

Original Paper

Route Optimization of MSW Collection and Transport Using a GIS-Based Analysis on the Tourism Island

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Abstract

The Municipal Solid Waste (MSW) management on Si Chang Island is challenging in terms of its limited land resources, high cost of waste treatment, and seasonal fluctuations in waste volumes from tourists and shipping activities. There are sufficient waste bins available to cover MSW production on the island. The downside of the management is an inappropriate open dumping site that is prone to environmental pollution and health risk. However, resilience is shown in the implementation of an integrated approach of waste separation, composting, and incineration. This study developed a complete road network and applied a network analyst extension, which was useful in the area of optimization of MSW collection and transport. Two optimal routes were shown for MSW collection. Two vehicles were utilized to collect about 10 tons of MSW per day in two trips. A total travel distance for one-day transportation was 38.5 km. Carbon dioxide (CO₂) emission from vehicles during MSW collection and transport was 0.85 g/km, accounting for 119 t CO₂/yr.

Keywords

municipal solid waste, GIS, network analysis, tourism, island

1. Introduction

Between 2015 and 2016, the Ministry of Tourism and Sports in Thailand revealed that Chonburi province recorded an almost 50% increase in visitors, tourists, and excursionists reaching 8,153,960 people. Total expenditure on island tourism in 2016 was 58,487 million baht (1 USD = 31 baht). Si

Chang Island is one of the most attractive destinations, accounting for about 0.35% of the tourist population in the Chonburi province. This small island is geographically the nearest island from the capital city of Bangkok. As the number of visitors and residents grow, the island is struggling to deal with the increased amount of Municipal Solid Waste (MSW). A generation of MSW is 10-12 tons/day, which rose by 19% during the last decade (Supakata et al., 2016). An open burning at a dumpsite is a common practice for MSW disposal systems (88%), followed by recycling (10%), and composting (2%) (Supakata, Puangthongtub, Srithongouthai, Kanokkantapong, & Chaikaew, 2016).

A combination of Geographic Information System (GIS) with Global Positioning System (GPS) and other advanced techniques have been successfully applied in a wide range of implications, including waste management. The evaluation of a suitable index for landfill site selection within the GIS context involving environmental and socioeconomic criteria has been carried out (Kontos, Komilis, & Halvadakis, 2005; Nas, Cay, Iscan, & Berktaç, 2010; Rezaeimahmoudi, Esmali, Gharegozlu, Shabaniyan, & Rokni, 2014). Chalkias and Lasaridi (2009) report that the total cost for waste collection and transportation is usually responsible for more than 70% of the MSW operation cost. As the rocky landscape on the Si Chang Island is formed by limestone and granite (Geology Division, 2012), the topographic constraint limits options for landfill site selection. The dumpsite is established in the west away from residential areas. The municipality is undergoing consideration for waste incineration in the same area and the routing system optimization is therefore at the forefront of the current situation.

A GIS-based approach for optimization of MSW collection provides considerable economic savings and environmental improvement through optimal distance, time, and pollutant emission reduction (Johansson, 2006; Tavares, Zsigraiova, Semiao, & Carvalho, 2009; Gilberto Tavares, Zsigraiova, Semião, & Carvalho, 2008). Several studies have investigated optimization of routing systems to give an extensive advantage of spatial data. Ghose et al. (2006) applied a GIS model for bin distribution, load balancing of vehicles and optimal routes for MSW collection in the Asansol municipality. Nuortio et al. (2006) investigated the optimization of waste collection in Eastern Finland. They found that a GIS helped reduce cost by 40% and route improvement by about 12%. In Nikea municipality, Athens, an optimal route was sought for the reallocated waste collection bins. The collection time was improved by 3%-17% and travel distance was improved by 5.5%-12.5% (Chalkias & Lasaridi, 2009). More recently, Zsigraiora et al. (2013) successfully applied a GIS model that yielded substantial reductions of the total spent time (62%), the fuel consumption (43%), and pollutant emission (40%).

Considering an urgent circumstance under the database limitation on Si Chang Island, we aim to evaluate the sufficient number of bins to cover the MSW production and create a complete road map across the island. Based on the map and field survey information, the optimal routes for MSW collection and transportation are determined along with the carbon dioxide (CO₂) emissions from the MSW collection and transportation.

2. Materials and Methods

2.1 Study Area and the Existing MSW Collection

Si Chang Island is an archipelago located in the Upper Gulf of Thailand, about 12 km off the western shore of Sriracha district, Chonburi province (Figure 1). It consists of nine islands with Si Chang as the largest and most populated island. Si Chang Island, governed by Si Chang district municipality, has seven villages. The size of this island is approximately 8 km². The attractions on the island are Phra Judhadhat for King Rama V's royal palace, a Chinese-styled Buddhist shrine on the mountain, and a public beach. Approximately 4,800 population live on the main island (Supakata et al., 2016).

According to Tchobanoglous et al. (1993), the stationary container system is an MSW collection practice on Si Chang Island. The waste bins remain in the vicinity of waste generation and the waste is manually unloaded into a MSW collection truck. When fully loaded from multiple waste bins, a truck travels to the dumpsite. Currently, there are two vehicles (with a capacity of 12 m³) for MSW collection on the island and one small truck for organic waste. Waste is collected twice a day. On the first round is the main street and the road network is well built. The longest north-south road is 8 km. Two main roads and two lanes are enough to be used for waste collection vehicles. However, accessibility is difficult in some narrow streets.

There is a project in progress for the RRR (Reduce-Reuse-Recycle) communication strategy (Supakata et al., 2016). This program started at Koh Si Chang School and since then there has been a good guideline for people to separate wastes into dry waste, wet waste, recycle waste, and hazardous waste into the right bins before collection. The capacity of each bin is 120 L.

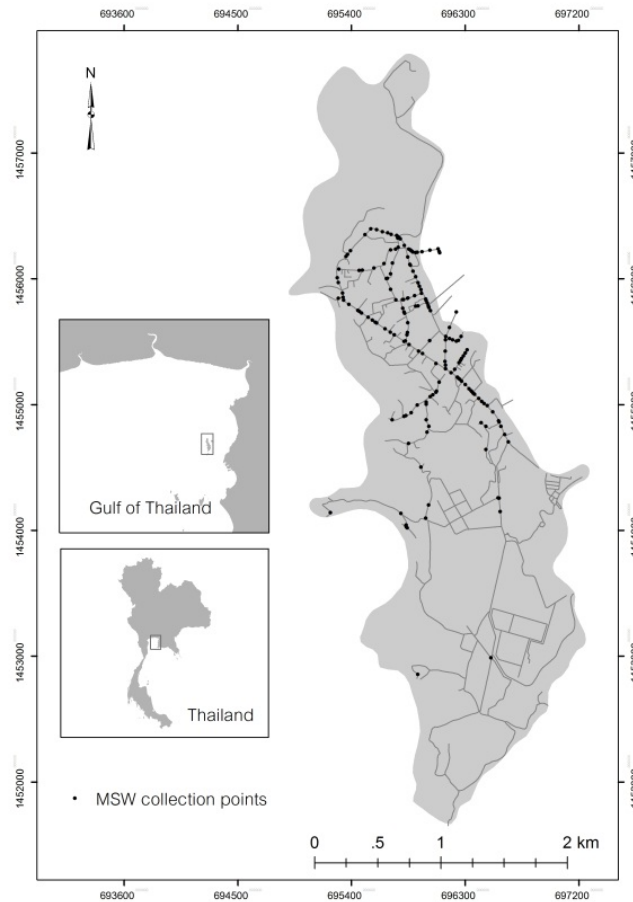


Figure 1. Road Network on Si Chang Island and Municipal Solid Waste (MSW) Collection Locations in Black Dots

2.2 Data Collection

The interviews with the Si Chang municipality officer and the truck driver were conducted as a preliminary step to generate background information on the MSW situation on the island. The empirical data of road surveys, open dumpsites, collection bin locations, vehicle parking area, collection vehicles, and collection time consumption was collected in 2015 and 2016. A local mini-pickup truck driver guided us to every route that had collection bins and then the coordinate was marked. The handheld GPS (model GPSMAP® 62sc) was used to record trip details based on the World Geodetic System (WGS84).

Secondary data included a topographic map from the Royal Thai Survey Department (1998, scale 1:50,000) and road maps from the Local Road Division, Department of Rural Roads (2007, scale 1:8,500) and the Ministry of Transportation (2011, 1:4,000). All the maps were overlaid and compared to the recent topography from Google Earth Pro v7.3.0.3832 (accessed December 2015). Si Chang Island road network was completely digitized from a combination of survey and secondary sources.

2.3 The Required Number of MSW Bins

To cover the MSW production, Eq. 1. was used to calculate the number of bins.

$$N = P \times R \times 1000 / D \times C \quad (1)$$

where N is the required number of bins; P is the number of island inhabitants (persons); R is the MSW generation rate (kg/person/day); D is the waste density (kg/day); and C is the bin capacity (L).

The waste generation rate was 1.48 kg/person/day and waste density in the bin was estimated as 162 kg/m³ (Pollution Control Department, 2016). The bin capacity was 120 L. A 1000 is a conversion factor changing from m³ to liter.

2.4 Network Analyst

This study used the ArcGISTM v.10.3 software as a platform to analyze the routing system optimization. The Network Analyst (NA) extension in ArcGIS provides network-based spatial analysis which includes routing, travel directions, closet facility, and service area analysis (Karadimas, Kolokathi, Defteraiou, & Loumos, 2007). The networks used by NA are stored as Network Dataset (NDS) platforms that contain network attributes and properties of network elements. The digitized spatial road network was stored in appropriate geographical features, i.e., polylines, nodes, and arcs. The optimal route finding in NA is an improved version of the classic Dijkstra's algorithm (1959). The real context of transportation data is essential to run the NA. Transportation on Si Chang Island is likely less restricted when compared to the mainland. Si Chang road system has two-way roads, no prohibited turns, and no traffic lights. The total vehicle time is the sum of the travel time and collection time for unloading of the bins. The final output is the optimal solution based on total time and total distance conditions.

The Vehicle Routing Problem (VRP) function was applied for searching for route optimization and the Best Route (BR) analysis was implemented to find the shortest route from the dumpsite to the parking area. Criteria to solve the optimal route for MSW collection system on the island included:

- Vehicles travel twice a day. One vehicle departs the parking area at 4 am, and another vehicle departs at 1 pm.
- Every bin needs to be collected in one day to avoid MSW overflow.
- MSW collection time from the observation is three minutes.
- The origin and the last destination of vehicles is the parking area.

2.5 CO₂ Emissions from Vehicle Transportation

Carbon dioxide during waste collection and transportation is impacted by travel distance, driving speed, and truck operating conditions. In this present study, the author used the formula from Hickman (1999). The CO₂ emissions were calculated using heavy vehicles (7.5-16 tons) coefficients.

$$\varepsilon = K + (av) + (bv^2) + (cv^3) + (d/v) + (e/v^2) + (f/v^3) \quad (2)$$

where ϵ is the emission (g/km); K is a constant value; v is an average speed of the vehicle, (km/hr); and a - f are coefficients for heavy vehicles.

3. Results and Discussion

3.1 Required Number of Disposal Bins and Waste Treatment

According to the interview with the Si Chang municipal officer, there are 300 waste collection bins on the island. However, an available 265 bins were observed on site. The calculation from Eq. 1 showed that the sufficient number of disposal bins is suggested to be 366 to cover all the MSW generation in one day. Despite tourism growth and limited disposal bins, local inhabitants have never experienced MSW overflow. Up to present, the bi-daily MSW collection frequency has played an important role in keeping the disposal bins empty. Si Chang municipality should be in charge of managing the MSW records and consider the number of residents and tourists to plan for the future scenarios. Besides locals and tourists, the 400,000 commuter population is expected to increase (Puangthongtub et al., 2016). The positions of the bins seem to cover all households.

Puangthongtub et al. (2016) investigated the characterization of MSW on Si Chang Island and found that food waste was a major portion (69.48%), followed by glass (14.41%), and plastic (8.79%). The rest of the percentage included paper, metal, and green waste. The proportion of MSW involved tourism goods and services, as these types of waste are the components of food and beverage containers. One serious issue about MSW management was the inappropriate disposal treatment. The open burning dumpsite, located on the west side of the island has been contaminated by hazardous waste and MSW. Such accumulation and burning may cause soil pollution, polluted water leachate, and toxic gases. Chiemchaisri and Visvanathan (2008) predicted that Chonburi province will generate methane gas (CH_4) emissions of 7,945 Mg/yr in 2020 compared to 5,938 Mg/yr in 2015. Si Chang Island is inevitably a part of this contribution. These wastes cannot be burned when it rains, thus the dumpsite piles up with increasingly more waste. Severe sanitation/hygiene occurring at the dumpsite also cannot be ignored since there were an uncountable number of flies and the area was easily accessible for animals. Even though the MSW treatment problem is usually considered a local issue, excessive flows can be associated with negative results on a larger scale, i.e., national and global levels (Sasikumar & Krishna, 2009).

Recently the Thai Government has attempted to implement an Integrated Waste Management System (IWMS), which includes waste separation, composting, and incineration. The management may vary depending on the local context. On the tourism island, there is no one solution, but application of IWMS should reduce stress from the current situation and help shape the future policy.

3.2 Optimal Routing System and CO₂ Emissions

In the past decades, Thailand has improved in waste collection and transport systems. Bangkok collects nearly 100% of MSW generation, while rural areas collect about half of MSW production (Chiemchaisri & Visvanathan, 2008). Si Chang Island municipality showed its ability to collect MSW close to 100% from the collection bins along the road network. The routing system using the GIS modeling resulted in two routes of different distances. This implies that Si Chang municipality needs one MSW collection vehicle in the morning and another in the afternoon. The vehicles depart the parking area and visit every bin location to the dumpsite. The collection time to manually unload each bin per location was about three minutes. The average collection speed was 30 km/hr. Under the same condition, Route 1 showed a total distance of 7.5 km and a total collection time of 15 minutes (Figure 2a). Route 2 provided a longer distance of 15 km and a total collection time of 30 minutes (Figure 2b).

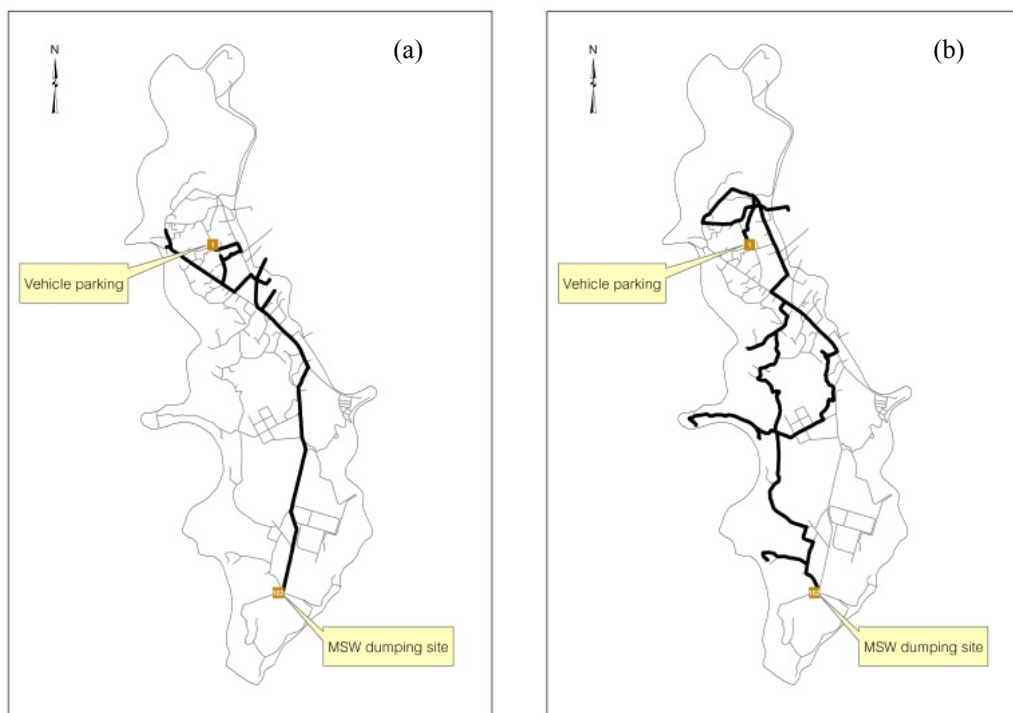


Figure 2. The MSW Collection Vehicle Route for Si Chang Island, Optimized for the Shortest Distance for All Disposal Bin Locations Derived by Vehicle Routing Problem (VRP). Route 1 (a) Is 15 Minutes for 7.5 km and Route 2 (b) Is 30 Minutes for 15 km

After collecting MSW, the modeled vehicle distance is estimated at 3.9 km in eight minutes (Figure 3).

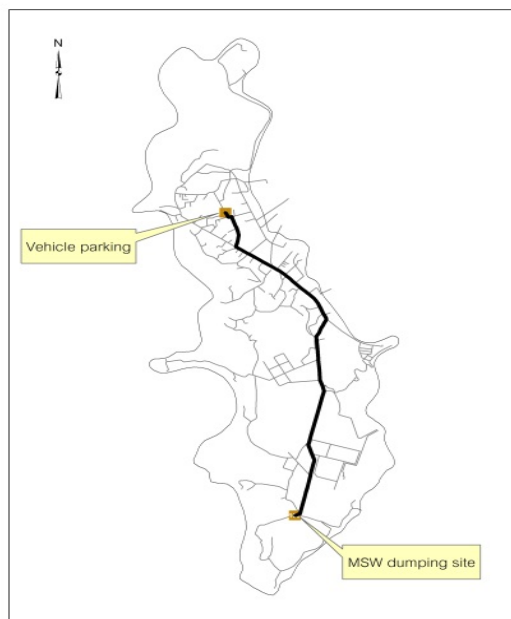


Figure 3. The Shortest Distance from the Dumping Site Back to the Parking Area after MSW Collection Activity Derived by the Best Route (BR) Analysis

The calculation of CO₂ emission from MSW collection and transportation on Si Chang Island was 0.85 kg/km or 119 tons/yr. The result was calculated from the GIS model when the travel distance for MSW transportation was 38.5 km/day. The CO₂ emissions accounted for 1.7% of emissions in the Thailand transport sector in 2015 (7,000 tons) (Energy Policy and Planning Office, 2016). In Nikea, Greece, 0.93 kg/km CO₂ was emitted into the atmosphere in the existing MSW transportation condition. For the optimal route, the CO₂ contribution was reduced to 0.83 kg/km (Chalkias & Lasaridi, 2009) which was similar to number calculated in the Si Chang Island case.

4. Conclusion

Si Chang Island is a fast growing tourism business in Thailand. Although the situation of MSW collection seemed to be under control due to frequency of collection and enough waste bins, MSW production is expected to increase in the near future. This study illustrated the value of GIS application as a waste collection and transportation tool. Once the road network was completely prepared, the network analyst approach was implemented to search for the optimal routing system. Two routes were shown for the best alternative. The distance for Route 1 was 7.5 km and the travel time was 15 minutes. The distance and time for Route 2 was double. Each vehicle required 8 minutes for 4 km from the dumping site back to the parking area. The CO₂ emissions from vehicles during MSW collection and transport were 0.85 g/km. This number may sound subtle but when added to the atmosphere, in

particular for a long distance and long-time operation, it is significant. The results from GIS-based analysis are beneficial for planning and decision-making. To improve the quality of life for local communities, a burning open dumpsite must be urgently replaced by a proper MSW treatment scheme.

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