FINDING AN ALTERNATIVE ROUTING FOR SOLID WASTE MANAGEMENT

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FINDING AN ALTERNATIVE ROUTING FOR SOLID WASTE MANAGEMENT

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LIST OF SYMBOLS

A	Arc
A(*i*)	Arc permanent
C(G)	Circle graph
c_{ij}	Current Distance
d(-)	Shortest path distance
d(i)	Distance of shortest path
d(j)	Temporary distance
d_k	Distance of destination
G	Graph
i	Shortest path length
j	Temporary node
K	Destination (ending node)
m	Number of arcs
N	Nodes
n	Number of nodes
P	Path
q	Subpath
S	Starting node.
T	Shortest path tree
t	time
V	Vertex

x_{ijt}	Network from *i* to *j* is used in step *t* of the route
z	Minimum sum cost
ϵ	Element
Σ	Subtotal

LIST OF ABBREVIATIONS

GIS	Geographical Information System
GPS	Global Positioning System
NSWMD	National Solid Waste Management Department
GAMS	General Algebraic Modeling System
SWM	Solid Waste System
DSWM	Domestic Solid Waste Management
MBSA	Majlis Bandaraya Shah Alam
MBPJ	Majlis Bandaraya Petaling Jaya
MBPP	Majlis Bandaraya Pulau Pinang
MBSP	Majlis Bandaraya Seberang Perai
GSH	Greener, Safer, Healthier
PPP	Public Private Partnership
DSS	Decision Support System
MILP	Mixed Integer Linear Program
MSW	Municipal Solid Waste
BILP	Binary Integer Linear Program
RSM	Response Surfaces Model
VRP	Vehicles Routing Problem
CFC	Chlorofluorocarbon
CO_2	Carbon Dioxide
ALNS	Adaptive Large Neighbourhood Search
GHG	Green House Gas
EPA	Environment Protect Agency
UNFCCC	United National Framework Convention on Climate Change
MANFIS	Multiple Adaptive Neural Fuzzy Inference System

PENCARIAN LALUAN ALTERNATIF BAGI PENGURUSAN SISA PEPEJAL

ABSTRAK

Mencari jalan terpendek bagi memindahkan sisa buangan tempatan adalah salah satu cabaran terbesar bagi setiap organisasi pengurusan sisa pepejal. Kos operasi bagi pengurusan sampah yang telah mencecah sehingga 74% seluruh dunia memberi impak yang amat serius terutamanya di kawasan perindustrian. Dalam penyelidikan ini, algoritma Dijkstra dan Jurujual kembara (TSP) menggunakan perisian GIS versi 10.1 digunakan untuk mengoptimumkan laluan pengangkutan dari kawasan perindustrian Seberang Perai ke stesen pemindahan sampah, Ampang Jajar. Menggunakan teknik ini, objektif kajian dicapai dengan membandingkan laluan yang sedia ada dan bagi 24 syarikat dari fasa I, II dan IV di kawasan perindustrian Seberang Perai ke stesen pemindahan sampah. Algoritma Dijkstra dan TSP adalah algoritma klasik dalam GIS yang digunakan untuk mencari laluan alternatif untuk mengurangkan kos operasi. Pelepasan karbon adalah objektif tambahan dalam penyelidikan ini melalui perbandingan penggunaan diesel pengangkutan di antara laluan yang sedia ada dan laluan alternatif. Penyelidikan ini, mendapati bahawa laluan alternatif 1 adalah 19.74% lebih terdekat. Manakala, laluan alternatif 2 sebanyak 3.73% lebihan jarak berbanding dengan laluan sedia ada. Dalam penyelidikan ini, algoritma Dijkstra dan Jurujual Kembara mencari jalan terpendek dari satu titik (node) ke titik lain yang searah dimana titik asal (Depot) sampai titik tujuan (stesen pemindahan sampah Ampang Jajar). Jarak laluan dapat dioptimumkan sebanyak 6.61% berbanding dengan laluan yang sedia ada ketika menggunakan algoritma TSP.

MBSP berpotensi menjimatkan sebanyak 19.75% kos pengangkutan dengan menggunakan laluan alternatif 1 ke stesen pemindahan Ampang Jajar. Seterusnya, tahap pelepasan karbon pengangkutan yang sedia ada ialah 92.16 kg setahun. Dengan penggurangan jarak laluan alternatif 1 dan laluan TSP berpotensi untuk mengurangkan tahap pelepasan karbon menjadi 73.96 kg setahun, dan 86.04 kg setahun. Penemuan ini dapat membantu MBSP menjimatkan kos operasi pengumpulan sampah, masa dan menjaga persekitaran lebih bersih seperti yang ditetapkan dalam wawasan Pulau Pinang 2030.

FINDING AN ALTERNATIVE ROUTING FOR SOLID WASTE MANAGEMENT

ABSTRACT

Finding the shortest route for transferring solid waste is one of the biggest challenges for every solid waste management organization. Globally, waste collection process represents 74% of operating costs, yet it has been given minor attention. In this research, Dijkstra Algorithm and Travelling Salesman Problem (TSP) using GIS Software 10.1 were used to optimize the route from Seberang Perai Industrial area to Ampang Jajar waste transfer station. Using the technique, we compare the existing and optimized route with the 24 companies from phases I, II and IV in the Seberang Perai Industrial area to waste transfer stations. Dijkstra and TSP are some of the classic algorithms in the GIS which are used to find the shortest route to reduce the operating cost. Carbon emission is an extended part of this study by comparing transportation fuel consumption between existing routes and optimized routes. This study revealed that optimized route 1 which is shorter by distance 19.74% and alternative route 2 found 3.73% extra distance compared to the existing route used by MBSP. But the route is using the forward Dijkstra Algorithm which is from the cleaning Depot to the landfill area. TSP is introduced to solve cycle from cleaning depot to cleaning depot. By using the TSP algorithm, the route distance has been optimized for about 6.61% compared to existing route. The optimized route suggested in this work, can help MBSP to save 19.75 % of fuel costs by adapting to effective shortest route 1 for transporting solid waste to Ampang Jajar transfer station. The existing transportation carbon emission level stood at 92.16 kg per year based on single trip basis. Alternative route 1 and TSP route have the potential to reduce the carbon emission level

to 73.96 kg per year, and 86.04 kg per year, respectively. The findings could assist MBSP to save waste collection operating costs, transportation time and keep environment cleaner as per the Penang 2030 vision.

CHAPTER 1

INTRODUCTION

1.1 General Introduction

Technology evolution and the process of developing country are rapidly increasing industrial activities. It makes a more expanded, solid waste era (Patel et al., 2016). Moreover, global industrial waste becomes a major concern. According to the World Bank Group (2018), the world contributes about 2.01 billion tonnes of solid waste annually. Following the increase in the population and the progress made more industrial waste are produce and it is estimated between 1.6 - 2.0 billion tons annually which represent about USD 433 billion annually. According to world bank group (2018), the world waste will be increased to 3.09 billion tonnes in the year 2050. Figure 1.1 shows the world projected waste generation by region.

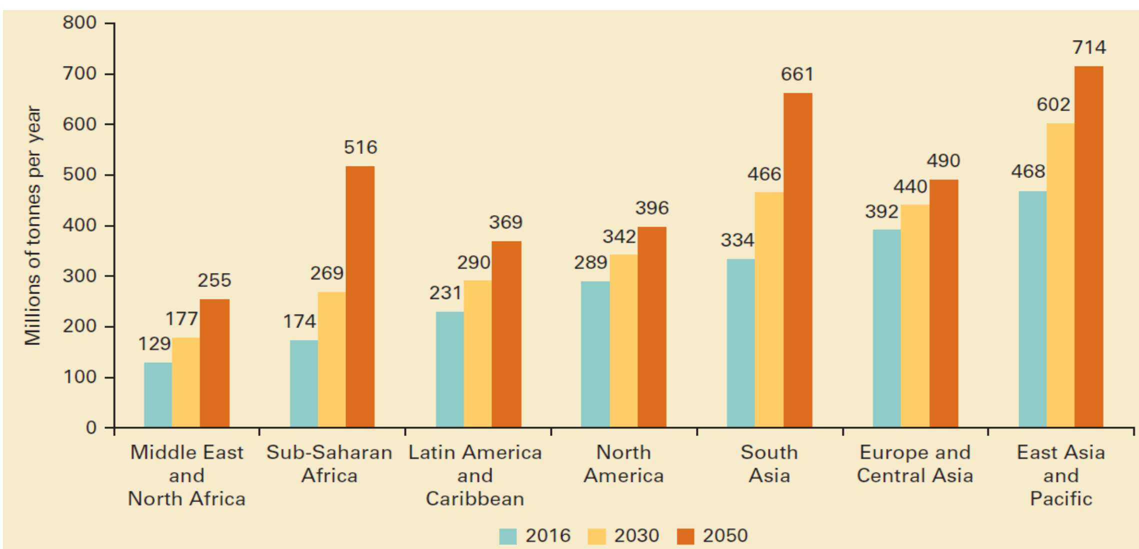

Figure 1.1 Projected waste generation, by region (millions of tonnes/year)

Source: (World Bank, 2018)

In the sixty years following independence, Malaysia was developed with various industries of equal status to other countries. With this industrial development, solid waste disposal activities have also increased. In the local newspaper, Kumpulan Utusan (2017) stated that every day a total of 37,000 tons of waste is produced in Malaysia. That means about 13.5 million tons of garbage is produced every year. Meanwhile, the cost of managing all the garbage weight is RM 2.2 billion a year. According to on website Department of Statistics (2017), Malaysia generated about 25 000 tonnes of daily industrial waste in the year 2014. The National Solid Waste Management Department (NSWMD) (2013), reports show that the Penang industrial area produced 109.4 tonnes of waste per day. Figure 1.2 shows the waste generation rate in the East and the Asia Pacific by region.

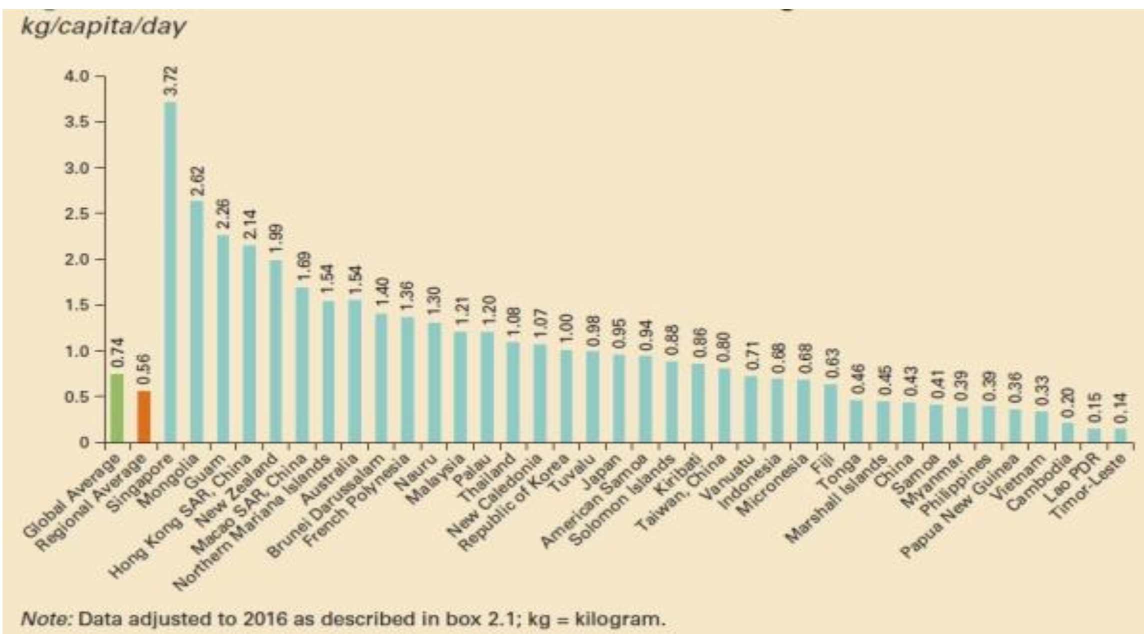

Figure 1.2 Waste Generated rate in the East and Asia Pacific Region

Source: (World Bank, 2018)

1.2 Solid Waste Management (SWM)

Apart from understanding the global waste increased due to the globalization growth of the industrial and manufacturing sector are increasing in Malaysia. According to Hareesh et al., (2015), in developing countries, due to the growth of the industrial area in the urban cities, results in the increasing of solid waste and created a major problem. Meanwhile, solid waste management plays an important role in waste collection and disposal and having a problem in minimizing operation cost, travel distance and optimizing the labor.

Transportation, collection of waste, composting, recycling, and final disposal are the major role of SWM. The SWM operation cost is expected to rise until US$50 billion by 2025 (Hoornweg & Thomas, 1999). It is meaning that SWM has become a costly service. Therefore, there is a need to strategically plan to reduce the waste generation.

Systematic system is needed to be implemented in solid waste management to help overcome issues on operation activities. Governments need acceptable planning and targets on the long-term prospects of this situation as a support system. Zhu et al., (2008), posits that a successful application system needs, and the teamwork of all stakeholders must be considered as many aspects as possible to overcome issues on operational activities. The essential stakeholders for the Domestic Solid Waste Management (DSWM) system, must be responsible for household waste and general waste, as their value of awareness and contribution to the formulation of a successful system.

A proper collection system has been adapted in high-income or population cities such as in foreign countries while other cities, they look to an alternative way to allocate a dumpsite such as industrial area. Other than that, there is no proper decision and layout for new landfill and avoidance reconstruction of existing dumpsites that can be used as sanitary landfills (Zhu et al., 2008).

The main goal of establishing a DSWM system is to preserve the clean environment of wellness of the people. At the same time, DSWM also can build strong business opportunities by giving support to economic development and to give rise to employment.

1.2.1 Solid Waste Management Practices

Currently, the SWM system in Malaysia is still struggling to manage solid waste in transferring, disposal and controlling. Alam Flora Sdn Bhd, manage the garbage collection in the central and eastern zones which comprise the Federal Territory of Kuala Lumpur, Putrajaya, Pahang, Terengganu, and Kelantan. SWM Environment Sdn Bhd, manage the southern zone which includes Johor, Melaka, and Negeri Sembilan. Environment Idaman Sdn Bhd manage the state cleaning in northern zones of Kedah and Perlis (Omran et al., 2009) and Kumpulan Utusan, 2017). Table 1.1 shows the contractor are responsible SWM by region in Malaysia.

Table 1.1 Contractors responsible for managing solid waste association by region in Malaysia

Region	Contractor	Operation Coverage
Central and Eastern Peninsular	Alam Flora Sdn. Bhd. MBSA, MBPJ, and MBSJ	Kuala Lumpur, Putrajaya, Pahang and Selangor.
Southern Peninsular Malaysia	SW Environment Sdn. Bhd.	Johor, Negeri Sembilan, and Melaka.

Northern Peninsular Malaysia	E-Idaman Company MBPP & MBSP	Kedah, Perlis Penang

(*Sources*: Omran et al., 2009 and Kumpulan Utusan, 2017)

Both Pulau Pinang and Selangor manage their waste independently (Official Portal Penang State, 2016). The Executive Council is the highest administrative body in the Penang State, while at the local government level, the state is divided into two local authorities, one in the Island and the other in the mainland, namely the Municipal Council of Penang Island, or Majlis Bandaraya Pulau Pinang (MBPP, 2006) in Province Wellesley (or Municipal Council of Seberang Perai (MBSP) respectively (Omran et al., 2009).

The two councils oversee the full state of Pulau Pinang. In the Island, eight zones are sectioned which are Tanjung Tokong, Batu Maung, Gelugor, Air Itam, Pulau Tikus, Jelutong, Padang Kota Lama, and Balik Pulau. These zones are managed by MBPP. While in Seberang Perai, MBSP delineated three main zones which are northern, central, and southern. These main zones have been separated into 36 sub-zones (official Portal Penang State government, 2016).

According to the portal penang.gov.my (2016), state government has introduced the cleaner, greener, safer & healthier (GSH) initiatives from Penang as a benchmark on the rank of global and smart city status. To accomplish Penang's GSH the State Government has already designed an appropriate new approach involving the private sector through Public Private Partnership (PPP) to address hygiene issues. PPP's impact on GSH initiatives have been increasingly showing positive results, including consistency from the people of Penang.

The State Government is convinced that both local authorities have carried out their duties effectively in terms of cleaning, garbage collection, waste transfer and disposal. For the above-mentioned reason, the Penang state government intention is to pay out three concessionaires to manage solid waste management in Penang: Alam Flora (central zone), and Southern Waste (southern zone). By privatizing solid waste management, the state government successfully achieved reducing environment pollution and have decreased open area garbage.

1.3 Industrial Area

Industrial area developed every year. Based on the Companies Commission of Malaysia (2017) there are about 1,203,319 companies in West and East Malaysia. The main industrial areas in East Malaysia are in Selangor, Penang, Kedah, and Johor. While in west Malaysia, it is in the city of Kota Kinabalu and Miri, Sarawak.

In Penang, most of the industrial plant are in Seberang Perai industrial area, which is a free industrial zone. The Seberang Perai District covered an area of 238 square kilometers, including the Perai industrial zone. The Perai industrial area is divided into four phases: Perai industrial area Phase I, II, III, and IV. About 440 industries are in these industrial zones (Official Portal Penang State Government, 2016). One of the responsibilities of MBSP in the Seberang Perai industrial zone is the collection of garbage for every phase, using only one route according to the time schedules. This study was conducted on the municipal solid waste collection route by the SWM Municipal Council of Seberang Perai (MBSP) in Seberang Perai District.

1.4 Problem statement

Due to the growth of the industrial area and industrial plant, the process of waste generation and environmental pollution increased drastically. The solid waste management spent about USD 1.6 - 2.0 billion tons annually for collection of waste which is big amount of money. The collection of municipal solid waste is one of the most difficult operational problems faced by local authorities in any city (Nuortio et al., 2006). In recent years, due to several cost, health, and environmental concerns, many municipalities, particularly in industrialized nations, have been forced to assess their solid waste management and examine its cost-effectiveness and environmental impacts, e.g. in terms of designing collection routes.

In the Seberang Perai industrial area, MBSP is responsible for handling waste and drain cleaning. From the interview with the operation manager of MBSP, who is in charge of the Seberang Perai division it has been determined that MBSP in the Seberang Perai industrial zone is collecting garbage for every phase and is using only one route and one truck according to the time schedules. According to the MBSP Operation Manager and truck driver, there are 440 companies in the industrial area, whereas MBSP only collects the solid waste for 24 companies, with fee for garbage collection. During the festival period, the truck will travel multiple times to the Ampang Jajar waste transfer station. It also causes collection delay due to traffic impediments or due road construction delays.

The focus of this study is to the solve the MBSP problem in handling solid waste management in the industrial area. Also, this research focuses on minimizing the cost of diesel by distance reduction to the landfill. Besides, the alternative ways as a sustainable solution to the SWM in the Perai industrial area are also discussed.

In addition, the carbon emission from the waste trucks also addressed to making as Penang vision 2030 in achieving environment cleaner, greener, and safer. Ghadimzadeh et al., (2015) posits that the total carbon emissions level in expanding countries is still comparatively less than those of developed countries. Malaysia has targeted to reduce its greenhouse gas (GHG) emissions by up to 40% by the year 2020. So, this research will identify the percentage of carbon emission release by trucks every month by calculating usage of diesel and waste(kg) with using the alternative routes.

1.5 Research Objectives

From the discussion in section 1.3 and 1.4 the objective of these studies are as follows: -

a. To identify the alternative routes by using GIS for phases I, II, and IV in Seberang Perai industrial area.

b. To determine the shortest path using the Dijkstra Algorithm and Traveling Salesman Problem cycle route using GIS for phase I, II, and IV.

c. To compare the management, fuel cost, and carbon emissions using shortest path, Dijkstra Algorithm, and Traveling Salesman Problem.

1.6 Significant of the study

Based on the objective of these studies, identifying solutions for solid waste management in the industrial area is a key starting point towards reaching the vision of Penang 2030. Improvement and enforcement of such solutions have a significant impact on the Municipals of Penang. Penang is a rapidly growing state that aims to be a smart city. Consequently, implementation of sustainable waste management solutions is important on order to transform into a smart central city in which industrial waste is properly managed. Another significant reason is that no research has been done on solid waste in Penang industrial area. Therefore, this research can provide a reference to the stakeholders that involved in waste management also to the public in order to better understanding of their roles in realizing sustainable solutions to solid waste management in Seberang Perai and the region beyond. This research also explains that there are efficiency measures in identifying the shortest way to transfer the waste from industry to Ampang Jajar waste transfer station with minimizing the working hours, and reducing carbon emission that release from the waste and the combustion of truck diesel.

1.7 Scope and limitation of the Study

The main aspect of the study is the determination of the shortest routes for transporting solid waste, at Seberang Perai industrial area by using Geographical Information System. In this study, route characteristics such as the width of the lane and speed limit are not included. Secondly, the results relate only to the transportation of municipal solid waste in the industrial area in Seberang Perai district to Ampang Jajar transfer station. Also, this study only emphasizes a directed graph in mathematical modelling such as Dijkstra algorithm and Hamilton cycle. Other than that, the carbon emission is calculated based on weight (kg) of waste and diesel that are used by trucks in a month for travelling from Seberang Perai industrial area to the Ampang Jajar transfer station only. Only solid waste such as leftover food, plastic and paper is considered as waste for the purpose of this study. No chemical, heavy metal, heavy wood waste is considered in these studies. Lastly, the collection schedule time includes 8 am to 4 pm only.

1.8 Organization of Thesis

The research consists of five chapters starting with an introduction in chapter 1 about solid waste management globally, Malaysia and the industrial area in Penang. Also, the problem that are faces by the SWM are highlighted. This is followed by literature reviews presented in Chapter 2, which reviews the theoretical aspect of the SWM system, mathematical modelling, and carbon emission calculation method. While chapter 3 introduces the methodology proposed for this research to achieve the objectives of study. The method discusses are Network Analysis (ArcGIS), Dijkstra algorithm, Hamilton cycle (TSP), and carbon emission. Chapter 4 provides a brief discussion of the expected analyses and results that are achieved from the method Network Analysis (ArcGIS), Dijkstra algorithm, Hamilton cycle (TSP), including the carbon emission. Finally, Chapter 5 five presents the conclusion of the results, a recommendation to the current SWM system, and future research.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

This chapter covers past research that are related to this study. Also, the reviews that are relevant to various waste management activities such as waste processing, storage, transferring, transporting and disposal. Furthermore, the literature review proposed different methods used to solve the design and operation of SWM such as Dijkstra, Travelling Salesman Problem algorithms, and software.

2.2 Solid Waste and Industrial Solid waste

According to a report from World Bank, the solid waste defined as any scrap material or other unwanted items or rejected products arising from the use of any process, a thing that broken, damaged items and foods (Hoornweg et al., 1999). Whereas a study by Zarcinas et al., (2004) said that industrial waste could be any medium, solid, organic, or non-organic substances in whatever solid that are produced either directly or indirectly from any industrial activity as its direct or indirect by-products.

According to the Li, (2009), the industrial waste is defined as solid waste generated in production activities such as growth industry, vehicle traffic, and living product development. Industrial solid wastes are categorized into organic wastes and inorganic wastes into solid wastes, semi-solid wastes, and liquid (gaseous) wastes based on their species.

2.3 Transportation

Solid waste management (SWM) consist transportation as an essential element. Effective transportation by selecting the shortest route can save time and cost in handling the waste (Manoharam et al., 2019). Furthermore, transportation including the schedule of collection vehicles, aimed to minimize the traffic impact (Lin et al., 2006). A study by Forko et al., (2018) posits that an enhanced transportation system by modification of delivery schedule, optimizing the fleet of truck routes and combined traffic condition data into models will manage to avoid traffic congestion.

The multi-objective analytical scheme used by Chang and Wang (1996), seeks to minimize the expenditure cost of waste recycling and transportation, which has been found to account for about 70% of the total expenditure. Forko et al., (2018) proposed a mixed-integer program to minimize the length of the route into waste collection and transportation for the SMW in Kumasi, Ghana. Table 2.1 shows different transportation studies were conducted in solid waste management. Based on the table, we can observe that no research in transportation of SWM has been done in Malaysia.

Table 2.1 Summary of route optimization studies in transportation.

No	Author	City	Title	Method	GIS	Cost	Optimization	Industrial	Housing	Results
1	(Anghinolfi et al., 2013)	Italy	A dynamic optimization model for solid waste recycling	GIS-based Decision Support System (DSS) & MILP model	√	√	√		√	Minimize collection and transportation costs.
2	(Eiselt & Marianov, 2014)	Chile	A bi-objective model for the location of landfills for municipal solid waste	Mixed integer		√			√	Cost minimizing and minimizes pollution
3	(Markovic et al., 2010)	NIS	Application Method for Optimization in Solid Waste Management System In The City Of Nis	Clarke-Wright savings algorithm	√		√		√	Vehicle movement costs, route duration time. Distance between users/waste generators
4	(Rhoma et al., 2010)	Germany	Environmental & Economical Optimization for Municipal Solid Waste Collection Problems, A Modeling and Algorithmic	MSW logistic mathematic-al model		√			√	Estimating the collection and transportation costs as well as the environmental

No	Author	City	Title	Method	GIS	Cost	Optimization	Industrial	Housing	Results
5	(Lin et al., 2006)	Taiwan	Evaluation of Solid Waste Management Strategies in the Taipei Metropolitan Area of Taiwan	linear programming		√	√		√	The minimum costs from the alternative way.
6	(Ghose et al., 2006)	India	A GIS-based transportation model for solid waste disposal – A case study on Asansol municipality	GIS	√			√		Minimum cost/distance efficient collection paths for transporting the solid wastes to the landfill
7	(Patel et al., 2016)	India	GIS-Based Route Optimization for Solid Waste Management: A Case Study of Surat City	Network Analysis	√		√			Route length, time duration, and fuel consumption can be minimized by GIS
8	(Chang & Wang, 1996)	Taiwan	Solid Waste Management System Analysis by Multi-objective Mixed Integer Programming Model	compromise programming method		√	√	√		Total solutions for long-term waste stream allocation, sitting, resource recovery, and tipping fees evaluation

No	Author	City	Title	Method	GIS	Cost	Optimization	Industrial	Housing	Results
9	(Forko et al., 2018)	Ghana	Optimal Routing of Solid Waste Collection Trucks: A Review of Methods				√			Minimize operating cost, travel distances of trucks, the quantity of collected waste, number of truck trips.
10	(Ericsson et al., 2006)	Sweden	Optimizing route choice for lowest fuel consumption – Potential effects of a new driver support tool.	ArcGIS, Arc-view, and module Network Analysis,	√	√	√		√	Traffic flow reduction, fuel reduction and truck reduction
11	(Vecchi et al., 2016)	Brazil	A Sequential Approach for the Optimization of Truck Routes for Solid Waste Collection	BILP & MILP		√	√			Reduction in the distances traveled by trucks, as well as a decrease in carbon dioxide emissions.
12	(Rathi, 2006)	India	Alternative approaches for better municipal solid waste management in Mumbai, India	Mathematical model of PPP		√		√		Reduction in the cost of waste management and reduction in the requirement for community bins and transportation of waste

2.4 Cost

An effective transportation system in SWM causes an effective cost saving. Cost-saving is the most expedient manner in every operation cost. In Norhafezah et al., (2017) SWM occur mostly in the housing areas, business areas and industrial areas. Waste collection is an essential factor for solid waste management. Thus, to design and develop a suitable collection route plan is essential. By using a proper collection path, the SWM system can support the operation cost-efficiently. Besides avoid unnecessary operating budgets and reduced collection time during the economic crisis.

Using a bi-objective mixed-integer programming model for location-routing industrial hazardous waste, Boyer et al., (2013) demonstrated that minimizing total cost, including transportation cost, operation cost, initial investment cost can be achieved. This method also decreased transportation risks such as facilities considering risk and cost criteria. For the transportation risk, Boyer et al., (2013) used the General Algebraic Modeling System (GAMS) software with IBM ILOG CPLEX Optimization Studio (CPLEX) to decrease the value and vice versa from the transportation risk.

Khaing et al., (2018) used Dijkstra's Algorithm in routing and network connected to find the cost of the shortest route in the SWM system. This algorithm finds the quickest way from one source of the vertex to one destination vertex until the shortest path reached the destination vertex. Table 2.2 shows the different methods used to reduce the cost of transportation in SWM. As in the Table 2.2, Nadia et al., (2011) in Malaysia minimize the labor cost, machinery, and fuel consumption by using Respond Surface Method (RSM). There is no evidence that shows the use of the Dijkstra algorithm or TSP method used to solve the shortest path problem.

Table 2.2 Different methods used to reduce cost in the SWM.

No	Author	City	Title	Method	GIS	Cost	Optimization	Industrial	Housing	Results
1	(Boyer et al., 2013)	Iran	A mathematical model for the Industrial Hazardous Waste Location-Routing Problem	MILP	√	√	√	√		Operation cost for each facility and saving cost from selling recycled waste
2	(Nuortioa et al., 2006)	Eastern Finland	Improved route planning and scheduling of waste	heuristic solution method	√	√	√			savings compared to the current practice can be obtained in both studied
3	(Badran et al., 2005)	Egypt	Optimization of municipal solid waste management in Port Said – Egypt	MILP	√	√			√	Reduce overall operation costs.
4	(Tavares et al., 2008)		A case study of fuel savings through optimization of MSW transportation routes	3D route modeling	√	√	√		√	52 percent savings in fuel & shortest distance
5	(Shamshir et al., 2011)	Malaysia	Optimization of Municipal Solid Waste Management	RSM		√	√		√	The costs of labor, machinery, and fuel consumption can be
6	(Nguyen-Trong et al., 2017)	Vietnam	Optimization of municipal solid waste transportation by integrating GIS	equation-based, and agent-based mod	√	√	√			Cost of the MSW collection is reduced by 11.3%

No	Author	City	Title	Method	GIS	Cost	Optimization	Industrial	Housing	Results
7	(Nadia et al., 2011)	Malaysia	Response Surfaces Model for Optimization of Solid Waste Management	RSM		√	√	√	√	Minimize the labor cost, machinery, and fuel consumption.
8	(Kirca et al., 1988)	Turkey	Selecting transfer station locations for large solid waste systems			√				savings attained by locating an additional transfer station in the collection.
9	(Nganda, 2007)	Sweeden	Mathematical Models in Municipal Solid Waste Management	MILP		√		√		Gives better total cost estimates and more precise waste amount measurements
10	(Lopeza et al., 2017)	Spain	Developing an indicator plan and software for evaluating Street Cleanliness and Waste Collection services			√				Analysis and optimization of the Street Cleanliness and Waste Collection Service.
11	(Mehr et al., 2017)	US	Planning Solid Waste Collection with Robust Optimization: Location-Allocation, Receptacle Type, and Service Frequency	Robust optimization techniques		√	√		√	78 percent over this solution’s best-case cost and the highly robust solution’s cost increasing by 47 percent over this solution’s best-case cost

2.5 Geographical information system (GIS)

In SWM, GIS is used to identify the shortest route for effective cost-saving in transportation. Hua, (2015) stated that the Geographic Information System (GIS) could be defined as a system for capturing, storing, checking, integrating, manipulating, analyzing, and displaying data related to spatial that guided the earth. GIS were used in variety of activities in the government sector, especially for the socioeconomic purposes. GIS will typically be used in health departments, local government departments, transport planning departments, planning department services and urban management departments. Not only that, GIS application is also widely used in the network management, service provision, telecommunications, and emergency repairs. Meanwhile, defense agencies too are using GIS to identify the site and the design of tactical support.

Among other things, Patel et al., (2016) stated that GIS is a device for working with the geological framework. GIS is a network, constructed by an intelligent setup of the system and proposes to design, secure, store, oversee, change, break down and imagine geo-referenced dimensional information. GIS can be considered to be a software package, which includes various components and tools used to enter data, manipulate data, analyze data, and generate data. The GIS components can be divided into three main parts, firstly a computer system (hardware and operating system); secondly GIS (ArcGIS) software which involves GIS data (spatial data and data management) and lastly the method used (analytical procedures). Each component is important to run GIS in separate fields. If there are any faulty or missing components, the GIS cannot operate properly. For example, before entering any primary data or analyzing data, it is mandatory to have basic requirements (three main components) to handle GIS, such as hardware, software, and users. Note that "hardware" is referred to as a computer consisting of monitors, system units or CPUs, keyboards, and mouse (Heywood, 2002).

GIS also plays a role in the business perspective, where the tool is very useful in broadcasting and retailing, trading, and transporting, where it is used to find and start a business like a strategic business site. Such as Kalle et al., (2016), explains that the collection and transportation of solid waste improved since the use of an appropriate software system such as in 3D GIS modeling and eventually helped to achieve up to 8–12% of fuel savings, even by traveling a longer distance compared to the shortest way. Also, the same study confirms that by using GIS tools is saves labor cost, time distance and fuel consumption, CO_2 emissions, hours of work and vehicles maintenance.

Table 2.3 shows other previous studies that are related to the obstacle and alternative decisions in SWM and also several studies that were conducted by using GIS. It showing that, only Ali, (2000), has used linear programming model in GIS to optimize the solid waste collection system in Malaysia.

Table 2.3 Summary of route optimization study by using GIS

No	Author	City	Title	Method	GIS	Cost	Optimization	Industrial	Housing	Results
1	(Rupani et al., 2015)	Iran	Optimization of Municipal Solid Waste Management System	SWOT analysis			√			Improvement operation in MSW Management.
2	(Chalkias & Lasaridi, 2009)	Nikea, Athens, Greece	A GIS-based model for the optimization of municipal solid waste collection: the case study of Nikea, Athens, Greece	GIS, Network Analysis	√		√		√	More efficient in terms of collection time and distance traveled, savings gas emissions, and fuel consumption savings.
3	(Beijoco et al., 2011)	Portugal	Optimization of a municipal solid waste collection and transportation system	GIS	√	√	√	√		Reducing fuel consumption, pollutant emissions, and costs.
4	(Bovwe et al., 2016)	Nigeria	Development of Ant Colony Optimization Software as a Solid Waste Management System	Floyd-Warshalls Algorithm & Ant Colony	√		√	√		The analysis presented a total distance of 15,682 m saving a total distance of 17.15 m when compared with other route options.
5	(Lyeme et al., 2016)	Tanzania	Implementation of a goal programming model for solid waste management: a case study of Dares Salaam − Tanzania	Goal program-ming		√			√	Cost minimization, minimization of final waste disposed to the landfill and environmental impact minimization.

No	Author	City	Title	Method	GIS	Cost	Optimization	Industrial	Housing	Results
6	(Shirazi et al., 2016)	Tehran	Mathematical modeling in municipal solid waste management: a case study of Tehran	Linear Mathema-tical Programming		√	√		√	Tehran has 22 municipal regions with 11 transfer stations and 10 processing units. By running the model, the transfer stations and processing units are decreased to 10 and 6 units, respectively.
7	(Bhambulkr, 2011)	India	Municipal Solid Waste Collection Routes Optimized with ArcGIS Network Analyst	ArcGIS Network Analyst	√	√			√	GIS technique, the optimum route, was identified, which found to be cost-effective and less time consuming when compared with the existing run route.
8	(Singh et al., 2015)	India	Optimization Models for Solid Waste Management in Indian Cities: A Study	MILP		√	√		√	4R principles involving reduce, reuse, recycle, and recover to minimize solid waste.
9	(Beijoco et al., 2011)	Portugal	Optimization of A Municipal Solid Waste Collection and Transportation System	GIS	√	√	√		√	-shortest traveled distance with those representing -optimized for the minimum time with those representing.

No	Author	City	Title	Method	GIS	Cost	Optimization	Industrial	Housing	Results
10	(Zam et al., 2013)	Phuents-holing	Optimization of solid waste collection and transportation route in Phuentsholing city using GIS	GIS	√	√	√		√	Collection time reduction, savings fuel consumption & minimizing operational costs of the collection vehicles
11	(Yu et al., 2015)	China	Optimization of long-term performance of municipal solid waste management system: A bi-objective mathematical model	BILP		√				Optimizes the system operating cost and environmental pollution
12	(Agha, 2006)	Gaza	Optimizing Routing of Municipal Solid Waste Collection Vehicles in Deir El-Balah − Gaza Strip	MILP		√	√		√	The model improves the collection system by reducing the total distance by 23.47%, thus saving around US$1140 per month.
13	(Ahmad, 2016)	Qatar	Sustainable Solutions for Domestic Solid Waste Management in Qatar	GIS	√	√	√		√	Waste generation and waste accumulation in a sustainable manner.
14	(Kallel et al., 2016)	Tunisia	Using GIS-Based Tools for the Optimization of Solid Waste Collection and Transport: Case Study of Sfax City, Tunisia	GIS	√	√	√		√	Terms of collection time and distance fuel consumption can be expected with savings hours of work, vehicles wear, / maintenance.

No	Author	City	Title	Method	GIS	Cost	Optimization	Industrial	Housing	Results
15	(Kinobe et al., 2015)	Kampal	Optimization of waste collection and disposal in Kampala city	GIS	√	√			√	Help KCCA to decrease costs of managing wastes and environmental as well as social impacts.
16	(Yıldız-Geyhana et al., 2017)	Turkey	Social life cycle assessment of different packaging waste collection system	Social analysis		√				Existing system and informal collection scenarios had socially fewer score than the formal scenarios in almost all impacts
17	(Ngoc et al., 2009)	Southeast Asian	Sustainable solutions for solid waste management in Southeast Asian countries	AIZES model		√		√		The utilization of renewable energy and economic aspects are considered to adapt to environmental and economic issues and the aim of ecoefficiency.
18	(Bai et al., 2002)	Singapore	The practice and challenges of solid waste management in Singapore			√		√		Solid waste incineration has been identified as the most preferred disposal method
19	(Mohamed, 2009)	Malaysia	Recycling System in Malaysia: Case studies on Industrial Waste	Japan emphasizes recovery		√		√		Create alternative resources & minimize the negative impact of waste on the environment and human health.