garbage gathering points (Orders) has the following main information requirements: the consuming time when transporting garbage on the vehicle, the time of waste collection in the day, the waste volume at each point and the side which garbage is taken (right, left or both sides of the road). The data of the vehicle characteristics (Depots) includes the following main information: start and end locations of the waste trucks on the route; start time, end time; driving rules (left, right or can run on both sides), etc. Subsequently, the Routes data includes the following information: route name; starting point, ending point; the earliest start time and the latest one; load capacity; maximum number of stops and transportation time. Figure 6 is a demonstration of parameter setting up for Network Analysis in ArcGIS.

As a result, we have built a completed GIS database of garbage transportation. This is the important input data source for establishing the network analysis in GIS to determine the optimal waste transportation route in Lien Chieu District, Da Nang City. This study has focused on optimization of the waste transportation route for the forklift trucks which are the major collection means in Lien Chieu District (Figure 2c).

3. Results and Discussions

3.1 Generation of Current Waste Transportation Map for Forklift Trucks in Lien Chieu District

In Lien Chieu District, there are currently two transportation routes of forklifts denoted Lien Chieu A (LCA) and Lien Chieu B (LCB). In this study, the Network Analysis application in GIS was applied to reconstruct the waste transportation route for the forklift trucks based on investigating the route-related information such as: gathering location, waste volume, transportation time, etc. The survey results show that the amount of daily household waste transported by forklifts in Lien Chieu District is about 96 tons, with a total distance of about 165km and a time of 14.7 hours. In order to build the current waste transportation route map for forklifts, we have fixed the parameters such as the order of transported locations, routes (including non-garbage collection routes), the actual amount of garbage collected. The waste transportation route includes the following major information: trip order, starting time, ending time, place, order of transportation, amount of garbage, distance, etc. Results of generation the current waste transportation map for forklifts in Lien Chieu District using the Network Analysis application are shown in Figure 7a, Figure 7b and detailed information of each trip is represented in Table 2.

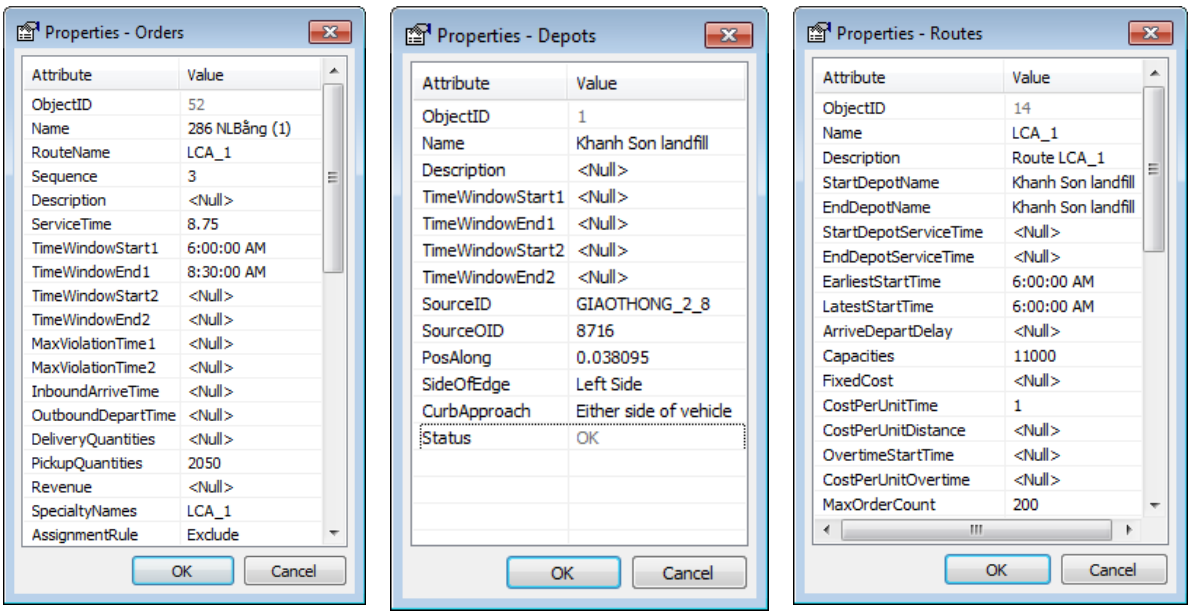


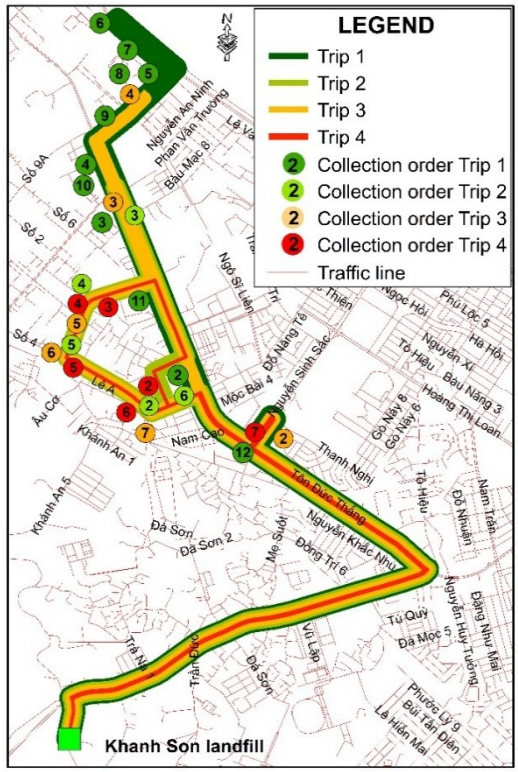
Figure 6: Setting up the parameters in Network Analysis

Table 2: Information on the current transportation of forklifts in Lien Chieu District

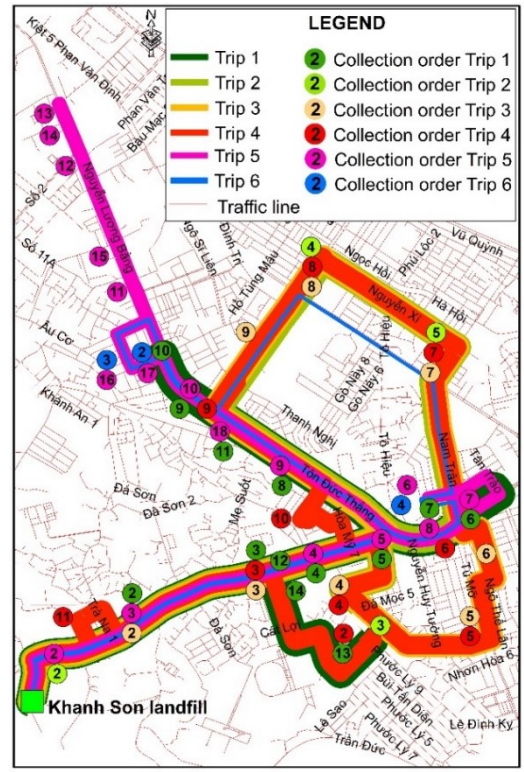
Trip name	Total time (hours)	Starting time	End time	Distance (km)	Waste volume (tons)
LCA_1	1.65	6:00 am	7:39	18.3	11.0
LCA_2	1.30	9:00	10:17	15.8	11.0
LCA_3	1.28	11:00 am	12:17	17.6	11.0
LCA_4	1.12	13:30	14:37	14.8	6.4
Total LCA	**5.37**			**66.5**	**39.4**
LCB_1	2.05	6:00 am	8:03	16.5	11.4
LCB_2	1.28	9:00	10:17	14.3	11.2
LCB_3	1.45	11:00 am	12:27	14.9	10.9
LCB_4	1.48	13:30	14:58	19.2	10.4
LCB_5	2.13	18:00	20:07	17.9	10.3
LCB_6	0.93	20:30	21:25	14.8	3.0
Total LCB	**9.33**			**97.5**	**57.1**
Total	**14.70**			**164.0**	**96.5**

Based on Table 2 and Figure 7, it can be seen that the number of trips, travel time and distance of route B are larger than the route A. Specifically, route A transports average 4 trips per day while route B transports an average of 6 trips per day. The transportation time of route B is about 4 hours longer than route A. Route A is usually ended before 15:00 hours daily while route B has to carry two overnight trips. This is consistent with the amount of waste generated during the day in Lien Chieu District. In order to do garbage collection in places such as Hoa Khanh market, Hoa My market, the waste trucks have to wait for workers to collect rubbish at the end of the market, usually until the mid-night. Moreover, in order to save the transportation costs, the company has also make a reasonable arrangement when the remaining amount of waste from route A is insufficient, the vehicles of route B will transport to avoid the residual waste into the next day.

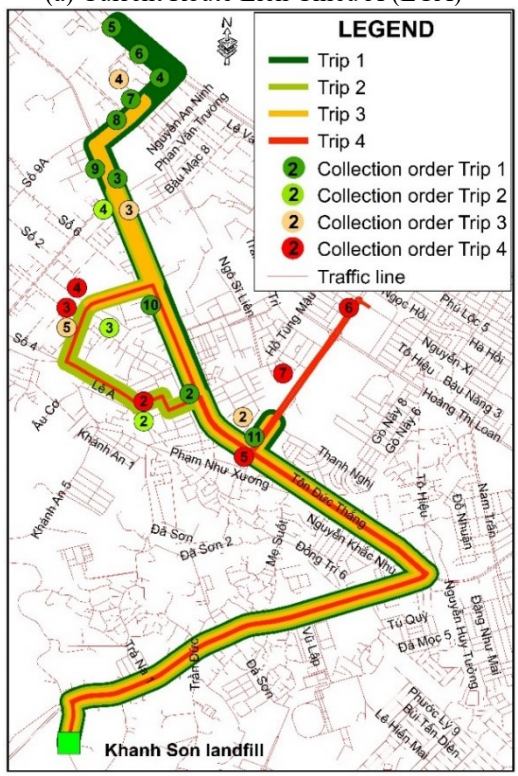
Since the volume of waste is not same at different times in the month, the number of trips can be increased or decreased in order to adapt to the actual situation. Therefore, the current waste transportation route in this paper is based on the average waste collection data that have conducted from the survey (Figure 7a and Figure 7b). In these routes, the waste is transported almost throughout the areas of Hoa Khanh Nam, Hoa Khanh Bac and Hoa Minh wards.



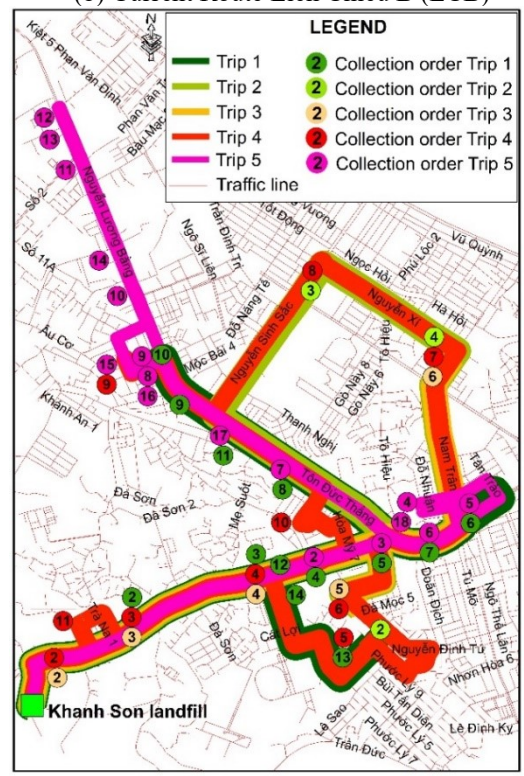
(a) Current Route Lien Chieu A (LCA)



(b) Current Route Lien Chieu B (LCB)



(c) Optimal Route LCA



(d) Optimal Route LCB

Figure 7: Current and optimal waste transport route maps of forklift truck in Lien Chieu District, Da Nang City

3.2 Optimization the Waste Transportation Route for Forklifts in Lien Chieu District

3.2.1 Optimize the current waste transportation route for forklifts

The current waste transportation routes of Lien Chieu A and Lien Chieu B forklifts basically meet the needs of garbage transportation in the District. In this study, optimization of the current waste transportation route is the process of finding the optimal routes in case of the total waste collection volume of the forklifts is not changed. In order to generate a better waste transportation route, we have adjusted the parameters on Network Analyst such as:

- Transportation route: It is not required for the vehicle to pass through the roads without garbage collection.
- The amount of waste that can be collected at gathering points: in principle if the waste volume of a certain collected points exceeds the current loading capacity of the forklift, it will not take the waste at this location. In this case, we combine the data of the Lien Chieu A and B routes and break down the waste at gathering locations into smaller locations to satisfy the condition of the vehicle's loading capacity.
- Order of garbage transportation: It is not required that vehicles have to move in the existing order. They only need to satisfy the garbage collection time which is specified by the company.

In this study, we tried to optimize the current waste transportation route based on the assumption that the forklifts are almost at the maximum waste volume (11 tons). The results of optimal waste transportation for forklift trucks in response to the current waste volume of Lien Chieu District are represented in Figure 7 and Table 3. Comparing between the current and optimal waste transportation routes, we can see that in case of Lien Chieu A (LCA) route (Figure 7a and Figure 7c), the travel time and distance in the optimal route is slightly increased compared to the current route, especially the forklift has to pass through Nguyen Sinh Sac street in the final trip (trip 4) of LCA optimal route (Figure 7c). This is because of our modification when combining the waste collection database of LCA and LCB in order to reduce the travel time and distance in LCB. Since a part of waste in LCB has been collected in LCA, the number of trip in LCB optimal route has been reduced into 5 trips and the travel time and distance were also much saved compared to the current route (Figure 7b and Figure 7d). It can be concluded from Figure 7 and Table 3 that the optimal waste transportation route can reduce the total travel time and distance compared to the current route. Specifically, the waste transportation time is reduced by nearly 40 minutes, traveling distance is reduced by about 14 km and the number of trips is also saver with 1 trip smaller than the current route. This will enhance the efficiency of the waste collection and reduce the environmental pollution caused by waste transportation.

Table 3: Information on the optimal waste transportation of forklifts in Lien Chieu District based on the current waste volume situation

Trip name	Total time (hours)	Starting time	End time	Distance (km)	Waste volume (tons)
LCA_1	1.65	6:00	7:39	18.3	11.0
LCA_2	1.28	9:00	10:16	15.6	11.0
LCA_3	1.28	11:00 am	12:16	17.4	11.0
LCA_4	1.42	13:30	14:54	17.2	10.1
Total LCA	**5.62**			**68.5**	**43.1**
LCB_1	2.05	6:00	8:03	16.5	11.0
LCB_2	1.23	9:00	10:14	14.3	10.6
LCB_3	1.28	11:00 am	12:17	11.9	9.7
LCB_4	1.57	13:30	15:03	18.8	11.0
LCB_5	2.32	18:00	20:19	20.4	11.0
Total LCB	**8.45**			**81.8**	**53.4**
Optimal route	**14.07**			**150.4**	**96.5**

3.2.2 Optimization of Waste Transportation Route Based on Different Waste Volume Scenarios in Lien Chieu District

Since the amount of waste is always changing due to the influence of many reasons such as the local economic development, disasters and disease situations. Therefore, we need to change the collection plan to suit each specific time. In this study, based on the data on the average volume of garbage transported by forklift trucks is 96.5 tons per day, we build an optimal garbage transport route for forklifts in Lien Chieu District based on different scenarios of daily household waste from 70 to 115 tons. Subsequently, corresponding to the actual garbage generation situation, the local government can choose the best garbage transportation plan. Based on the current optimal garbage transportation route built in the above step, we continue to adjust the parameters of the collection volume and time. In this study, we assume that the waste volume increases steadily in Lien Chieu District and the maximum amount of garbage per transported trip is also 11 tons. The statistical information of the optimal waste transportation routes corresponding to the different scenarios of garbage generated by forklifts are shown in Table 4.

Figure 8 show that in all scenarios even when the waste volumes are increased, the travel distance of our proposed optimal waste transportation are always saver compared to the current route.

Table 4: Information of the optimal waste transportation route corresponding to different scenarios of waste generated by forklift truck

Waste volume (tons)	Waste change rate (%)	Distance (km)	Distance change rate (%)	Time (hour)	Time change rate (%)
Current Route (96.5)	0	164.0	0.0	14.7	0.0
Optimal Route (96.5 tons)	0	150.4	-8.3	14.1	-4.2
115 tons	19	162.0	-1.2	16.4	11.9
110 tons	14	150.3	-8.4	15.3	3.8
105 tons	9	150.2	-8.4	15.0	1.7
100 tons	4	150.2	-8.4	14.5	-1.1
95 tons	-2	147.1	-10.3	13.8	-6.1
90 tons	-7	147.1	-10.3	13.4	-8.9
85 tons	-20	133.5	-18.6	12.4	-15.5
80 tons	-17	133.5	-18.6	12.0	-18.3
75 tons	-22	123.0	-25.0	11.1	-24.7
70 tons	-27	123.5	-24.7	10.7	-27.4

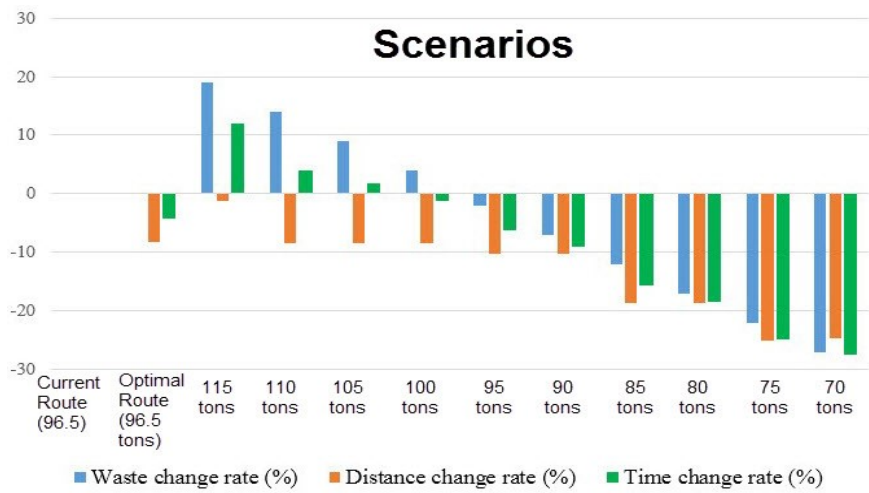


Figure 8: Comparison of the change (%) of waste volume vs. travel distance and time in the optimal waste transportation route (11 tons/trip)

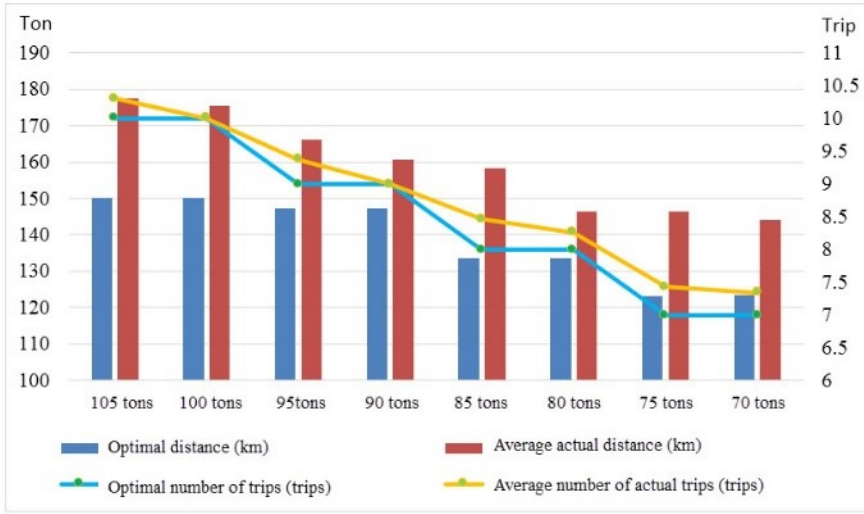


Figure 9: Comparisons between the optimal and actual waste transportation routes

Table 5: Comparisons between the optimal and actual waste transportation routes for different scenarios of waste volume

Waste volume (tons)	Optimal distance (km)	Average actual distance (km)	Optimal number of trips	Average number of actual trips	Residuals trips between actual and optimal route
115	162.0	No data	11	No data	No data
110	150.3	No data	10	No data	No data
105	150.2	177.4	10	10.30	- 0.30
100	150.2	175.4	10	10.00	0.00
95	147.1	166.1	9	9.37	- 0.37
90	147.1	160.6	9	9.00	0.00
85	133.5	158.2	8	8.46	- 0.46
80	133.5	146.4	8	8.25	- 0.25
75	123.0	146.5	7	7.43	- 0.43
70	123.5	144.0	7	7.33	- 0.33

When the waste volume increases to 115 tons per day (about 20% compared to current scenario), the transported time is only about 12% increasing and the travel distance is almost equivalent to the current route. Similarly, when the amount of waste increased to 110 tons per day (about 15% increase), the travel time would increase only 3.8% (15.3 hours) but the distance is relatively reduced with 8,4% (150.3km) saver compared to the present scenario. As the volumes of waste are reduced, we can also see more reduction in transported time and distance. Accordingly, when the amount of garbage reduced by an average of 14.5%, the travel distance can be saved by an average of 18% and the travel time is reduced by 17% compared to the current route.

3.3 Evaluation of the Optimal Waste Transportation Route in Lien Chieu District

In order to evaluate the efficiency of the generated optimal waste transportation routes, we have used the practical information about the travel distance and trips of the respective forklifts that have been used in the Da Nang URENCO Company. The reference data provided by URENCO is the practical data of all waste transportation routes in 2020 in Lien Chieu District. We have classified the routes based on different waste volumes and take the average parameters of each group, then compared to the optimal route developed from this study. It is clear to see from Table 5 and Figure 9 that comparing to the reference data, the travel distance and the number of trips of the optimal routes generated from this study are always saver than the actual route.

It can be concluded that the optimization results from this study have also demonstrated the effectiveness in different scenarios of waste transportation for forklifts in Lien Chieu District.

4. Conclusions

Waste Collection and Transportation Problem is always a difficulty of any urban area. This study has proposed an optimal waste transportation for forklift truck in Lien Chieu District, Da Nang City that can bring the efficiency in time and travel distance. From the results of building and evaluating the efficiency of waste transportation routes using GIS in Lien Chieu District - Da Nang City, it can be concluded that:

- Using OpenStreetMap and other open source data in generation of traffic database can save the time and costs, bring the high efficiency in many applications. This is a useful data source for not only waste collection but also many studies related to spatial traffic data. However, the Open Source GIS data needs to be evaluated and validated to meet the requirement of each application.
- The application of GIS with the Network Analyst tool in the construction of the garbage transportation route brings the high efficiency and quick results. It helps us to come up with the most reasonable garbage transportation option according to the required conditions and the available database source.
- This study has given the process to collect and generate the optimal waste transportation route on GIS and Network Analysis. Accordingly, the project has built the current roadmap for transporting garbage of forklifts in Lien Chieu District. Based on the generated results, we have adjusted parameters related to optimal route such as time, road distance, etc to provide the optimal transported route.
- The project has also built an optimal garbage transportation route based on different scenarios of household waste generation in the District. Accordingly, for each scenario, we can transport garbage according to the best routes. Thereby, the optimal route can save time, travel distance and costs for garbage transportation in the District. This data source can well serve the garbage transportation of Lien Chieu District in the coming time.

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