Assessment of waste collection systems and separate collection alternatives in Vietnam

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ABSTRACT

The volume of solid waste has been increasing in recent years with the rapid growth of economics and population in many countries all over the world. Especially, it becomes a critical issue for developing countries in solid waste management due to lack of careful management of system including collection and treatment. As one of the forward thinking municipalities in Vietnam, Da Nang city has been trying to improve the operation efficiency of waste collection and transport, and has introduced various collection systems in some parts of the city; e.g., tricycle collection, dustbin collection, and truck collection. However, the plan for waste collection and transport has been empirically designed, and the operation efficiency has not been well considered even in this motivated city. Increase in collection efficiency and introduction of separate collection are the key issues with high priority in Vietnamese MSW management under the rapid increase of MSW generation. To achieve the challenging national targets, municipalities in Vietnam need to consider the operation and factors to improve the efficiency, and design a rational plan for waste collection and transport with the support of scientific information.

Meanwhile, in City A, Japan, waste system is currently being implemented with separate collection with low frequency. To reduce resource and proper disposal, the sorting division of garbage was changed drastically in FY 1999, and four types (combustible waste, incombustible waste, bulky waste, used batteries). It was applied in the whole area. In addition, the municipality started collecting PET bottles from October 2009 and pick up of used small electronic equipment from January 2005. Also, from April 2008, a digital tachograph was installed on all collection and transport vehicles in the same area, and the work time by classification such as waste loading, running, moving etc… are sequentially recorded. These data are being used for operation management / planning etc. Therefore, in order to solve the current waste problems, primarily it is a need to create a waste arising database whether in Vietnam or Japan to provide credible information for waste managers and planners into local and region term.

In the study in Da Nang city, the authors focused on the major alternatives to waste collection and transport practices used in Da Nang city. GPS devices and a GIS software were used to survey and analyse the detailed tracking data on 3 current practices; “Door-to-door collection by tricycle and transport by truck”, “Door-to-door collection and transport by truck”, and “Fixed time dustbin collection and transport by truck”. The operation efficiency indicators, such as unit operation time, person-hours/t and operation velocity were calculated using a detailed operation category: moving forward and backward, waste collection waste, unloading and other activities. Using multi-regression analysis, the authors estimated the unit loading time and the unit waste amount for 4 types of containers, 240-L dustbin, 280-L dustbin, 660-L dustbin and Handcart. To provide the scientific base for rational planning of waste collection and transport, the authors aimed to estimate and compare the operation efficiencies of major alternatives in Da Nang city, and clarify the impacts of policy factors such as the truck capacity and the collection frequency. In addition, the authors also tried to estimate the operation efficiency of separate collection of biodegradable waste as the most likely alternative in the near future. By using the data for the 3 current practices on operation time, operation distance, and collected amount, key statistics for each parameter were calculated. And the operation efficiency indicators such as unit operation time, person-hours/t and operation velocity were calculated by the detail operation category: Moving forward and backward, waste collection, waste unloading and other activities. By using multi-regression analysis, the authors estimated the unit loading time and the unit waste amount for 4 types of containers, 240-L dustbin, 280-L dustbin, 660-L dustbin and Handcart. Models of operation parameter (moving velocity, transport velocity) were also constructed in related to area factors and characteristics as population density, road category, moving distance. Moreover, the author suggested the current problems of waste collection system in Da Nang are still remained: the mixed waste collection is implemented daily, and all the waste stream come to landfill site while landfill capacity is limited. A large quantity of recyclable waste was not recovery due to this combine collection system, and this might burden on the landfill capacity and demonstrate the inefficiency in material recovery. Besides, waste separation collection as well as impact factors have not been strongly considered in designing the system. Therefore, waste separation collection could be examined in term of collection efficiency and financial aspects in Da Nang city to solve these problems, however to reduce the cost, the impact factors by system and area characteristic should be also approached and researched.

Regarding on waste system operation analysis in a Japanese city, in terms of basic unit of collecting work time by item, the total working time per ton, total distance of collecting / transporting per 1t, collected weight per station, significant difference was found among items. According to the waste type, the total working time per 1t, which is a representative index of collection efficiency, the combustible waste was the smallest at 1.21 hours/t, equivalent to 2.42 person-hours/ton with 2 workers/truck. And the PET bottle was the longest at 10.41 hours/t. Based on the population data of the target area and the amount of collected waste, the basic unit of collected amount was determined by first 4 days in the week and 3 days in the latter half of the week. Waste amount was divided by the number of days to calculate the basic unit. Monday was 589.9 g / person / day and 608.9 g / person / day on Thursday, 551.3 g / person / day on Tuesday and 550.3 g / person / day on Friday were nearly equivalent values. The basic unit of recycled materials was 2.6 ~ 21.0 g, which was considerably smaller than 575.4 g of combustible waste. This separation waste type collection system could be a feasible solution for developing countries in term of operation efficiency and recyclable material recovery as well as aesthetic of the city by informal sector reduction.

Regarding on scenario analysis, the results were indicated that, in Hoa Cuong Nam ward in Hai Chau district, the operation efficiency of “Door-to-door collection” was 4.37 person-hours/t, which was lowest among the current 3 practices, and that of “Door-to-door collection and transport by truck” was 3.65 person-hours/t. “Fixed time dustbin collection and transport by truck” achieved the highest efficiency of 2.10 person-hours, which was less than half of “Door-to-door collection and transport by truck”. The operation efficiency would be affected by truck capacity and collection frequency. By sensitivity analysis on “Fixed time dustbin collection and transport by truck”, the best efficiency was 0.64 person-hours/t achieved at “Once per week and 9t”, and the worst efficiency was 2.52 person-hours/t at “7 times per week and 4.5t”. The variation range of operation efficiency by collection frequency from “Once per week” to “7 times per week” was 1.46 person-hours/t, while the ranges by truck capacity from “4.5t” to “9t” were from 0.42 person-hours/t to 0.63 person-hours/t. To improve the collection efficiency, the expected impact of collection frequency was larger than that of truck capacity, even in the farthest collection area. The operation efficiency of separate collection of bio-waste by plastic bag was 3.40 person-hours/t. It was better than door-to-door collection scenarios, which means it would be a feasible alternative that can replace door-to-door collection practices.

As sensitivity analysis of separate collection of bio-waste by plastic bags, the operation efficiencies by various combinations of collection frequencies of bio-waste and other waste were assessed. The best efficiency was 0.82 person-hours/t achieved at “Once per week for 2 waste categories”, and the worst efficiency was 3.40 person-hours/t at “7 times per week for 2 waste categories”. The authors found some conditions with better efficiencies than “Fixed time dustbin collection and transport by truck”, e.g., “7 times per week for bio-waste and once per week for Other waste”. The variation ranges of operation efficiency by separation rate were 2.20 person-hours/t, which was the largest range among those of influence factors considered in the sensitivity analysis. To introduce separate collection of bio-waste, it is indispensable to consider proper collection frequency. Separation rate is a critical factor on operation efficiency, and should be carefully considered for planning separate collection. Moreover, to obtain the acceptance and be further utilized in areas, waste collection system should also be proven their efficiency in term of financial performance. Therefore, the author also estimated efficiency of practices in cost/t. Interestingly; waste separate collection often has higher cost than commingle collection, however with lower frequency it would reduce expenditure significantly. By propose one scenario for separate waste type collection, the results showed this system can achieved well efficiency not only in operation but also financial aspects compare to informal sector.

Results of this dissertation suggested the methodology of waste collection survey, and identify the efficiency of each collection system clearly. Based on that, the operation efficiency of collection system among alternative countries can be compared to clarify the feasible improvement in the system. And the impact of other factors to waste collection system which were assessed by sensitivity analysis this dissertation are expected to be useful for decision-makers, authorities,

and planners of municipalities to choose, plan as well as improve waste collection system to achieve the sustainable development regarding solid waste collection and transportation.

Keyword: Waste collection and transport; Operation efficiency; GPS; GIS; Scenario estimation; Sensitivity analysis; Person-hour; Cost estimation

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ANOVA	Analysis of variance
DB	Dustbin
D-to-D	Door to Door
EU	European Union
FY	Fiscal Year
GIS	Geographic Information System
GPS	Global positioning system
HSW	Household Solid Waste
JICA	Japan International Cooperation Agency
MoNRE	Ministry of Natural Resources and Environment
MSW	Municipal solid waste
MSWM	Municipal solid waste management
PET	Polyethylene Terephthalate
SD	Standard Deviation
SE	Standard Error
SPSS	Statistical Package for the Social Sciences
SWM	Solid Waste Management
UNEP	United Nations Environment Programme
URENCO	Urban Environment Company
VND	Vietnam Dong
WC&T	Waste Collection and Transport
WHO	World Health Organization

1 INTRODUCTION

1.1 Research background

1.1.1 World trend of Municipal solid waste generation

Solid waste is becoming a serious problem in the world nowadays. Municipal solid waste (MSW) is a result of human activities (Sun et al., 2017), and the amount of MSW increases with population and economic growth (Das et al., 2014; Kumar et al., 2017; Magrinho et al., 2006). Current global MSW generation is about 1.3 billion tonnes, and is expected to reach approximately 2.2 billion tonnes in 2025 (Hoornweg et al., 2012). According to the World Bank, these figures should be considered as a waste crisis (Ahmed et al., 2006). And the increasing trend of MSW poses serious environmental and health challenges to cities worldwide (Qdais, 2007; Sankoh et al., 2013).

Waste disposal causes many problems, such as: bad odor, disease bacteria, unhealthy living conditions (El-Fadel et al., 1997). More seriously, wastes are discharged into water, soil, whether treated by burial or burning, causing severe pollution. Plastic waste in the oceans is now at an alarming level, severely affecting marine habitats: lack of oxygen, destruction of ecosystems, environmental degradation, from the sea (Eriksen et al., 2014). Oceans around the world have also become a huge landfill with nearly 6.5 million tons of waste in it (Lebreton et al., 2018)

And not only the MSW amount is increasing around the world, but also composition of solid waste are also diversified according to the rapid development of countries. In most countries in the world, organic materials and paper are the main contributors to municipal waste (Dincer, 2000; Kathiravale et al., 2003). As a country of development and people become wealthier, the consumption of inorganic materials (e.g paper, and aluminium) increases, while the organic fraction decreases. In contrast , in low-income countries, high levels of organic matter in urban waste streams range from 40 to 85% of the total (Hoornweg et al., 2012).

The generation trends of each different waste type among countries in the world are changing. And solid waste management system is needed to be adjusted and adapted with these changes in quantity, quality and composition (Manaf et al., 2009).

1.1.2 World trend of Municipal Solid Waste regulation and management

Waste reduction at source implies minimizing material and energy consumption including reduction in use of toxi/hazardous substances.

Currently, many countries have been seeking and applying effective policies to help reduce waste and consumption (Zaman et al., 2011a, 2011b). Some examples are; UNEP/UNIDO Cleaner Production approach, China's circular economy approach, Japan's sound material recycling society and 3R approach, EU's waste prevention and recycling strategy, etc.

Waste is sometimes considered as a potential source when processed into fertilizers, chemicals or energy. Some cities have set up positive examples of minimizing waste (Klass, 1998). San Francisco (USA) has an ambitious goal of "zero emissions" by 2020, and about 55% of the waste is recycled in this city (Rauch et al., 2008). Zero Waste is a philosophy that encourages the redesign of resources life cycles so that all products are reused The goal is for no trash to be sent to landfill or incinerators. France has become the first country in the world to ban supermarket food waste and require large-scale retailers to donate the amount of food left over (Mourad, 2015). Other countries such as Denmark, Germany, the United Kingdom and the United States are also participating in the zero-waste program, implementing waste prevention strategies (Lehmann, 2010). Recently, European Union countries have adopted a strategy called "European Strategy for Plastics in a Circular Economy" to guide how to make and use plastics in the future (Haas et al., 2015; Stahel, 2016). Specifically, according to a report published by the EU (European Union), recycling rates for urban waste from households and businesses would reach at least 55% by 2025, then increase to 60% by 2030 and 65.% by 2035.

From an environmental point of view, the depletion of natural resources and the lack of attention to the environment has pushed the international community in general to face a series of worrisome consequences such as drought, natural disasters tai, typhoon. The circular economy is a revolutionary concept (Tukker, 2015), that is understood through a closed production cycle where waste is returned to become a material for production, thereby reducing any negative impact on the environment, protect the ecosystem and human health and optimize the use of natural resources (Ghisellini et al., 2016). In addition, the circular economy will also help reduce carbon emissions, improve the quality of life around the world in line with the Paris Agreement (Bodansky, 2016) and the United Nations' sustainable development goals (Peters et al., 2007) which together work to keep the global temperature low enough that society can correct the inequalities that burden our world. The circular economy is an important step on the procedure to protect the green planet (Stahel, 2016). Recycling of waste will greatly contribute to the protection of natural resources, and reduce negative environmental impacts. Economists and environmentalists have started a process of making goods, using the goods and ending the process of dealing with waste. In the past, waste was the end of the process, but nowadays it is not the end, waste should be turned to to resources for others.

In addition to some regulations on the control of goods in production and use, some countries have policies towards a holistic approach for addressing marine waste issues such as Japan has issued a separate waste policy on the Promotion of Marine Waste (Shinohara, 2010), the Republic of Korea enacted the Marine Environment Management Law (Hong, 1995), which required the development of a Marine Waste Management Master Plan. Other solutions have also been implemented in some countries, such as purchasing plastic waste from fishermen (Lusher et al., 2017), or providing garbage bags and installing dumpsters for boats.

Mean whiles, for dealing with waste generation trends, developing countries still have a number of issues that need to be addressed in relation to solid waste management, such as the lack of national policies related to solid waste management, the lack of rules and regulations, and, last but not least, of policies related to preserving or creating a 'circular economy' (Choi et al., 2011; Demirbas, 2009).

1.1.3 Overview of waste collection in developed countries and Japan

Solid waste management refers to the handling of waste material from generation at the source through the recovery processes to disposal (Pappu et al., 2007).. ~~Solid waste management consists of waste generation, collection, treatment and disposal (Sharholy et al., 2008)~~, in which waste collection is an important component, because waste collection and transport accounted for 30-70 % of total system cost (Doğan et al., 2003; Ghose et al., 2006; Hoornweg et al., 2012). It also offers solutions for recycling items that do not belong to garbage or trash (Ebreo et al., 1999). And waste collection system is also different among countries in the world in diverse aspects. Solid waste can be separately collected by some categories such as bio-waste for biological treatment and recyclables for resource recovery, depending on local regulations.

In developed countries, solid waste is often collected with separation (Tai et al., 2011; Zhuang et al., 2008). The degree of source separation affects the total amount and the quality of recovered materials by recycling process. Recyclables recovered from mixed waste tend to be contaminated, reducing the market value and possibilities. For example, in EU, to reduce the environmental and health impacts of waste and improve, generators are required to separate their waste at source, e.g., into “wet” (food waste, organic matter) and “dry” (recyclables), and other waste (Hoornweg et al., 2012). In many EU countries, residents recycle wastes at home by different waste bins. On average, 19 % of generated municipal waste is collected separately, in which 36 % of the paper, around 44 % of glass is recycled c through the use of a separate collection system (Seyring et al., 2015).

At the meantime, in some countries, organic waste is segregated for collection (David, 2013; Seyring et al., 2015). Organic waste can be included for composting, too, such as cut flowers, corks, coffee grindings, rotting fruit, tea bags, egg- and nutshells, paper towels etc. These organic fractions of waste when buried in the landfill site could increase amount of greenhouse gas release to environment (Rezaee, 2014). The separate collection of bio-waste is also a precondition for reutilizing of organic matter and nutrients (Schüch et al., 2016). Moreover, the environmental impact can also be significantly reduced by the separate collection and recycling use of organic waste (Canter et al., 1996).

In Japan, waste generation has been increasing rapidly. And to promote the formation of a recycling-oriented society, the Ministry of the Environment of Japan has set policy targets such as improvement of recycling rate and reduction of final disposal site, and promote municipalities to separate waste collection (Ministry of Environment, 2014).

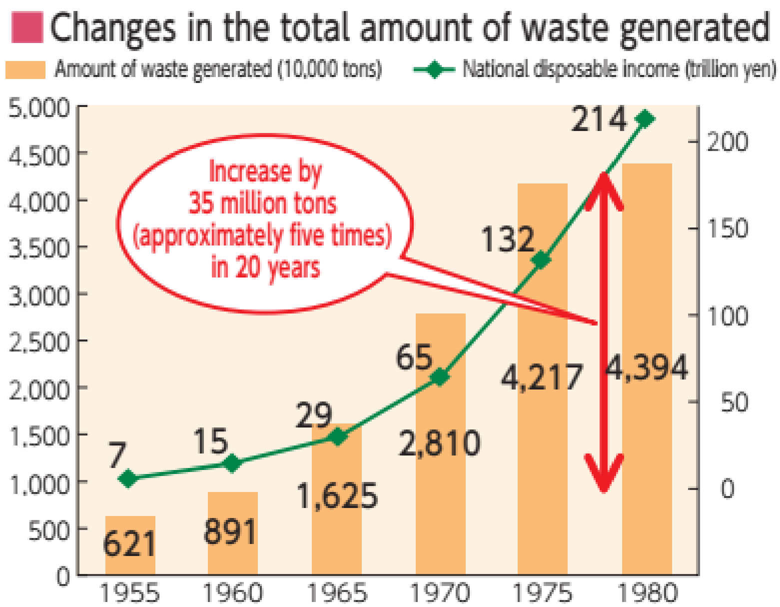


Figure 1-1 Waste generation trend in Japan Ministry of Environment, 2014 (Ministry of Environment, 2014)

Waste collection system in Japan is performed with separate collection for different type of wastes. Waste is often categorized into 4 types including combustible, incombustible, bulky waste, bottle and can. Garbage collection dates, collection areas, and collection rules differ depending on the area. Every city, town and county has a different system. Number of separation categories in some municipalities in Japan in FY2015 was up to 26 categories or more (Yolin, 2015). The PET bottles is collected with approximately 100%, and nearly 99% for glass waste. Containers and wrapping waste account for about 60% of this waste by volume and collected by 35.4 % (Kubo et al., 2014; Okuwaki, 2004).

Also, in order to collect waste in far and low population density areas, it is expected that collection area will be widened. But at the same time, concerning on this issue, the transportation distance will be increased, and imply the cost increases. Therefore, increasing waste collection efficiency, maximizing waste value and minimizing system cost are essential to achieve significant waste management improvements.

1.1.4 Overview of waste collection in developing countries and Vietnam

In developing countries, there are very few waste separate collection system. Recycle materials are not sorted, and dump in landfill site (D. C. Wilson et al., 2006). The recycle materials are only collected at generation source and separate at some treatment facilites or at landfill site (Sasikumar et al., 2009).

Regarding on waste collection method, door to door collection is usually implemeted (Abarca-Guerrero et al., 2015; N. Thanh et al., 2009), and this door to door collection process can be implemented by manual or mechanism. Regarding manual collection, the worker moved from house to house in collection area to pick up waste. After each collection trip, the collector releases the waste at some discharge point or transfer station. The popular method to investigate tricycle waste collector is questionnaire and estimate without exact figures (Issahaku et al., 2014)**.** Another common collection method in developing countries is truck collection. The truck with two to three crew members go around collection point and upload solid waste in dustbins into trucks (Ghose et al., 2006), then carry and unload waste at disposal site.

Particularly, MSW is not separated when collected, but recyclables are removed by waste pickers (informal sector) during the collection process, and at disposal sites (Hoornweg et al., 2012). This informal sector plays an important role in municipal solid waste system in many cities of the developing countries (D. C. Wilson et al., 2006). The informal recovery of recyclables from the solid waste system reduces overall solid waste management costs for municipalities (D. C. Wilson et al., 2009). Waste pickers, or scavengers collect and sell recyclable materials, bottles, waste papers, plastic bottles to private treatment facilities (Shahmoradi, 2013). Organizing the informal sector and promoting micro-enterprises were mentioned by Sharholy et al. (2008) as effective ways of waste management procedure (Abarca-Guerrero et al., 2015).

Besides, optimization of solid waste collection is also important where significant amount of the time is spent for loading and unloading as well as driving (Apaydin et al., 2007; Malakahmad et al., 2014) . However, in developing countries, optimizing of collection services is still depending on the experiences and knowledge of local conditions and the collection teams (Talebbeydokhti et al., 2013). Careful planning for waste collection and allocation of facilities are indispensable to achieve a well operation system and high collection efficiency. Recyclable waste separation not only enhances the reuse of materials, but also reduces the volume of waste come to landfill or incineration. Many studies indicated that source segregation and separate collection are vital requirement for sustainable recycling (Agarwal et al., 2015; Premakumara et al., 2011). With waste streams comprised high fraction of organic matter in developing countries, bio-waste separation collection should be considered in many parts of the world (especially in the tourist and agricultural sectors) as a method to reduce waste destined for the landfill and in the circumstance which incineration for energy recovery can be a costly capital investment for most communities in the developing world (Troschinetz et al., 2009) .

Vietnam is the country in the process of industrialization and modernization of the country, in recent years economic growth rate in all sectors reached a high level (DO-PHAM et al., 2004). Along with the economic growth, the population has grown rapidly, the development of new centres, the consumption of goods, materials and energy is increasing, and consequently the volume of solid waste has been increasing. The amount of domestic waste generated from urban areas in Vietnam was 17,682 tons/d in 2007 and 26,224 tons/d in 2010. This represents an average increase of 10% per year during the period of 2007 to 2010. The amount continued to increase to about 32,000 tons/d in 2014, which means an average yearly increase of 12% during the period of 2010 to 2014 (MONRE, 2015).

Regarding waste collection, the average collection rate in Vietnamese urban areas in 2014 was reported to be 85% (MONRE, 2015). In the “National strategy on integrated management of solid waste to 2025, vision to 2050” issued in 2009 (Vietnam Government, 2009), the Vietnamese government describes the national target of collection rate as 90% of the total MSW generated in 2020, and 100% in 2025. The strategy also indicates the national target for recovery rate including recycled, reused, composted, and energy recovered as 60% of MSW generated in 2020, and more than 85% in 2025. In a related move, the Vietnamese government also issued a decree on waste management and discarded materials in 2015 (Viet Nam, 2007), which prescribes the classification of daily-life solid waste into 3 groups, “Biodegradable organic group”, “Reusable and recycled group” and “the other group”, instead of 2 groups (including “reuse and recycle group” and “buried group”) as stated in the former decree in 2007 (Viet Nam, 2015).

Waste collection and transport in Vietnam has been generally served daily without separation. The conventional style is the combination of manual door-to-door collection by handcarts, 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 site (Organisation, 2007; N. Thanh et al., 2009; N. P. Thanh et al., 2011). But, the man-powered collection is slow-moving and consequently labour-intensive.

In Vietnam, there were some pilot projects for bio-waste separation, for example 3R Project of JICA in Hanoi for waste separation (JICA REPORT, 2012), but the collection is done by manual collection, not by vehicles. And the lack of organization and management of Urban Environment Company as well as awareness of residents have led to a small amount of separated waste be collected, besides there was lack of monitoring staff and proper collection facilities (JICA, 2013) . Obviously, it is not sustainable to implement MSW collection and transport by manual collection considering the future rise of labour cost. And recyclable materials in Vietnam are collected by informal sector and activities of individual persons for economic purpose, and there is no official separate collection for recyclables in Vietnam.

Increase in collection efficiency and introduction of separate collection are the key issues with high priority in Vietnamese MSW management under the rapid increase of MSW generation. To achieve the challenging national targets, municipalities in Vietnam need to consider the methods and factors to improve the operation efficiency, and design a rational plan for waste collection and transport with the support of scientific information.

Lessons from experiences in developed countries can be learned for developing countries to improve existing Municipal Solid Waste Management (MSWM) systems, because it can be said that developed countries have already experienced in periods which are similar to those in developing countries at present (D. C. Wilson, 2007).

1.1.5 GPS/GIS application in Municipal Solid Waste management

Monitoring and evaluation can also help planners adjust system to be better efficiency (Zall Kusek et al., 2004). Monitoring is an important issue because waste collection accounts for a major part of solid waste system due to big cost for waste collection and transportation (Tavares et al., 2009). Monitoring and careful planning activities seem to be neglected by most municipal managers responsible for waste collection (Lohri et al., 2014; Longe et al., 2006). Particularly, planning a waste collection and transport system is often designed by personal experience, especially in developing countries. And there are very few studies on operation parameters for waste collection and transport system, especially on separate collection due to lack of reliable data. Whereas, in developed countries, some researches mainly focused on financial aspects of waste collection system (D'Onza et al., 2016; Greco et al., 2017). But no detail operation information were indicated in these studies , and the information on cost was not comparable among studies due to the different labor cost among countries .

To collect the data on waste collection and transport process, some studies applied GPS (Global Positioning System) devices to get the tracking data on vehicles from satellite, and also analyzed the data by GIS (Geographic Information System) software (Kallel et al., 2016; Yadav, 2013). GPS devices were applied to collect data based on global positioning system for travel time and distance (Pan et al., 2008).

In addition, a function of optimization served by GIS software was also applied to minimize the fuel consumption, travel distance and time (Chalkias et al., 2009b; Tavares et al., 2009). Tavares et al. (2009) also applied GIS to optimize waste collection and transportation route for minimum fuel consumption, and reported that the collection distance was also estimated to reduce 46% as well as 86% expenditure of collection cost in their study in Singanallurm India. Matsui (Thanh et al., 2009, 2011; Matsui et al., 2005, 2008, 2009, 2012) had done various researches which appliel GPS and GIS software for waste collection and transport in Japan and Vietnam, and it showed that the applications of GPS devices and a

GIS software enabled the detailed analysis and modelling of operation time and distance of waste collection and transport.

1.1.6 Influence factors and modelling on waste collection system

In previous studies, many factors were reported to affect waste collection system such as area factors like waste generation rate, population density, and road characteristics, and decision factors like collection frequency, truck capacity, location and allocation of waste bins, and transport distance (Dahlén, 2008; McAllister, 2015; Olukanni et al., 2016).

Waste generation rate and collection frequency decide the collection amount of collection day. Higher generation rate and lower collection frequency lead to larger collection amount of collection day, which means that per area collection amount and per distance collection amount become larger. Higher population density also means larger per area collection amount and per distance collection amount. For waste collection planning, the data need to be collected on collection area is waste amount information (Beliën et al., 2011; Hoornweg et al., 2012). Collection frequency is one critical decision factor need to be highly considered when designing the collection system. Climatic conditions and requirements of a locality as well as containers and costs affect the collection frequency. And, as residential wastes usually contain food wastes and other putrescible (rotting) material, frequent collection is desirable for health and aesthetic reasons. In hot and humid climates, for example, solid wastes must be collected at least twice a week, as the decomposing solid wastes produce bad odour and leachate (NPTEL). Besides climates, the quality of solid waste on site also determines the collection frequency. The collection frequency varies among the cities, but it is mainly twice a week for most fractions. Bio-waste collection tends to be more frequent, presumably due to the nature of this fraction, while many cities apply more frequent collection during the warmer period of the year (Dri M., Canfora P., Antonopoulos I. S., Gaudillat P. , 2018).

Truck capacity is another critical decision factor for collection system planning. Bigger trucks have worse gas milage than smaller trucks on the one hand, but bigger trucks can carry more amount of waste and consequently reduce the number of needed trips and transport distance compare to smaller trucks on the other hand (Nguyen et al., 2010).

Currently, some studies constructed models for operation parameters in waste collection system. Aremu created a trip time model with average value of system parameters (Aremu et al., 2011). Similarly, in study of APAYDIN and GONULLU (Apaydin et al., 2011), a model was built to estimate total route time based on average value of components such as: distance between stop, number of stop, number of stop sign. In other studies, there were many components of collection system were assumed with the constant values, such as hauling speed (40km/h) (Sonesson, 2000) or 20 km/h for inner and 30 km/h for suburban areas (Malakahmad et al., 2014). In fact, these parameters might be varied highly and depend on many other factors such as: road network, population density, house density. Therefore, applying average value of data in model to estimate parameter in waste collection system is not appropriate, especially in high variation characteristic areas.

However, very few studies have conducted this modelling in consideration with the regional characteristics to estimate the variation of parameters in the system. It was mentioned that model should be constructed based on a big amount of data and further could apply directly for most waste collection cases (Sonesson, 2000). And it requires to collect the detail data in each components of waste collection process (Chalkias et al., 2009a). To estimate the operation efficiency of waste collection system in given target area, it is indispensable to clarify the relationships between operation parameters and influence factors, and to model operation parameters in consideration of factors.

1.1.7 Estimation by scenario analysis

An attempt was made to find alternative systems appropriate to the present situations for collection improvement. An economic costing procedure was used to find the least-cost option, and comparison between the proposed and existing systems were studied on the basis of cost—benefit analysis (Tin et al., 1995).

Due to the multiform and combination of various collection methods, how much effectiveness of each operating system is a difficult question for planners. Accordingly, in order to make suitable decision, scenarios establishment for further estimation is an significant approach for decision makers. Using assessments of scenarios can help evaluate and compare between alternative options, the difference in finance and technology elements (Zurbrügg et al., 2014). Two scenarios were constructed and compared in study of Chalkias (2009) in one city in Greece. The results pointed out that route optimization can save 3% of collection time and 5.5% distance, whereas reallocation and route optimization of dustbins, the time can be reduced 17% and 12.5% of distance reduction. However, the impact of other factors on efficiency such as collection frequency and truck capacity well as transport distance has not been researched.

Moreover, to obtain the acceptance and be further utilized in areas, waste collection system should also be proven their efficiency in term of financial performance (Zsigraiova et al., 2013). Among combined collection and separate collection system, the degree of source separation impacts the total amount of material recycled and the quality of secondary materials that can be supplied. Recyclables recovered from mixed waste, for example, tend to be contaminated, reducing marketing possibilities (Hoornweg et al., 2012). However, source separation and separate collection can add costs to the waste collection process. The waste collection cost in developing countries is ranged from 30-70 US dollars/ton

In fact, there are few studies related to financial estimation of collection and transport systems in developing countries. Besides, to assess a system, a comprehensive evaluation must consider all direct and indirect impacts such as acceptable cost, balancing environmental, economic, technical (Allesch et al., 2014). Therefore, construct scenarios to assess various collection methods in areas in term of financial aspects as well as collection efficiency is a necessary procedure for waste collection system assessment.

1.2 Objective of this study

In this study, the author focused on the major alternatives of waste collection and transport used in Da Nang City and City A, and intended to compare the operation efficiencies of them. As the representative indices of operation efficiency, this study calculated person-hours/ton, operation velocity (km/h), and collection distance per waste amount (km/ton). So, in Da Nang city, the author collected data on operation time, operation distance, and collected waste amount by 3 surveys: video recording for operation time, using GPS devices and a GIS software for operation distance, and measurement by a weighbridge at the entrance of the landfill site and a 1-ton digital scale for collected waste amount. To provide the scientific base for rational planning of waste collection and transport, the authors aimed to models of operation parameters (preparation time, loading time, moving velocity) related to area factors and characteristics as population density, road width, road material. Besides, author also concerned about impacts of policy factors such as the truck capacity and the collection frequency. Lastly, author also tried to clarify the current problems of waste collection system in Da Nang city such as low operation efficiency, low recyclable material recovery, and informal sector in waste collection.

Mean while, in City A where data on actual process on collection and transportation is being developed, author also collects basic data that contributes to the design of efficient collection and transportation system. Specifically, data on waste collection system were accumulated and analyzed by using the digital tachograph and GIS (geographic information system) software. From these data, author clarified the relation between working time, working distance, collection efficiency of waste collection and transport and regional factors. And this separation waste type collection system could be a feasible solution for Da Nang city in term of operation efficiency and recyclable material recovery as well as growth restriction of informal sector.

The author intended to estimate the operation efficiencies of waste collection and transport scenario which are simulated from Vietnam and Japan system. The data for scenarios was achieved from previous sectors. And author also clarified the impacts of policy factors such as truck capacity and collection frequency. Moreover, the operation efficiency in unit person-hour/ton for each practice was also estimated. In addition, the author also tried to estimate the operation efficiency of separate collection of bio-waste as well as different waste types collection as the most likely alternatives in the near future. Futhermore, the results showed that with low collection frequency, waste separation collection could increase the collection efficiency as well as reduce the financial burdens.

To sum up, this study aimed to clarify the impacts of policy factors such as the truck capacity and the collection frequency on operation efficiency among cities with different status. In addition, the author also tried to estimate the operation efficiency and cost estimation of separate collection as the most likely alternative in the near future.

The objectives of this study can be summarized as following:

- Accumulate operational data by GPS and GIS application on representative systems of MSW collection and transport in Vietnam and Japan
- Understand the influence factors of operation parameters and efficiency
- As generalization of MSW collection and transport, develop estimation models of operation parameters considering the influence factors
- By scenario analysis, clarify the operational efficiency and feasibility of major alternatives of MSW collection and transport, including the comparison with recycling by informal sectors
- Understand the impact of decision factors such as collection system, collection frequency, capacity of truck, separation rates of recyclables, etc.
- Understand the uncertainty of the parameters obtained in this thesis and used in the scenario analysis

This study focuses only on different waste collection systems of household solid waste in Da Nang city, Vietnam and City A, Japan.

1.3 Outline of this dissertation

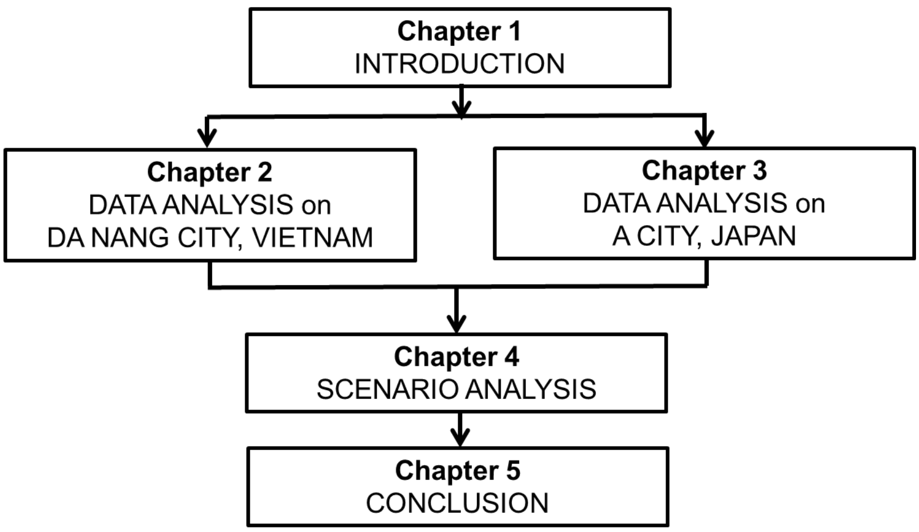


Figure 1-2 Outline of dissertation

This dissertation consists of 5 section, the contents of each section are shown as follows:

Section 1 introduces the research background, overview of solid waste collection in developed countries and developing countries, particularly in Da Nang city, Vietnam and City A, Japan. The research framework was shown in this section Author also reviewed all the materials concerning with the topic of this dissertation. First of all, the information on solid waste amount and solid waste collection was reviewed. Then applying GPS/GIS in waste system, the operation on waste collection in other researches were also synthesized and compared among systems in different countries. The information on various factors which affect collection system e.g collection frequency, truck capacity was also reviewed. Lastly, scenario analysis from other studies was referred to understand the current status in research as well as the novelty of this study. Then the research area, and the scope as well as objectives of the study were drawn. The outline of whole study was also presented in this section.

Section 2 described the methodology in this, an overview of the research areas and the major alternatives to waste collection and transport practices used in Da Nang city. GPS devices and a GIS software were used to survey and analysed the detailed tracking data on 3 current practices; “Door-to-door collection by tricycle and transport by truck”, “Door-to-door collection and transport by truck”, and “Fixed time dustbin collection and transport by truck”. The operation efficiency indicators, such as unit operation time, person-hours/t and operation velocity were calculated using a detailed operation category: moving forward and backward, waste collection waste, unloading and other activities. To provide the scientific base for rational planning of waste collection and transport, the authors aimed to models of operation parameters (e.g moving velocity, transport velocity) related to area characteristics as population density, moving distance, road category. Lastly, author also tried to clarify the current problems of waste collection system in Da Nang city such as low operation efficiency, low recyclable waste recovery, informal sector.

In Section 3, the author collected basic data that contributes to the design of efficient collection and transportation system, and collect the actual work in a Japanese City where data on collection and transportation is being developed.

Specifically, basic data on waste collection and transportation was accumulated and analysed using the digital tachograph and GIS (geographic information system) software. From these data, author clarified the relation between working time, distance, work efficiency and regional factors of waste collection and transport. And this separation waste type collection system could be a feasible solution for developing countries in term of operation efficiency and recyclable material recovery as well as growth restriction of informal sector.

In Section 4, the authors intended to estimate the operation efficiencies of waste collection and transport scenario which are simulated from Vietnam and Japan system. The data for scenarios was synthesized from previous sectors. And author also clarified the impacts of policy factors such as truck capacity and collection frequency. Moreover, the operation efficiency in unit person-hour/ton for each practice was also estimated. In addition, the author also tried to estimate the operation efficiency of separate collection of bio-waste as well as different waste types collection as the most likely alternatives in the near future.. The results showed that with low collection frequency, waste separation collection could increase the collection efficiency as well as reduce the financial burdens.

Finally, section 5 summarizes the main conclusions of the dissertation and shows the reasonable suggestions for improving and managing solid waste collection and transport system. Additionally, recommendations for future research and the possible development are represented

1.4 Research framework

The entire schematic framework was illustrated as in Table 1.1, including various data sources by different approaches among countries. The target objects were waste collection trucks in Da Nang City and City A, and the data collection process was conducted as follow: video recording, GPS tracking data, social and demographic data, or tachometer. Then author categorized the collected tracking data of collection waste vehicle according to categories: moving forward/backward, collection, unloading, others. The modeling was achieved from regression analysis and concern with impact factors such as demographic data, area characteristics. Finally, the scenarios was constructed for an area in Da Nang city based on all above data and combination between Japan and Da Nang data to find out the most effective operation scenario and feasible alternative scenario for waste separation collection.

Table 1.1 Research framework

Target area	**Waste collection system in Da Nang city (combined collection)** - Tricycle DtD collection and Truck Transport - Compactor DtD collection and Transport - Forklift Truck Dustbin collection and Transport **Waste collection system in Japan (separate collection)** - Station collection by Truck by the following separation - Combustible waste - Recyclables: Can, Bottle, PET, plastics, papers…
Data collection methods	Video recording GPS logger GIS Software GIS database (Demographic and Socio-economic variables) Waste amount data Digital Tachometer GIS software
Data analysis	Operation indicator in Vietnam - Transport forward and backward: distance, time, velocity - Collection: preparation time, loading time, collection distance, moving velocity - Unloading time - Other time Operation indicator in Japan - Transport forward, backward: distance, time, velocity - Collection: moving velocity, loading time, collection distance, velocity - Unloading time - Other time
Modeling	Modelling waste collection parameter by influence factors Velocity: Transport, moving for collection Loading time Waste amount per container Modelling waste collection parameter by influence factors Loading time by each different recyclable waste type Moving collection velocity
Scenario estimation in Vietnam city	Scenario construction Current 3 practices in Da Nang city Bio-waste separation scenario Recyclable separation scenarios Scenario estimation Estimation by person-hour/ton Sensitivity analysis of political parameters Uncertainty analysis of operation parameters Estimation on cost and expected revenue from recyclables
Output of this study	- **Suggest methodology for waste collection and transport system analysis** - **Modelling waste collection parameters by influence factors** - **Clarify the operation efficiency of current practices in Da Nang city** - **Estimate the operation efficiency and feasibility of separate collection** - **Indicate the impact of political parameters on operation efficiency** - **Examine the reliability of operation parameters**

Reference for section 1

Abarca-Guerrero, L., Maas, G., & Hogland, W. (2015). Solid waste management challenges for cities in developing countries. Revista Tecnología en Marcha, 28(2), 141-168.

Abdulai, H., Hussein, R., Bevilacqua, E., & Storrings, M. (2015). GIS Based Mapping and Analysis of Municipal Solid Waste Collection System in Wa, Ghana. Journal of Geographic Information System, 7(02), 85.

Agarwal, R., Chaudhary, M., & Singh, J. (2015). Waste Management Initiatives in India for human well being. European Scientific Journal, ESJ, 11(10).

Ahmed, S. A., & Ali, S. M. (2006). People as partners: Facilitating people's participation in public–private partnerships for solid waste management. Habitat International, 30(4), 781-796.

Allesch, A., & Brunner, P. H. (2014). Assessment methods for solid waste management: A literature review. Waste Management & Research, 32(6), 461-473.

Apaydin, O., & Gonullu, M. (2007). Route optimization for solid waste collection: Trabzon (Turkey) case study. Global NEST Journal, 9(1), 6-11.

Apaydin, O., & Gonullu, M. (2011). Route time estimation of solid waste collection vehicles based on population density. Global NEST Journal, 13(2), 162-169.

Aremu, A. S., Mihelcic, J. R., & Fatai Sule, B. (2011). Trip time model for municipal solid waste collection applicable to developing countries. Environmental technology, 32(15), 1749-1754.

Beliën, J., De Boeck, L., & Van Ackere, J. (2011). Municipal Solid Waste Collection Problems: A Literature Review.

Bhambulkar, A. V. (2011). Municipal solid waste collection routes optimized with arc gis network analyst. International Journal Of Advanced Engineering Sciences And Technologies Vol(11), 202-207.

Bodansky, D. (2016). The legal character of the Paris Agreement. Review of European, Comparative & International Environmental Law, 25(2), 142-150.

Canter, L. W., Canter, L. W., Canter, L. W., & Canter, L. W. (1996). Environmental impact assessment.

Chalkias, C., & Lasaridi, K. (2009a). A GIS based model for the optimisation of municipal solid waste collection: The case study of Nikea, Athens, Greece. technology, 1, 11-15.

Chalkias, C., & Lasaridi, K. (2009b). Optimizing municipal solid waste collection using GIS. Paper presented at the 5th International Conference on Energy, Environment, Ecosystems and Sustainable Development/2nd International Conference on Landscape Architecture, Greece. In: Proceedings of Energy, Environment, Ecosystems, Development and, Landscape Architecture.

Choi, H. C., & Turk, E. S. (2011). Sustainability indicators for managing community tourism Quality-of-life community indicators for parks, recreation and tourism management (pp. 115-140): Springer.

D'Onza, G., Greco, G., & Allegrini, M. (2016). Full cost accounting in the analysis of separated waste collection efficiency: A methodological proposal. Journal of Environmental Management, 167, 59-65.

Dahlén, L. (2008). Household waste collection: factors and variations. Luleå tekniska universitet.

David, A. (2013). Technical document on municipal solid waste organics processing: Environment Canada= Environnement Canada.

Demirbas, A. (2009). Political, economic and environmental impacts of biofuels: A review. Applied energy, 86, S108-S117.

Dincer, I. (2000). Renewable energy and sustainable development: a crucial review. Renewable and sustainable energy reviews, 4(2), 157-175.

DO-PHAM, C., & Tran-Nam, B. (2004). The Vietnamese economy: Awakening the dormant dragon: Routledge.

Doğan, K., & Süleyman, S. (2003). Report: Cost and financing of municipal solid waste collection services in Istanbul. Waste Management & Research, 21(5), 480-485.

Ebreo, A., Hershey, J., & Vining, J. (1999). Reducing solid waste: Linking recycling to environmentally responsible consumerism. Environment and Behavior, 31(1), 107-135.

El-Fadel, M., Findikakis, A. N., & Leckie, J. O. (1997). Environmental impacts of solid waste landfilling. Journal of Environmental Management, 50(1), 1-25.

Eriksen, M., Lebreton, L. C., Carson, H. S., Thiel, M., Moore, C. J., Borerro, J. C., . . . Reisser, J. (2014). Plastic pollution in the world's oceans: more than 5 trillion plastic pieces weighing over 250,000 tons afloat at sea. PloS one, 9(12), e111913.

Ghisellini, P., Cialani, C., & Ulgiati, S. (2016). A review on circular economy: the expected transition to a balanced interplay of environmental and economic systems. Journal of Cleaner Production, 114, 11-32.

Ghose, M., Dikshit, A. K., & Sharma, S. (2006). A GIS based transportation model for solid waste disposal–A case study on Asansol municipality. Waste management, 26(11), 1287-1293.

Greco, G., Cenciarelli, V. G., & Allegrini, M. (2017). Tourism's impacts on the costs of municipal solid waste collection: Evidence from Italy. Journal of Cleaner Production.

Haas, W., Krausmann, F., Wiedenhofer, D., & Heinz, M. (2015). How circular is the global economy?: An assessment of material flows, waste production, and recycling in the European Union and the world in 2005. Journal of Industrial Ecology, 19(5), 765-777.

Hong, S.-Y. (1995). Marine policy in the Republic of Korea. Marine Policy, 19(2), 97-113.

Hoornweg, D., & Bhada-Tata, P. (2012). What a waste: a global review of solid waste management.

Issahaku, I., Nyame, F. K., & Brimah, A. K. (2014). Waste Management Strategies in an Urban Setting Example from the Tamale Metropolis, Ghana. Journal of Waste Management, 2014.

JICA (2013). Ex-Post Project Evaluation 2012: Package III-9 (Vietnam) http://open_jicareport.jica.go.jp/pdf/1000015555.pdf

Kallel, A., Serbaji, M. M., & Zairi, M. (2016). Using GIS-Based Tools for the Optimization of Solid Waste Collection and Transport: Case Study of Sfax City, Tunisia. Journal of Engineering, 2016.

Karadimas, N. V., & Loumos, V. G. (2008). GIS-based modelling for the estimation of municipal solid waste generation and collection. Waste Management & Research, 26(4), 337-346.

Kathiravale, S., Yunus, M. N. M., Sopian, K., Samsuddin, A., & Rahman, R. (2003). Modeling the heating value of Municipal Solid Waste☆. Fuel, 82(9), 1119-1125.

Klass, D. L. (1998). Biomass for renewable energy, fuels, and chemicals: Elsevier.

Kubo, K., & Leader, P. T. (2014). Recycling in Japan. Application of Reclaimed Asphalt Pavement and Recycled Asphalt Shingles in Hot-Mix Asphalt, Vols. TR Circular E-C188, 60-66.

Lebreton, L., Slat, B., Ferrari, F., Sainte-Rose, B., Aitken, J., Marthouse, R., . . . Levivier, A. (2018). Evidence that the Great Pacific Garbage Patch is rapidly accumulating plastic. Scientific reports, 8(1), 4666.

Lehmann, S. (2010). Resource recovery and materials flow in the city: Zero waste and sustainable consumption as paradigms in urban development. Sustainable Dev. L. & Pol'y, 11, 28.

Lohri, C. R., Camenzind, E. J., & Zurbrügg, C. (2014). Financial sustainability in municipal solid waste management–Costs and revenues in Bahir Dar, Ethiopia. Waste management, 34(2), 542-552.

Longe, E., & Williams, A. (2006). A preliminary study of medical waste management in Lagos metropolis, Nigeria. Iran J Environ Health Sci Eng, 3(2), 133-139.

Lusher, A., Hollman, P., & Mendoza-Hill, J. (2017). Microplastics in fisheries and aquaculture. Status of knowledge on their occurrence and implications for aquatic organisms and food safety. FAO Fisheries and Aquaculture Technical Paper, 615.

Malakahmad, A., Bakri, P. M., Mokhtar, M. R. M., & Khalil, N. (2014). Solid waste collection routes optimization via GIS techniques in Ipoh city, Malaysia. Procedia Engineering, 77, 20-27.

Matsui, Y. & Yasue, T (2008). Uncertainty analysis on estimation models for cost and environmental loads on waste collection and transport. Proceedings of the 19th conference of annual conference of Japan Society of Material Cycles and Waste Management,185-187. (in Japanese)

Matsui, Y., Anh, T. T. Y., Trang, D. T. T., Thanh, N. P., Nu, P. T. & Vi, L. T. T. (2012). Comparison of operational efficiency among waste collection systems in Da Nang city, Vietnam. Proceedings of the 7th asian pacific landfill symposium (APLAS): Sustainable Solid Waste Management for a Better Life, P36_84-89.

Matsui, Y., Osako, M., Moriguchi, Y., Takahashi, K., Saito, S. & Kurihara, K. (2004). A study on cost and environmental loads of separate collection and transport of containers and packaging. Proceedings of the 25th conference of Japan Waste Management Association, 4-6. (in Japanese)

Matsui, Y., Tanaka, M., Tsukuni, Y. & Tekeuchi, C. (2005). Estimation on cost and environmental loads of separate collection and transport of containers and packaging in consideration of area characteristics. Proceedings of the 26th conference of Japan Waste Management Association, 106-108. (in Japanese)

Matsui, Y., Trang, D. T. T., Muroyama, K. & Aihara, K. (2012) Scenario analysis on separate collection of food waste from business sectors and kitchen waste from households. Proceedings of the 33rd conference of Japan Waste Management Association. (in Japanese)

Matsui, Y., Yasue, T., Lu L. & Tanaka, M. (2009). Development of Predictive Models for Cost and CO2 emission on Segregate Collection System. Proceedings of Waste and Climate Conference.

Ministry of Natural Resources and Environment (MONRE) (2015). National environment report 2011-2015. (in Vietnamese).

McAllister, J. (2015). Factors influencing solid-waste management in the developing world.

Mourad, M. (2015). France moves toward a national policy against food waste. Natural Resources Defense Council.

Nguyen, T. T., & Wilson, B. G. (2010). Fuel consumption estimation for kerbside municipal solid waste (MSW) collection activities. Waste Management & Research, 28(4), 289-297.

NPTEL. Unit3: Waste collection, Storage and Transport. https://nptel.ac.in/courses/120108005/module3/lecture3.pdf

Okuwaki, A. (2004). Feedstock recycling of plastics in Japan. Polymer Degradation and Stability, 85(3), 981-988.

Olukanni, D., Adeleke, J., & Aremu, D. (2016). A Review of Local Factors affecting Solid Waste Collection in Nigeria. Pollution, 2(3), 339-356.

Organisation, A. P. (2007). Solid waste management, issues and challenges in Asia. AP Organisation, Tokyo Google Scholar.

Pan, C., Lu, J., Wang, D., & Ran, B. (2008). Data collection based on global positioning system for travel time and delay for arterial roadway network. Transportation Research Record: Journal of the Transportation Research Board(2024), 35-43.

Pappu, A., Saxena, M., & Asolekar, S. R. (2007). Solid wastes generation in India and their recycling potential in building materials. Building and environment, 42(6), 2311-2320.

Peters, G. P., Weber, C. L., Guan, D., & Hubacek, K. (2007). China's growing CO2 emissions a race between increasing consumption and efficiency gains: ACS Publications.

Premakumara, D., Abe, M., & Maeda, T. (2011). Reducing municipal waste through promoting integrated sustainable waste management (ISWM) practices in Surabaya city, Indonesia. WIT Transactions on Ecology and the Environment, 144, 457-468.

Qdais, H. A. (2007). Techno-economic assessment of municipal solid waste management in Jordan. Waste management, 27(11), 1666-1672.

Rauch, J. N., & Newman, J. (2008). Research and solutions: zeroing in on sustainability. Sustainability: The Journal of Record, 1(6), 387-390.

Rezaee, R. (2014). Estimation of gas emission released from a municipal solid waste landfill site through a modeling approach: A case study, Sanandaj, Iran. Journal of Advances in Environmental Health Research, 2(1).

Sankoh, F. P., Yan, X., & Tran, Q. (2013). Environmental and health impact of solid waste disposal in developing cities: A case study of granville brook dumpsite, Freetown, Sierra Leone. Journal of Environmental Protection, 4(07), 665.

Sasikumar, K., & Krishna, S. G. (2009). Solid waste management: PHI Learning Pvt. Ltd.

Schüch, A., Morscheck, G., Lemke, A., & Nelles, M. (2016). Bio-waste recycling in Germany–further challenges. Procedia Environmental Sciences, 35, 308-318.

Seyring, N., Dollhofer, M., Weißenbacher, J., Herzog, M., McKinnon, D., & Bakas, I. (2015). Assessment of separate collection schemes in the 28 capitals of the EU. Final report, Nov.

Shahmoradi, B. (2013). Collection of municipal solid waste in developing countries: Taylor & Francis.

Sharholy, M., Ahmad, K., Mahmood, G., & Trivedi, R. (2008). Municipal solid waste management in Indian cities–A review. Waste management, 28(2), 459-467.

Shinohara, M. (2010). Maritime cluster of Japan: implications for the cluster formation policies. Marit. Pol. Mgmt., 37(4), 377-399.

Sonesson, U. (2000). Modelling of waste collection–a general approach to calculate fuel consumption and time. Waste Management and Research, 18(2), 115-123.

Stahel, W. R. (2016). The circular economy. Nature News, 531(7595), 435.

Tai, J., Zhang, W., Che, Y., & Feng, D. (2011). Municipal solid waste source-separated collection in China: A comparative analysis. Waste management, 31(8), 1673-1682.

Talebbeydokhti, N., Amiri, H., Shahraki, M. H., Azadia, S., & Ghahfarokhi, S. G. (2013). Optimization of Solid Waste Collection and Transportation System by Use of the TransCAD: A Case Study. Archives of Hygiene Sciences Volume, 2(4).

Tavares, G., Zsigraiova, Z., Semiao, V., & Carvalho, M. d. G. (2009). Optimisation of MSW collection routes for minimum fuel consumption using 3D GIS modelling. Waste management, 29(3), 1176-1185.

Thanh, N., Matsui, Y., Ngan, N., Trung, N., Vinh, T., & Yen, N. (2009). GIS application for estimating the current status and improvement on municipal solid waste collection and transport system: Case study at Can Tho city, Vietnam. Asian Journal on Energy and Environment, 10(02), 108-121.

Thanh, N. P., Matsui, Y., & Fujiwara, T. (2011). Assessment of plastic waste generation and its potential recycling of household solid waste in Can Tho City, Vietnam. Environmental Monitoring and Assessment, 175(1-4), 23-35.

Tin, A. M., Wise, D. L., Su, W.-H., Reutergardh, L., & Lee, S.-K. (1995). Cost—benefit analysis of the municipal solid waste collection system in Yangon, Myanmar. Resources, conservation and recycling, 14(2), 103-131.

Troschinetz, A. M., & Mihelcic, J. R. (2009). Sustainable recycling of municipal solid waste in developing countries. Waste management, 29(2), 915-923.

Tukker, A. (2015). Product services for a resource-efficient and circular economy–a review. Journal of Cleaner Production, 97, 76-91.

Vietnam Government (2007). Decree No. 59/2007/ND-CP on Solid Waste Management.

Vietnam Government (2009). Decision No. 2149/QD-TTg on approving the National Strategy of Integrated Solid Waste Management up to 2025, vision towards 2050.

Vietnam Government (2015). Decree No. 38/2015/ND-CP on Solid Waste Management.

Wilson, D. C. (2007). Development drivers for waste management. Waste Management & Research, 25(3), 198-207.

Wilson, D. C., Araba, A. O., Chinwah, K., & Cheeseman, C. R. (2009). Building recycling rates through the informal sector. Waste management, 29(2), 629-635.

Wilson, D. C., Velis, C., & Cheeseman, C. (2006). Role of informal sector recycling in waste management in developing countries. Habitat International, 30(4), 797-808.

Yadav, S. K. (2013). GIS Based approach for site selection in waste management. International Journal of Environmental Engineering and Management, 4, 507-514.

Yolin, C. (2015). Waste management and recycling in Japan opportunities for European companies (SMEs focus). EU-Japan Center for Industrial Cooperation: Tokyo, Japan.

Zall Kusek, J., & Rist, R. (2004). Ten steps to a results-based monitoring and evaluation system: a handbook for development practitioners: The World Bank.

Zaman, A. U., & Lehmann, S. (2011a). Challenges and opportunities in transforming a city into a “zero waste city”. Challenges, 2(4), 73-93.

Zaman, A. U., & Lehmann, S. (2011b). Urban growth and waste management optimization towards ‘zero waste city’. City, Culture and Society, 2(4), 177-187.

Zhuang, Y., Wu, S.-W., Wang, Y.-L., Wu, W.-X., & Chen, Y.-X. (2008). Source separation of household waste: a case study in China. Waste management, 28(10), 2022-2030.

Zsigraiova, Z., Semiao, V., & Beijoco, F. (2013). Operation costs and pollutant emissions reduction by definition of new collection scheduling and optimization of MSW collection routes using GIS. The case study of Barreiro, Portugal. Waste management, 33(4), 793-806.

Zurbrügg, C., Caniato, M., & Vaccari, M. (2014). How assessment methods can support solid waste management in developing countries—a critical review. Sustainability, 6(2), 545-570.

2 OPERATION ASSESSMENT AND COLLECTION EFFICIENCY OF WASTE COLLECTION SYSTEM IN DA NANG CITY

2.1 Waste collection research in Da Nang city, Vietnam

2.1.1 Current practices of waste collection and transport in Da Nang

Da Nang city, a port city located on the coast of South China Sea, is the largest city in central Vietnam. Da Nang is fifth populated city in Vietnam with a population of 1,046,876 as of 2015, and with an area of 1,285.4 km² (Da Nang General Statistics Office 2015). Da Nang is subdivided into 8 districts: 6 urban districts (Cam Le, Hai Chau, Thanh Khe, Lien Chieu, Ngu Hanh Son, and Son Tra), and 2 rural districts. They are further subdivided into 1 commune-level town, 14 communes, and 45 wards.

Waste type	Percentage
Organic matters	68.47
Plastic	11.36
Soil and sand	6.75
Paper	5.07
Wood	2.79
Textiles	1.55
Metal	1.45
Mud	1.35
Ceramics	0.79
Leather and rubber	0.23
Crystal	0.14
Other	0.03
Hazardous waste	0.02
Total	100%

Source: Report of MSWM status in the period of 2007-2011. Da Nang URECO, 2012

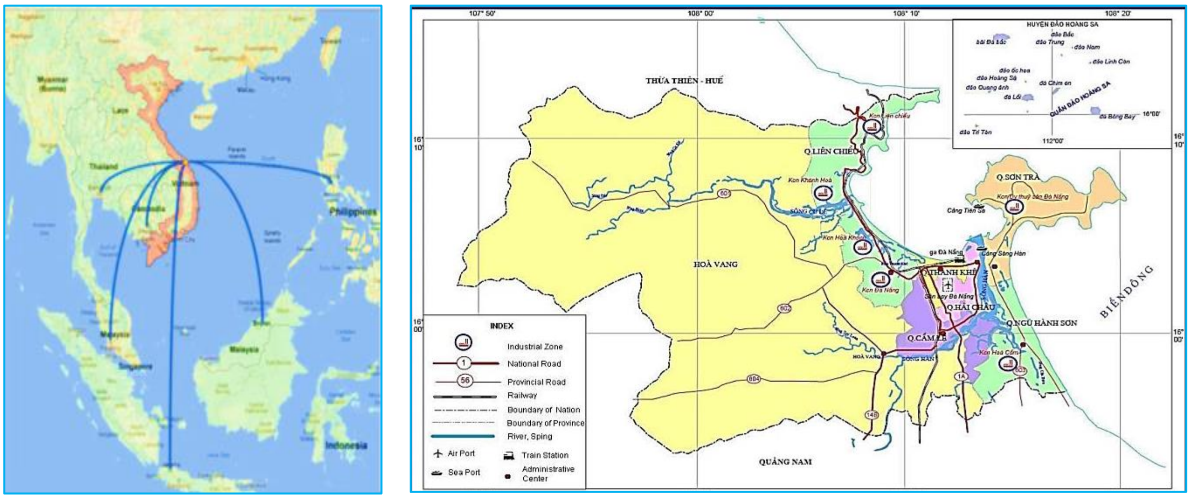
Municipal solid waste (MSW) in Da Nang city is generated from various sources including households, commercial and institutional sectors such as hotels, restaurants, markets, shops, offices, schools, institutions, hospitals, airports, parks, etc. MSW in Da Nang city is managed by Da Nang Urban Environment Company (hereinafter referred to as "Da Nang URENCO").

Table 2.1 Waste composition in Da Nang city, 2012

According to the report of Da Nang URENCO, the waste generation rate was approximately 0.65 kg/cap/d, and the average daily collection amount reached approximately 700 tons/d in 2014. Regarding the waste composition, organic matters accounted for 68.5%, followed by plastic (11.4%), soil and sand (6.8%), paper (5.1%), and wood (2.8%) (MONRE, 2011).

As one of the forward thinking municipalities in Vietnam, Da Nang city has been trying to improve the operation efficiency of waste collection and transport, and has introduced various collection systems in some parts of the city; e.g., tricycle collection, dustbin collection, and truck collection. In addition, Da Nang city has newly applied a GPS tracking system for monitoring waste collection trucks to improve the management for the system.

However, the plan for waste collection and transport has been empirically designed, and the operation efficiency has not been well considered even in this motivated city. The design of waste collection and transport is a key factor for planning waste collection and transport. Ishikawa developed a logistics model for estimating number of trucks using 3 policy variables: the truck capacity, the number of collection station, and the collection frequency (Ishikawa, 1996). Matsui et al. indicated that a larger truck capacity, a smaller number of stations, and less collection frequencies resulted in better collection efficiency (Matsui et al, 2004). Waste collection in developing countries is often planned empirically without considering influence factors of operation efficiency like collection frequency and truck capacity. Daily collection would be inefficient, and US EPA pointed to "Collection Frequency: Less is Often Best", and reported twice-per-week collection was almost 70 percent more costly than once-per-week collection. They recommended once-per-week collection even in the hottest climate where summertime temperatures soared to more than 100 degrees Fahrenheit by proper storage (U.S. EPA, 1999).



(a) (b)

Figure 2-1 Location of Da Nang in Vietnam (a) and administrative map of Da Nang city (b)

Da Nang city has introduced various collection systems in some parts of the city. The collection vehicle and equipment of representative systems for collection and transport in Da Nang is shown in Figure 2.2 and the outline of each system is indicated as follows:

(1) Small dustbins (240/280L)

(2) Large dustbins (660L)

(3) Handcart

(4) Pedal tricycle

(5) Motorbike

(6) Electronic bike

(7) Forklift truck (9 ton)

(8) Compactor truck (3.5 ton)

(9) Container truck (10 ton)

Figure 2-2 Collection vehicle and equipment in Da Nang city

There are currently three main practices of collecting waste

(1) Practice 1: Door-to-door collection by tricycle and transport by truck (hereinafter referred to as "Door-to-door collection by tricycle")

A waste collection worker visits households from door to door to pick up the waste discharged at the side of the road by plastic bag, basket or foam box. The worker moves by tricycle with a 660L dustbin (DB), loads the waste into the dustbin, and carries it to a meeting point for transfer. In some areas, the worker rings a bell to inform the residents of waste collection and waits for a while, then the surrounding residents bring their waste for collection. At the meeting point, a forklift truck with loading and compaction equipment transfers the waste by turning over the dustbin, and transports it to the landfill site. This combination system is the common and traditional system for domestic waste in the central area of Da Nang city. The load capacity of forklift truck generally ranged from 5 tons – 9 tons, and the truck is operated by 1 driver and 2 workers.

(2) Practice 2: Door-to-door collection and transport by truck (hereinafter referred to as "Door-to-door collection by truck")

A compactor 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 by plastic bag, basket or foam box. The driver keeps driving at a walking pace, and the collection workers follow the truck and load the waste directly into the truck. The truck plays music to inform the residents of waste collection, and some of the surrounding residents bring their waste for collection. After the waste collection, the truck directly carries the waste to the landfill site without transfer. This system is a newly introduced system, and applies in suburban and newly developed areas. The load capacity of compactor truck is generally 3.5 tons, and is operated by 1 driver and 2 workers.

(3) Practice 3: Dustbin collection and transport by truck (hereinafter referred to as "Fixed time dustbin collection")

Several tens of households share a dustbin with a capacity of 240 L/280 L/660 L. This is put at the side of the road based on the e agreement and convenience of surrounding residents. Every day, the empty dustbins are placed from 14:30 to 15:00 by a small lift-equipped truck (mini-truck). Then, the residents are requested to bring their waste and put it into the dustbin by themselves. A large forklift truck comes to transfer the waste by turning over the dustbin at the fixed time from 21:00 to 22:00, and directly carries it to the landfill site. The empty dustbins are subsequently collected by the mini-truck and cleaned (Anh, T. T. Y., 2013). This system was introduced on trial for 41 routes in 6 urban districts (Vietnam Environment Administration, 2014). The mini-truck is operated by 1 driver and 2 workers. The load capacity of forklift truck is generally approximately 4.5 tons – 10 tons, and the truck was operated by 1 driver and 2 workers.

Regarding business sectors with large amounts of waste generated, they keep their own dustbins and do not have a daily dustbin distribution. There are some dustbins for public use put along the main streets.

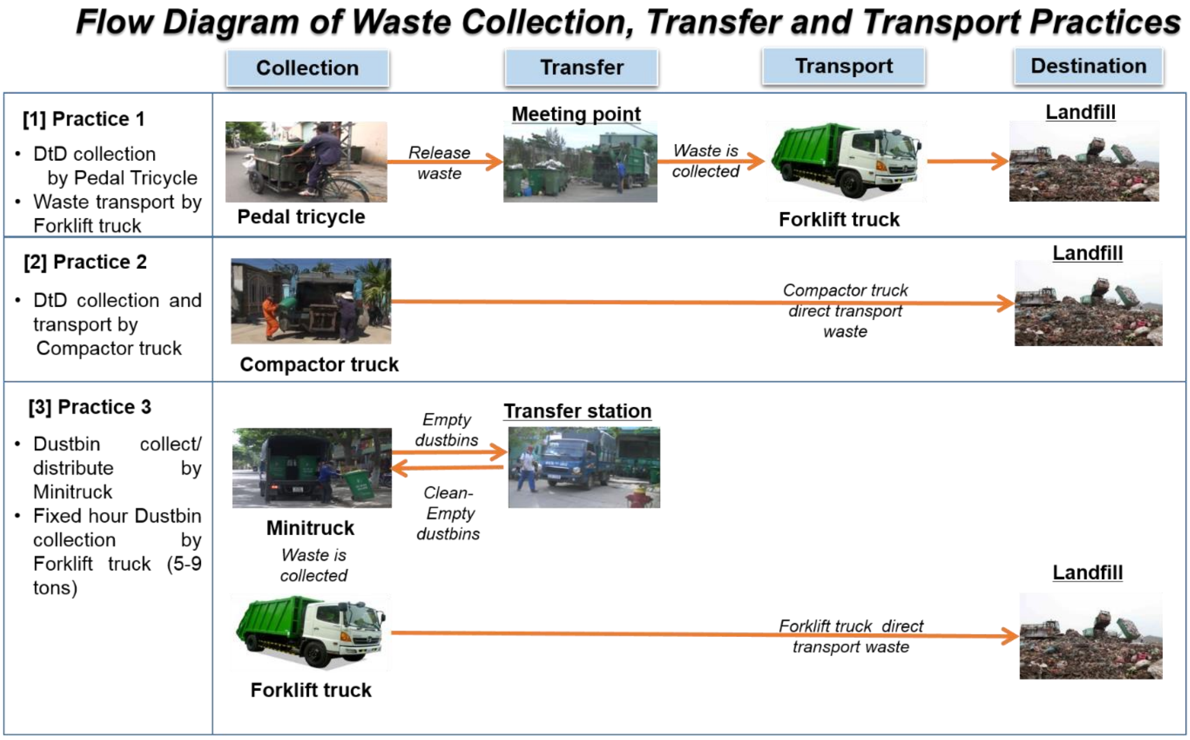


Figure 2-3 Flow diagram of waste collection, transfer, and transport practices in Da Nang city

(4) Other practices

Da Nang URENCO also applies some vehicle such as electronic bikes and motorbikes for Door to door collection, but the operation condition is quite different from the former 3 practices, e.g., applied for inconvenient routes and longer distance hauls.

Figure 2-4 Motorbike for door to door waste collection

Figure 2-5 Electronic bike for door to door waste collection

- Motorbike for door to door waste collection

The motorbike practice is different from the two above mentioned practices while working at collection area. The motorbike collector needs to take off the motorbike outside the frame with the dustbins and parked at one separate place. Then he must pull this frame by himself to collect waste along the streets. Later then he transfers the accumulated waste at transfer station.

- Electronic bike for door to door waste collection

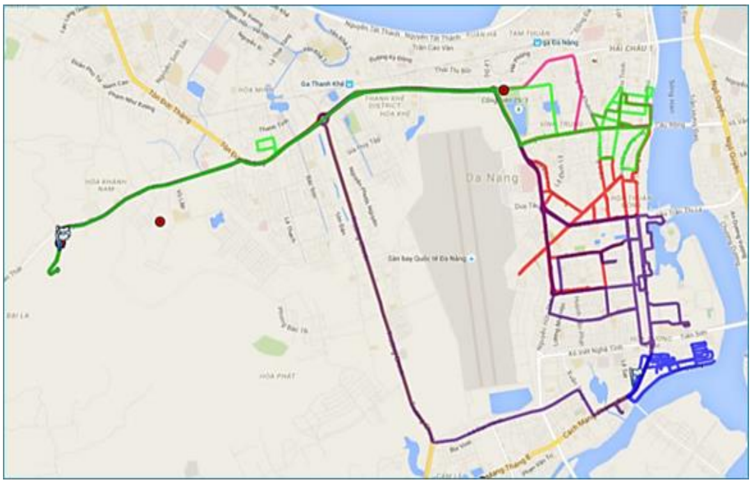
Electronic bike practice works similarly as the pedal tricycle does. A collector collects waste through D-to-D collection and carried waste to meeting point where the forklift truck transfer and transport to landfill site. Or electronic bike worker release the waste at transfer station where the waste is transferred into a container by the compressing machine and then carried to the landfill site by container truck.

- Transfer station

Da Nang city has 10 transfer stations located in the inner city with an average capacity of 23.6 tons per day. These transfer station gather solid waste mainly from alleys, narrow residential areas before transporting to landfill.

2.1.2 Outline of tracking survey and analytical method

In this study, the author focused on the vehicles used for the former 3 practices shown in Figure 2.2 such as tricycles, compactor trucks and forklift trucks, and conducted the following 3 surveys to collect data on distance, time and amount of waste collected and transport. The operation data on mini-trucks were obtained from Da Nang URENCO. For detail GPS data, a GPS logger, Transystem 747A+ GPS Trip Recorders (Transystem, 2010) with 1 second interval was attached to the target vehicles. The logger recorded the coordinate data by the second, and the tracking data were mainly used to analyze the distance and velocity of waste collection and transport by GIS software, ArcGIS 10.1.



(a) Transystem 747 A+ logger

(b) Photo Tagger Software (b)

Figure 2-6 Used GPS logger (a) and route tracking on Photo Tagger Software (b)

(1) Video recording

The surveyors followed the target vehicles and recorded the operations of vehicles and collectors by a video camera. The recorded movies were used to analyze the operation time by operation category and the number of loaded waste.

(2) Measurement of waste amount

The author surveyed the data on waste amount by a round trip. The weight of waste collected by a tricycle was measured at the meeting points by 1-ton digital scale measuring a minimum of 500 grams (g). The weight of waste transported by a truck was measured by the weighbridge at the entrance of the landfill site.

The author also counted the total number of bags/boxes/baskets/dustbins/handcarts by each round trip from the recorded movies. Based on the data on total collection amount and the total number of bags/boxes/baskets/dustbins/handcarts by each round trip, the author developed a regression model for the total weight by the total number of bags/boxes/baskets/dustbins/handcart as explanatory variables.

(3) Outline of survey

The outline of survey and target areas is summarized in Table 2.2. Three districts in Da Nang city, Hai Chau, Cam Le and Thanh Khe, were selected to conduct the survey from June 16th to July 17th, 2015.

Table 2.2 Outline of survey

Collection vehicle	Target district	Load capacity (ton)	No. of worker	No. of trips	Survey date
Tricycle	Cam Le		1	10	28/06/2015
				11	16/07/2015
	Thanh Khe			8	17/07/2015
Compactor truck	Cam Le	3.5	3	3	27/06/2015
Forklift truck	Hai Chau	7	3	1	02/07/2015
		9		3	04/07/2015
		9		2	07/07/2015
		9		5	01/07/2015
	Cam Le	5		5	16/06/2015
	Thanh Khe	4.5		5	15/07/2015

Table 2.3 Information of target districts

Characteristic	Thanh Khe	Cam Le	Hai Chau
Area (km^2)	9.44	35.25	23.28
Population (people)	187,766	108.805	205,380
Population density (people/km^2)	19,890	3,087	8,222
Waste amount by types of collection methods (ton/day)	149.3	68.3	189.3

(Da Nang URENCO 2015)

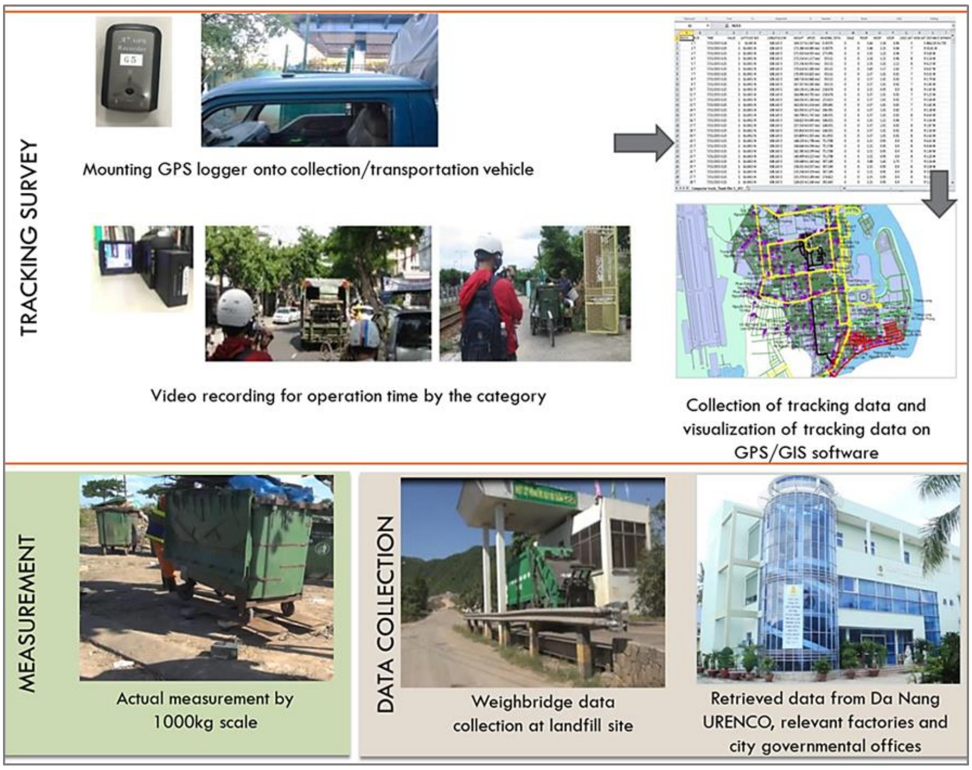


Figure 2-7 Outline of survey in Da Nang

The operations of waste collection and transport were composed of the following processes:

1) Moving forward to collection area (e.g., from the parking/meeting point/landfill site to the 1st collection point)

2) Waste collection in collection area

3) Moving backward from collection area (from the last collection point to meeting point/landfill site)

4) Unloading

5) Others

Others include the rest time for meals/drinks/toilets, the waiting time for the truck to transfer waste at the meeting point in case there were no available empty dustbins for collection, and the time for separating recyclables for selling.

Regarding “Practice 3: Fixed time dustbin collection”, the process of collecting waste was further categorized in detail as follows:

2a) Preparation at collection point: The time excluding "2b) Actual loading at collection point". At each collection point, the worker commonly spent time to prepare and carry the dustbin to the truck before uploading as well as sending them back to the original location afterward. The time for preparation at the collection point was separately considered in this study.

2b) Actual loading at collection point: The time for transferring waste from the dustbins to the truck, from the 1st touch to the last release of dustbins.

2c) Moving between collection points: The time for moving between collection points in the target collection area.

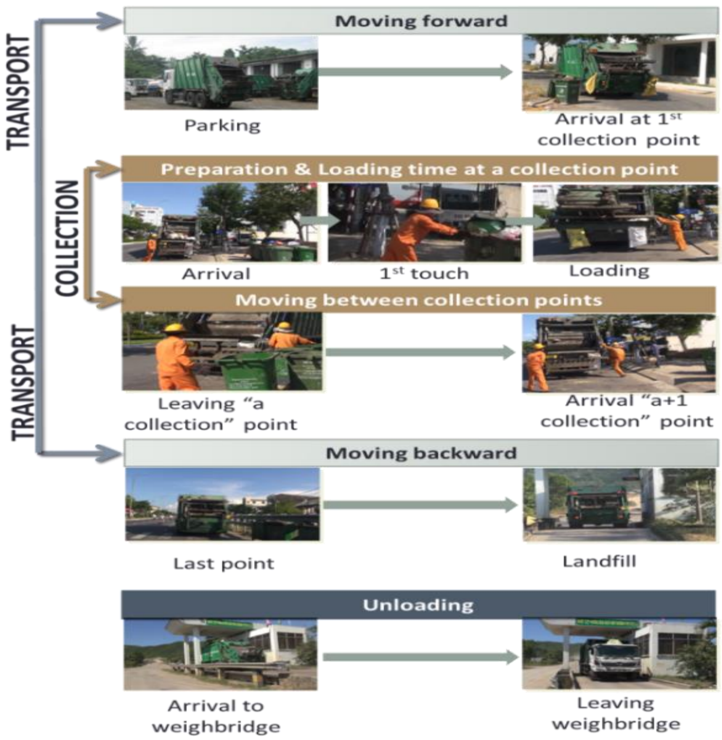


Figure 2-8 Operation categories of working time in dustbin collection

The data on operation distance and time were analyzed and discussed by the abovementioned operation categories. The operation velocity for moving was also calculated.

2.2 Outline of operation of pedal tricycle

(1) Daily operation and operation efficiency

The author surveyed 3 pedal tricycles in 3 wards. Table 2.4 shows the outline of operation of 3 tricycles and the average by trip.

Table 2.4 Outline of operation of workers by pedal tricycle

District	Ward	No. of trips	Collection amount	Working time					Operation efficiency	
				Total	Moving forward, backward	Loading waste	Unloading	Others		
		trip/day	ton/trip	hour/trip					Loading waste person-hour/ton	person-hour/ton
Thanh Khe	Chinh Gian	8	0.23	0.85	0.1	0.38	0.12	0.25	1.65	4.17
Cam Le	Khue Trung	10	0.2	0.71	0.12	0.46	0.08	0.06	2.3	3.73
Cam Le	Hoa Phat	11	0.21	0.71	0.08	0.48	0.08	0.06	2.29	3.07
Average of 3 workers		9.67	0.21	0.75	0.11	0.45	0.09	0.11	2.08	3.57
				100.00%	13.30%	59.50%	11.90%	15.10%		

The collectors made round trips for door-to-door collection for 8 to 11 times a day. The averages of collection amount and working time for 1 trip were 0.21 tons and 0.75 h, respectively. Regarding the detailed breakdown of working time, Waste collection was dominant (59.6%), followed by Others and Unloading. The time for moving forward and backward had a smaller proportion.

The tracking coordinate data for the tricycle were unstable especially for the data at narrow alleys, because GPS needs to have a “clear view” of the sky in order to give its most accurate reading (National Geographic Maps, 2017). So, the author did not analyze the distance and velocity for the tricycle in this study.

The operation efficiency was estimated by dividing the total working time by the collection amount. The average operation efficiency was 3.57 person-hours/t, and there was no significant difference among 3 wards by ANOVA ($F=2.135$, $p=0.136$).

(2) Waste weight and waste generation rate

The waste was discharged by bags/boxes/baskets from households for the door-to-door collection. The total collection amount in 3 wards was 5,569 kg, and the total number of discharged waste by bags/boxes/baskets was 2,485 pieces. Thus, the average waste amount per piece was calculated as 2.24 kg/piece. (Three trips including the collection of larger pieces, like dustbins, were excluded from this calculation)

Assuming the average weight of one piece was equivalent to the average of waste generation from one household with the average family size of 4.1 persons/family (Da Nang General Statistics Office, 2015), the per capita waste generation was calculated to be 0.55 kg/cap/d. This value was slightly less than the municipal solid waste generation rate reported by Da Nang URENCO (0.65 kg/cap/d). The target areas were residential areas and there were fewer business sectors than downtown, which is a possible reason for the difference in waste generation rate.

Besides, many households in Da Nang City Are implementing business at their house and solid waste generated from these houses is combined with waste from sole households. Therefore, solid waste from household with business is also considered in this study.

For the other door to door collection method, motorbike and electronic are collection methods applied later in Hai Chau district in Da Nang city. These 2 types of collection method transfer waste at transfer station instead of meeting point as Tricycle. Table 2.5 indicated that motorbike and electronic bike spent more time per trip than pedal tricycle. In average, motorbike spent 1 hour/trip for collection, and electronic bike took about 1,5 hour for one trip. This time include moving forward, collection, backward, unloading and other time. In each collection day, the worker can carry out 6 to 11 collection trips.

Table 2.5 Out line of operation of motorbike and electronic bike

	Moving forward/ trip	Collection/ trip	Moving backward/ trip	Unloading /trip	Others/ trip	Total/trip
Motorbike	00:03:10	00:32:36	00:05:14	00:12:50	00:06:46	01:00:36
	5.21%	**53.80%**	**8.63%**	**21.18%**	**11.18%**	**100.00%**
Electronic bike	00:07:04	00:38:59	00:10:18	00:13:50	00:17:03	01:27:14
	8.10%	**44.68%**	**11.81%**	**15.86%**	**19.55%**	**100.00%**

2.3 Outline of operation of compactor truck

The author surveyed 3 trips of 1 compactor truck with 3.5-ton capacity. Compactor trucks were used for Practice 2 “Door-to-door collection by truck” as well as the waste transport for Practice 1. The target truck served for Practice 2 “Door-to-door collection by truck” in some parts of the second trip, and also served for the waste transport for Practice 1 for the remaining part of the collection routes. Table 2.6 shows the outline of daily operation of 3 trips.

Table 2.6 Outline of operation of compactor truck

District	No. of trips	Collection amount	Operation distance	Forward, backward velocity	Working time					Operation efficiency
					Total	Moving forward, backward	Loading waste	Unloading	Others	
	trip/day	ton/trip	km/trip	km/hour	hour/trip					person-hour/ton
Cam Le	3	3.91	33.14	31.72	2.75	0.61	1.81	0.18	0.16	2.11
					100.00%	22.20%	65.70%	6.40%	5.70%	

The collection amount and the operation time for 3 trips were 11.73 tons and 8.24 h, respectively. Regarding the detailed breakdown of working time, Waste collection was dominant (65.7%), followed by Moving forward and Moving backward. The truck needed to transport the waste for longer distance to the landfill site, so they needed to spend more time for Moving forward and Moving backward than tricycles. The time for Unloading and Others had a smaller proportion.

Because the compactor truck collected waste by bags/boxes/baskets and dustbins in the same trip, the author could not calculate the waste weight per piece or dustbin based on the survey data on the compactor truck.

2.4 Outline of operation of forklift truck

(1) Daily operation and operation efficiency

There were several studies on waste collection and transport system in Da Nang city. Le Thi Tuong Vi (2015) has considered the dustbin collection process in the city without separate into 2 systems. Vi (2016) had analysed the operation and compared operation efficiency among different waste collection system but not clarify and compare in detail within each system. In her study, forklift truck achieved the efficiency 0.89 person-hour/ton in general.

In this study, the author summarized the outline of daily operation for 3 trucks with 21 trips. The target trucks in Cam Le and Hai Chau district served for Practice 3 in some parts of their trips, and also served for the waste transport for

Practice 1 for the remaining part of the collection routes. In these trips, there were 13 trips the trucks conducted waste collection as a transport function. In 8 trips remaining, the truck not only transported waste but also collected fixed time dustbin.

Table 2.7 Outline of daily operation of forklift truck

District	Collection method	No. of trips	Collection amount	Total Operation distance	Collection distance	Working time for 1 trip					Operation efficiency		
						Total	Moving forward/ backward	Waste collection	Unloading	Others	Total time/ total amount	collection time/ collection amount	Collection distance/ collection amount
			ton/trip	km/trip	km/trip	hour/trip					person-hour/ton		km/ton
Hai Chau	Only for waste transport	6	8.34	27.63	7.77	2.53	0.64	1.36	0.24	0.28	0.91	0.49	0.93
Cam Le	Only for waste transport	2	5.94	28.25	9.69	1.91	0.60	1.10	0.20	0.02	0.97	0.56	1.63
Thanh Khe	Only for waste transport	5	4.28	17.84	5.66	1.79	0.40	0.99	0.25	0.15	1.26	0.69	1.32
Average						2.15	0.54	1.18	0.24	0.19	1.05	0.58	1.19
Hai Chau	Fixed time DB collection and transport	5	8.55	26.33	6.62	2.36	0.54	1.39	0.29	0.15	0.83	0.49	0.77
Cam Le	Fixed time DB collection and transport	3	5.57	29.92	10.14	2.12	0.58	1.21	0.24	0.09	1.14	0.65	1.82
Average						2.27	0.56	1.32	0.27	0.13	0.95	0.55	1.17

In the traditional collection method of forklift truck at meeting point, the truck comes to meeting points three times/day to collect dustbin carried out in residential areas by tricycle workers. This collection method has lower efficiency than the method of fixed time dustbin collection.

However, fixed time dustbin collection system needed empty dustbin distribution and collection by a mini-truck. By the hearing from Da Nang URENCO, 2 mini-trucks worked for 3 h for distribution and collection for 364 dustbins in Hai Chau district as shown in Table 2.8 [Da Nang URENCO, 2015]. The time per dustbin was calculated as 59.34 s/dustbin.

Table 2.8 Outline of daily operation of mini-truck

Number of truck/day	Distribution/ Collection time/day (hour/day)	Number of dustbin/day	Time per dustbin (second/dustbin)
2	3	364	59.34

In both 2 system of transport waste by forklift truck and fixed time dustbin collection, the workers also spent some time for pick up recyclable waste to increase their daily income, and it might reduce the total collection efficiency accordingly.

(2) Waste weight and waste generation rate

Operational time of loading waste is defined in this study that includes times the processes of lifting up, discharging and lifting down of container through semi-automatic mechanism at the back of the vehicle. Dustbin/handcart is lifted up by means of a semi-automatic mechanism manually with the help of a collector and it is discharged into the vehicle from the back. As soon as the waste in the dustbin/handcart is discharged into vehicle, they are lifted down again.

Here, the operational time of loading waste was predicted by number of loaded waste bins/handcart. The relationships between operation times and these candidate predictors through multiple regression analysis by all the statistical analysis were stepwise method; confident interval 95%, p in $\leq$0.05, p out $\leq$0.10, no-intercept model). Similarly, loading waste was predicted by number of loaded waste bag/foam box, basket of D-to-D collection systems. Moreover, the loading waste amount of was predicted by number of loaded waste bag/foam box/basket and number of loaded bins/handcart for collection and transport by vehicle by multiple regress analysis.

In Da Nang city, 4 types of containers, 240-L dustbin, 280-L dustbin, 660-L dustbin and handcart, were used for MSW collection and transport. The former three types are dustbins used for waste collection and transport, while the handcarts are mainly used for street waste and managed by street sweepers. Table 2.9 shows the result of multiple regression analysis for collected waste amount by type of container.

Table 2.9 The result of multi-regression analysis for collected waste amount by container

	Explanatory variables	Coefficient
Type of container	240L dustbin	65.7***
	280L dustbin	43.6***
	660L dustbin	156.9***
	Handcart	175.4***
n	Number of case	21
R^2	Coefficient of determination	0.991***

*** p<0.001

2.5 Detail analysis on compactor and forklift trucks

The author analyzed the operation efficiency indicators and the effects of influence factors on compactor and forklift trucks by the detail operation category as follows: moving forward and backward, waste collection, unloading and other activities.

(1) Moving forward/backward

In Da Nang city, the trucks are parked next to the landfill site. The trucks move forward to collection areas and return to the landfill site to unload the collected waste. Table 2.10 demonstrates that the average distances for moving forward/backward for the target trucks were 19.8 km/trip in Hai Chau district, 19.3 km/trip in Cam Le district, and 12.2 km/trip in Thanh Khe district. It depends on the distance between the collection area and the landfill site.

Regarding the velocity of moving forward /backward, the author could not detect significant differences among districts and capacities of truck. The average velocity for the surveyed 24 trips was 32.8 km/h.

Table 2.10 Velocity for moving forward/backward by district and truck capacity (km/hour)

		n	Mean	SD	ANOVA (F)	Sig.
District	Hai Chau	11	33.8	3.8	1.22	0.316
	Cam Le	8	32.7	3.5		
	Thanh Khe	5	30.9	2.4		
Capacity	4.5t	8	31.1	2.0	1.42	0.268
	5t	5	33.5	4.3		
	7t/9t	11	33.8	3.8		
Total		24	32.8	3.5		

(2) Waste collection and transport

a) Waste collection by door-to-door collection by compactor truck

As mentioned above, the surveyed compactor truck was applied for Practice 2: door-to-door collection by truck as well as the waste transport for Practice 1. Within the interval part of collection, the truck collected 328 pieces of waste, which was estimated to be 0.74 tons by assuming the waste amount per piece to be 2.24 kg/piece as calculated in Section 3.5.1. The collection distance was 2.16 km, and the working time was 0.64 hour for waste collection. The average velocity for door-to-door collection was 3.39 km/hour. The operation efficiency was calculated as 2.60 person-hours/ton.

Table 2.11 Outline of interval of door-to-door collection by compactor truck

District	Collection amount		Operation distance	Velocity	Working time	Operation efficiency		
	No. of bags/boxes/ baskets	Estimated amount[1)]						
	piece	ton	km	km/hour	hour	hour/ton	person-hour/ton	km/ton
Cam Le	328	0.74	2.16	3.39	0.64	0.86	2.6	2.92

[1)]The collection amount was estimated by assuming the waste amount per piece as 2.24 kg/piece

b) Waste collection and transport by forklift truck

The target forklift trucks served for Practice 3 "Fixed time dustbin collection" in some parts of their trips, and also served for the waste transport for Practice 1 for the remaining part of the operation routes. The author separated the operation interval by 2 practices, and analyzed the operation data by practices.

The outline of interval of fixed time dustbin collection is shown in Table 2.12.

Table 2.12 Outline of interval of fixed time dustbin collection by forklift truck

District	Collection amount					Operation distance	Velocity	Working time	Operation efficiency	
	No. of 240L dustbin	No. of 240L dustbin	No. of 240L dustbin	No. of handcart	Estimated amount[1)]				Waste collection time/ collection amount	Collection distance/ collection amount
	piece	piece	piece	piece	ton	km	km/hour	hour/trip	person-hour/ton	km/ton
Hai Chau	103	216	27	4	5.63	3.53	11.87	0.96	0.51	0.63
Cam Le	62	82	12	4	3.41	5.64	13.59	0.79	0.7	1.65

[1)] Weight amount in interval part was estimated by the number of container collected with amount of waste/container.

The waste collection process was discussed by the following detail operation categories: Preparation at collection point, Actual loading at collection point, and Moving between collection points:

Preparation at collection point

There was significant difference in the time of preparation by the 2 practices ($F=14.29$, $p<0.001$). The time of preparation for Practice 3 was 7.5 s/point, approximately half of that of Practice 1, 15 s/point (Table 2.13). The dustbins for Practice 3 was often set at the roadside, and the truck workers did not need to spend so much time to move for loading and return them. In contrast, for Practice 1, the dustbins were sometimes kept farther from the roadside at the meeting points, and the workers needed to spend more time for preparation.

Table 2.13 Preparation time for dustbin loading per collection point by practice (second/point)

		n	Mean	SD	ANOVA (F)	Sig.
System	Practice 1 Transport	221	15.0	29.7	14.29	0.000
	Practice 3 Fixed time dustbin collection	255	7.5	10.4		
	Total	476	11.0	21.9		

Actual loading at collection point

As mentioned above, 4 types of containers were used for MSW collection and transport. Table 2.14 shows the result of multiple regression analysis for loading time by type of container.

Table 2.14 Loading time (second) by type of container by practice

Type of container	Explanatory variables	Practice 1 Only transport	Practice 3 Fixed time collection	Total
240L	240L dustbin	22.5***	23.4***	23.2***
280L	280L dustbin	28.5***	25.1***	26.0***
660L	660L dustbin	51.9***	47.3***	51.7***
Handcart	Handcart	45.1***	37.5***	42.0***
n	Number of case	234	262	496
R^2	Coefficient of determination	0.971***	0.909***	0.959***

The value for each size of dustbin indicates the partial regression coefficient.

*** $p < 0.001$

It is suggested that the partial regression coefficient indicates the corresponding loading time for each dustbin. The loading time of Practice 3 was slightly shorter than those of Practice 1 excluding 240-L dustbin. The forklift truck can upload 2 smaller dustbins with the capacities of 240 L and 280 L at one time, while the truck can transfer only one dustbin with the capacity of 660L or one handcart at one time. That would be the possible reason for the difference in loading time among containers. The loading time per dustbin is very similar with the value reported in the case of back-load vehicles, 25 s per dustbin, by Zamorano (Zamorano et al., 2009); and the reported value for average pick up time for one container, 39.43 s, by Apaydin (Apaydin et al., 2011).

Moving between collection points

The average distance between collection points for practices 1 and 3 were 495 m and 134 m, respectively, and the significant difference was found between 2 Practices. The dustbins for Practice 1 are put at the meeting points for door-to-door collection by tricycle, while the dustbins for Practice 3 are put at the side of the road by the agreement and convenience of surrounding residents. That would be the possible reason for the difference.

Table 2.15 shows the velocity of moving between collection points by practice. The average velocities between collection points for practices 1 and 3 were 16.3 km/h and 12.8 km/h, respectively, and the significant difference was found between 2 Practices. Because the truck needs some distance for acceleration, the shorter distance would result in the slower velocity for Practice 3. The velocity of the truck was similar with the velocity in the Japanese case, 15.6 km/h, reported by Ishikawa (1995) .

Table 2.15 Moving velocity between collection points by practice (km/hour)

		n	Mean	SD	ANOVA (F)	Sig.
System	Practice 1 Transport	225	16.3	6.0	62.17	0.000
	Practice 3 Fixed time dustbin collection	257	12.8	3.8		
	Total	482	14.4	5.2		

(3) Unloading time

After the trucks come back to the landfill site, they measure the waste amount at the weighbridge, and move into the landfill site to unload the waste.

Table 2.16 shows the unloading time per trip by truck capacity. There was no significant difference among the size of truck, and the average unloading time for the surveyed 24 trips was 0.242 h/trip. The value is near to the waste discharge time at the treatment plant, 10 min, reported by [Zamorano et al., 2009].

Table 2.16 Unloading time per trip by truck capacity (hour/trip)

		n	Mean	SD	ANOVA (F)	Sig.
Capacity	4.5t	8	0.224	0.074	0.685	0.515
	5t	5	0.224	0.036		
	7t/9t	11	0.263	0.099		
	Total	24	0.242	0.081		

(4) Other time

Table 2.17 shows the other time per trip by truck capacity. There was no significant difference among the size of truck, and the average other time for the surveyed 24 trips was 0.166 h/trip. Previous studies also reported the other time, and the reasons that were mentioned included truck break down, human factor, traffic, recycle waste, or queuing on the lane to Dumping site [Essien, O. E. and Udo, J., 2013], and the time varied from 7% to 30% of total time. During the survey in this study, the workers did not stop for resting and drinking water during collection. The other time was caused by the following reasons:

- In case there was no waste at the meeting point, the trucks for transport needed to wait for door-to-door collectors to bring the waste.

- The trucks stopped because of troubles with some of the trucks.

- At the end of each collection day, the trucks sometimes stopped at junkshops to sell recyclables

Table 2.17 Other time per trip by truck capacity (hour/trip)

		n	Mean	SD	ANOVA (F)	Sig.
Capacity	4.5t	8	0.153	0.194	0.86	0.437
	5t	5	0.062	0.119		
	7t/9t	11	0.222	0.279		
	Total	24	0.166	0.228		

2.6 Modelling of waste collection parameters

2.6.1 Transport velocity

The transport velocity is the velocity during truck travel from landfill site to collection area and in the reverse direction. Transport velocity was tested for the correlation with road category, population density extracted from GIS. There are 5 categories of road in Da Nang city, and during transport way of truck between landfill site and collection area. Transport distance was split in GIS by ward and road, then measure the distance in GIS. The model uses common statistics from these data.

Particularly, the analysed results indicated that there was no correlation between transport velocity and population density (Person = -0.059, p= 0.468). Regarding on road category, the road category is categorical variable, author checked whether any significant difference in transport velocity Among road categories. The results showed that there is significant difference between transport velocity and road category (F=13.634, p= 0.001), however, there was no significant difference within groups by post hoc analysis.

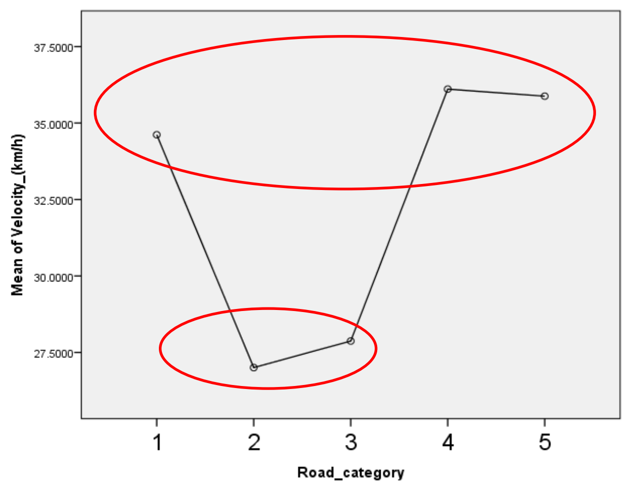


Figure 2-9 Difference of transport velocity among groups of road category

Hence, author combined the groups 2, 3 into one group, and group 1,4,5 into one group. And there is significant different in transport velocity Among 3 groups with F= 26.07, p=0.001.

Besides, the Correlation was also found between “Transport velocity” and “Transport distance”

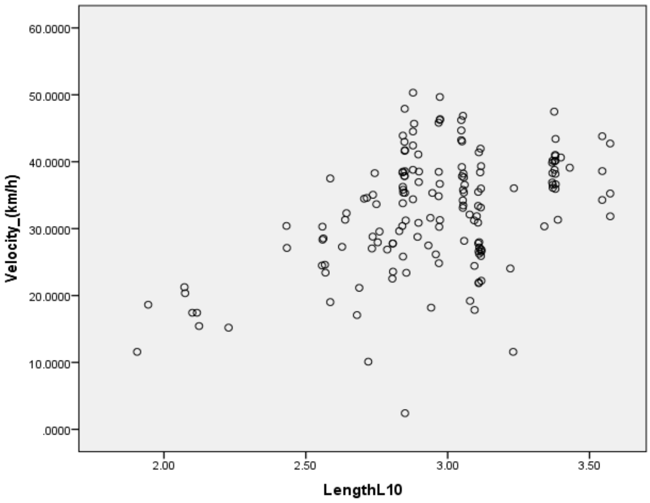


Figure 2-10 Correlation between transport velocity and transport distance

	Transport velocity
Transport distance	Person = 0.34**
Log10 converted distance	Person = 0.46**

The correlation was higher with logarithm 10 converted of transport distance

Then regression model then was applied with transport velocity As a dependent variable, and dummy variable of road category 23 and logarithm 10 converted of transport distance were independent variables. The results showed in Table 2.18 that

Table 2.18 Transsport velocity model

	Coefficient	SE	p
Constant	8.438	4.938	0.090
RoadCategory_23D	-7.337	1.078	0.001
LengthL10	9.223	1.631	0.001

The model showed the predicted output transport velocity in related to variables road category and transport distance. It indicates that there is a relative agreement between the two variables as confirmed by correlation plot of predicted and transport velocity (R^2 = 0.382).

2.6.2 Moving collection velocity

The moving collection velocity is the velocity of truck during collection between collection points. The model uses common statistics from population density, road categories and moving distance. The moving distance was extracted from GIS.

The author considered population density, road category and moving distance between collection points and by road during the waste collection process. Moving distance was split in GIS by each road, then measure the distance in GIS. There are 5 categories of road in Da Nang city

Regarding on road category, the road category is categorical variable, author checked whether any significant difference in ~~transport~~ moving velocity Among road categories. The results showed that there is significant difference among groups (F=13.971, p= 0.001), however, there was no significant difference within groups by post hoc analysis. Hence, author combined the category 2,3 into 1 group, and category 4,5 into one group, and group 1 into one group. Then, there was a significant difference in transport velocity Among 3 groups with F= 39.817, p=0.001.

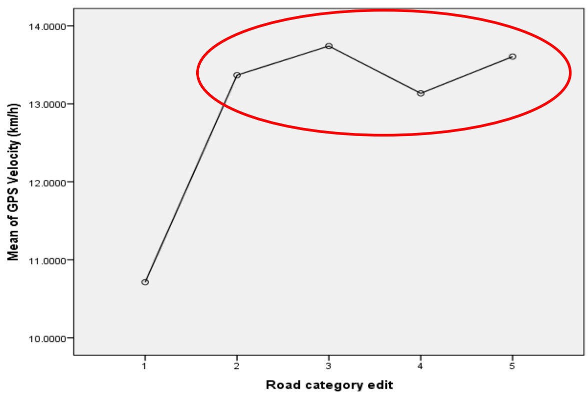


Figure 2-11 Difference of moving velocity among groups of road category

Besides, correlation was found between the moving velocity and the distance between the collection stations (Person = 0.75**, p= 0.001), and it was showed that the correlation coefficient is higher for logarithmically transformed of distance between collection stations Person = 0.85**, p= 0.001.

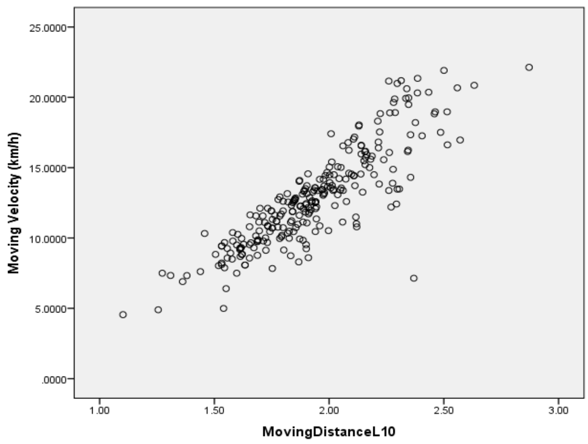


Figure 2-12 Correlation between moving velocity and moving distance

Because in this collection area, there was not any road with category 1, then regression model then was applied with dependent variable is moving collection velocity, and dummy variable of road category 23 and logarithm 10 converted of transport distance. The results showed that

Table 2.19 Moving collection velocity model

	Coefficient	SE	p
Constant	-7.525	.709	0.001
MovingDistanceL10	10.701	.356	0.001
RoadCategory_1D	-1.234	.225	0.001

The model showed the predicted output moving velocity in related to variables road category and moving collection distance. It indicates that there is a good agreement between the two variables as confirmed by correlation plot of predicted and transport velocity (R^2 = 0.806).

This model of moving velocity will be applied for Scenario analysis section in regarding with area characteristics and geographical information.

2.6.3 Loading time and Preparation time

Particularly, there was no correlation between loading time and number of containers (240L, 280L, 660L and handcart) which is Person correlation equals to 0.315; 0.430; 0.05; -0.509 and p = 0.318; 0.143; 0.987; 0.076, respectively. And the preparation time in each collection point had no correlation with road category

(F = 2.218, p= 0.068). Author hence applied total average of preparation time and assumed that this loading time is proportional to the waste amount and the results achieve by regression model showed in section for the Scenario Analysis Section.

2.7 Conclusion for section 2

1) By using the data for the 3 current practices on operation time, operation distance, and collected amount, key statistics for each parameter were calculated.
2) The operation efficiency indicators such as unit operation time, person-hours/t and operation velocity were calculated by the detail operation category: Moving forward and backward, Waste collection, waste unloading and other activities.
3) Tricycle for DtD waste collection has collection efficiency by 3.57 person-hour/ton, whereas Compactor truck had higher efficiency as 2.6 person-hour/ton compare to Tricycle.
4) Using multi-regression analysis, the author estimated the unit loading time and the unit waste amount for 4 types of containers, 240-L dustbin, 280-L dustbin, 660-L dustbin and Handcart.
5) Forklift truck has 2 forms of collection: transport waste and fixed time dustbin collection. These 2 forms can be combined together in actual situation. By interval analysis, the data for each operation components of each form was achieved in detail: moving forward, backward, preparation time, loading time by dustbin type, moving between collection points velocity, transport velocity, unloading time and other time.
6) Models of operation parameters in relate to transport and moving velocity was also constructed in concern with impact factors and area characteristics.
7) However the current problems of waste collection system in Da Nang City Are still remained: the mixed waste system collection is implemented daily, and all the waste stream comes to landfill site while landfill capacity is limited. Also, a large quantity of recyclable waste was not recovery due to this combine collection system, and this might burden on the landfill capacity and demonstrate the inefficiency in material recovery. Besides, the waste separation collection as well as influence factors have not been strongly considered in designing the system. Therefore, waste separation collection could be examined in developing countries to solve these problems, however to reduce the cost, the impact factors by system and area characteristic should be also approached and researched.

Reference for section 2

Anghinolfi, D., Paolucci, M., Robba, M., & Taramasso, A. C. (2013). A dynamic optimization model for solid waste recycling. Waste management, 33(2), 287-296.

Anh, T. T. Y. (2013). Comparison of operational efficiency among waste collection systems in Da Nang city, Viet Nam. (Master thesis of Okayama University). Retrieved from Okayama University Library database.

Apaydin, O., & Gonullu, M. (2011). Route time estimation of solid waste collection vehicles based on population density. Global NEST Journal, 13(2), 162-169.

Da Nang General Statistics Office (2015). Available at https://en.wikipedia.org/wiki/Danang

Da Nang URENCO (2015). Report on Solid Waste Management.

Essien, O. E., & Udo, J. (2013). Estimating Time Loss Effects On Municipal Solid Waste Collection Using Haul Container System In Uyo Nigeria. American Journal of Engineering Research.

Ishikawa M. (1996). A logistics model for post-consumer waste recycling. J. Pack. Sci. Technol. 5(2), 119-130.

Matsui, Y. (2009). Comprehensive report in FY 2008 for waste management research grant on “Cost-Effectiveness and Cost-Benefit Analyses on separate collection and junction transport”. Ministry of the Environment, Japan. (in Japanese)

Ministry of Natural Resources and Environment (MONRE) (2011). National environment report 2011. (in Vietnamese).

National Geographic Maps. (2017). Using a GPS unit. Available at http://www.software-maps.com/helpful-information-using-a-gps-unit.htm

Transystem (2010). Information on 747A+, Available at http://www.transystem.com.tw/product.php?b=g&m=pe&cid=4&sid=&id=59

Vietnam Environment Administration (2014). 44 routes for fixed time dustbin collection in Da Nang city. Available at http://vea.gov.vn/vn/quanlymt/kiemsoatonhiem/Pages/%C4%90%C3%A0-N%E1%BA%B5ng-44-tuy%E1%BA%BFn-%C4%91%C6%B0%E1%BB%9Dng-%C4%91%E1%BA%B7t-th%C3%B9ng-r%C3%A1c-theo-gi%E1%BB%9D-.aspx (in Vietnamese)

Vi, L.T.T. (2016). Modelling and scenario analysis of waste collection and transport by GPS/GIS application: A case study in Da Nang city, Vietnam. (Master thesis of Okayama University). Retrieved from Okayama University Library database.

Zamorano, M., Molero, E., Grindlay, A., Rodríguez, M. L., Hurtado, A., & Calvo, F. J. (2009). A planning scenario for the application of geographical information systems in municipal waste collection: A case of Churriana de la Vega (Granada, Spain). Resources, Conservation and Recycling, 54(2), 123-133. doi: http://dx.doi.org/10.1016/j.resconrec.2009.07.001

3 OPERATION ASSESSMENT AND COLLECTION EFFICIENCY OF A WASTE COLLECTION SYSTEM IN CITY A, JAPAN

3.1 Waste collection research in City A

3.1.1 Survey and summary of data

In order to ensure the reduction, recycling and proper management of waste, City A in Japan changed the waste separation category in 1999 from 4-type separation by “Combustible waste”, “Incombustible waste”, “Bulky waste” and “Used Batteries” to 5-type with 14-category separation by “Combustible waste”, “Landfill waste”, “Bulky waste”, “Used Batteries” and “Recyclables” including metals, glass bottles, textiles, papers by station collection; and PET bottles by drop-off collection. The A City Also started the station collection for PET bottles from 2008 (Japan for Sustainability, 2009).From April 1, 2008, digital tachographs (details will be described later) was installed on all collection and transport vehicles in the same area, and the operation time and traveling data for each operation categories such as loading, moving, and volume of waste are sequentially recorded, it is being used for operation management.

To assess the operation of waste collection and transport system in City A, authors based on collection data of five waste types as combustible waste, resource waste, landfill waste, bulky waste and used batteries separately. The collection method, collection frequency, and discharge method of these waste types are shown in Table 3.1.

Table 3.1 The overview of separate collection system in City A

Type		Category		Collection Frequency	Collection method	Discharge method
1	Combustible waste	1	Combustible waste	Twice a week	Station	Plastic bag
2	Landfill waste	2	Landfill waste	Once a month	Station	Plastic bag or lacing
3	Bulky waste	3	Bulky waste	Upon request	Door-to-door	Stick a voucher for collection
4	Used batteries	4	Used batteries	Every collection day	Station	Designated container
5	Recyclables	5	Cans & Metals	Once a		Designated

					month		yellow box
		6	Glass bottles	Colorless			Designated Blue box
		7		Amber			
		8		Other colors			
		9	Papers	Newspapers and ads			Lacing
		10		Magazines and others			Paper bag or lacing
		11		Corrugated cardboard			Lacing
		12		Paper drink packs			Lacing
		13	Textiles				Plastic bag or lacing
		14	PET bottles			Station	Plastic bag
						Drop-off	Without bag

The authors focused on 2 districts in City A, District W and District E, in which the tracking data was accumulated by the GPS devices. District W is located in the west part of City A with a population of 64 thousand, and District E is located in the east part of City A with a population of 70 thousand as of February 2018. Combustible waste is collected twice per week, e.g. on Monday and Thursday, on Tuesday and Friday. Recyclable waste is collected once a month on Wednesday.

This study focused on the station collection of Combustible waste, Landfill waste and Recyclables as the regular collection system in City A.

Outline of tracking data used in this study

In 2 target districts, there are 12 trucks with compaction with a load from 2,700 kg to 3,150 kg, and 2 trucks without compaction with a load of 2,000 kg that are mainly used for glass bottles carried directly with the box to avoid breaking of glass by compaction. Generally, one driver and one collection worker get on board. All the trucks are equipped with the digital tachographs (Fujitsu DTS-D1D), and the tracking data such as coordinate and velocity of the trucks are recorded. In addition, the drivers also record the information on operation category such as “loading”, “moving” and “unloading” by pushing the ten keys on the devices, then the input time for each is recorded. All the data are sent to the designated server by LTE communication module, and accumulated on the server.

A survey was conducted for 5 days from October 10 (Monday) to October 14 (Friday).

Furthermore, the information on collection area, waste type, collection station number were also recorded daily.

Figure 3-1 Image of digital tachograph equipment (Transtron Ltd., 2018)

3.1.2 Data Analysis

Regarding on operation categories, the data of digital tachograph for collection and transportation was classified into 4 categories of "transport time", "loading time", "moving time", "unloading time" and “other time”. There was some previous studies applied this method to break down the operation of collection system, but conducted manually by attached GPS device and video camera recording (Essien et al., 2013; N. Thanh et al., 2009).

Transporting waste is the time that truck moves from the facility (office etc.) to the first discharge point as well as moves back to the processing facility after collection is finished, "loading time" is time for loading the waste into the vehicle, the time truck moves between stations is "moving time", and "unloading time" is time for unloading waste at the processing facility. The time for other activities such as resting, truck washing, refuelling is also recorded by Tachometer, and named “Other time”.

The analysis method in each of these collection and transport processes will be described in next sections. For the analysis of tracking data and distance, ESRI's ArcGIS 10.1 was used. The tracking data, collection station data, etc. were imported into the software and analysed.

3.2 Daily working time and operation categories

Table 3.2 showed the breakdown by average working time per day and operation categories for 131 areas surveyed in district W for 5 days from October 10th to 14th. The average working time per day was 7:42:09. Regarding on each operation category, the percentage of transportation time was highest, accounting for about 35% of the total, and this seems to be influenced by the distance to a remote processing facility. Commonly, the waste facility is often located far from waste collection area. Therefore, the collection vehicles need a long time to travel to target area as well as return there after collection.

Regarding on waste collection, the loading time per day occupied for a small portion for 0:28:50. During loading time in this study, the case “a long waiting time” often occurred before loading the waste at one centre, and this was considered to be the biggest factor. Therefore, it is considerable to carry waste to one other centre where the loading time was short. In addition, the other time such as lunch time, toilets, waiting time before refuelling, refuelling and car washing reached 20%. The refuelling time was short and the car wash time was a little long, but the influences on total working time was small.

Table 3.2 Breakdown of average working time per day by operation categories in district W

	Loading	Moving	Transport	Unloading	Rest, standby, etc.	Refueling	Car wash	Total
Average	01:41:39	01:08:35	02:48:01	00:28:50	01:25:22	00:00:51	00:08:51	07:42:09
SD	00:31:55	00:27:25	00:58:00	00:20:17	00:30:39	00:01:11	00:12:30	01:48:02
%	22.0%	14.8%	36.4%	6.2%	18.5%	0.2%	1.9%	100.0%

Next, authors compared results in district W with the results of district E. Table 3.3 showed average daily working time and breakdown by operation categories. The average working time per day in district E was 7:24:53. By operation classification, the highest percentage was transport time, accounting for nearly 40% of the total. The loading time was 20% of the total and the moving time was about 15%. The unloading time in each trip was large as 0:37:19. In addition, break time such as toilets, refuelling and car washing occupied 18.1%. This was similar to the results in other study that other time occupied for 19 to 30% of total working time (Essien et al., 2013). And long other time can reduce collection efficiency.

There was no overall difference among two districts W and E. Loading/moving time were slightly larger in district W district than in district E. It is considered that district W has more collection stations, and it takes more time to collect and move between stations. Regarding on transport time, there was longer distance to the waste facility in district E, therefore transporting time was higher than district W.

Table 3.3 Breakdown of average working time per day by operation categories in district E

	Loading	Moving	Transport	Unloading	Rest, standby, etc.	Refueling	Car wash	Total
Average	01:28:45	01:03:47	02:54:38	00:37:19	01:16:40	00:00:46	00:02:58	07:24:53
SD	00:33:55	00:34:28	01:20:25	00:25:31	01:06:56	00:01:12	00:06:38	02:28:39
%	19.9%	14.3%	39.3%	8.4%	17.2%	0.2%	0.7%	100.0%

3.3 Operation of separate collection by different waste type

In this part, author calculated the total working time by 1 ton of waste, total distance by 1 ton of waste in district W and E of City A. Results were shown in Table 3.4. The unit working time among waste types are relatively different. For instance, the basic unit of working time of combustible waste was the smallest as 1.02 - 1.21 hour/ton, the PET bottle was the largest at 10.00 - 10.41 hour/ton. By this achieved value, it can be estimated that the total time required for collection each waste type in target area.

The value of time/weight, distance/weight in district W was smaller than district E, especially in the cardboard and old cloth, expressed by the difference in average time was large. In City A, since resource wastes is collected only once a month, it is conceivable that population density differs greatly between collection areas, and this would be the reason for the difference in unit working time.

Regarding on waste amount by waste type per station, the amount of PET bottle per station in district E was 5.6 kg/station and amount of combustible waste was 161.1 kg per station. It can be explained that waste density of PET bottle and combustible waste are different, then amount of waste type per station was also different. Therefore, to collect the same weight, it is necessary for a PET bottle to travel around many stations (161.1 kg/ 5.6 kg = 28.8 times), and collection distance/time becomes long.

Table 3.4 Operation unit by different waste type in two districts

	Day of the week	District W	District E	Total	F value	p
Total time / weight	Monday	0.84±0.21	1.08±0.32	0.9±0.26	7.58	0.01
	Tuesday	1.07±0.4	1.12±0.13	1.09±0.33	0.21	0.65
	Thursday	0.85±0.51	1.32±0.39	0.94±0.52	5.17	0.03
	Friday	1.01±0.3	1.36±0.27	1.15±0.33	11.42	0.00
Total distance / weight	Monday	14.12±3.86	19.53±6.76	15.38±5.15	10.33	0.00
	Tuesday	18.48±8.23	18.61±2.81	18.53±6.75	0.00	0.95
	Thursday	11.32±10.03	20.19±4.47	13.04±9.83	5.14	0.03
	Friday	15.39±5.1	20.95±5.29	17.65±5.8	8.92	0.01
Weight / Station	Monday	215.81±79.91	188.01±79.28	209.34±79.71	0.93	0.34
	Tuesday	227.34±91.33	182.9±59.26	211.39±83.28	2.67	0.11
	Thursday	173.19±61.37	136.25±31.65	166±58.35	2.35	0.13
	Friday	166.91±67.62	130.29±28.89	152.03±57.55	3.36	0.08
Weight / trip	Monday	2.37±0.35	2.35±0.42	2.37±0.36	0.02	0.88
	Tuesday	2.31±0.62	2.49±0.33	2.37±0.53	1.08	0.31
	Thursday	2.11±0.6	2.46±0.31	2.18±0.57	2.21	0.15
	Friday	2.29±0.46	2.45±0.18	2.36±0.38	1.36	0.25

3.4 Collection efficiency of Combustible Waste by Day of Week

Table 3.5 showed the comparison of the two districts by total working time per 1 ton, waste amount per station of combustible waste in different days in week. There was a significant difference for the total time per ton in Monday, Thursday, and Friday, except for Tuesday. The collected weight per station on Monday and Tuesday, which is the first half of the week, was often higher than amount in the second half Thursday and Friday it about 30% difference is recognized. It can be explained that this is influenced by the fact that the interval between collection dates is 4 days on Monday and Tuesday in the first day of the week and 3 days on Thursday and Friday in the latter half of the week.

Table 3.5 Collection of combustible waste by different day of the week in two districts

	Day of the week	District W	District E	Total	F value	p
Total time / weight	Monday	0.84±0.21	1.08±0.32	0.9±0.26	7.58	0.01
	Tuesday	1.07±0.4	1.12±0.13	1.09±0.33	0.21	0.65
	Thursday	0.85±0.51	1.32±0.39	0.94±0.52	5.17	0.03
	Friday	1.01±0.3	1.36±0.27	1.15±0.33	11.42	0.00
Weight / Station	Monday	215.81±79.91	188.01±79.28	209.34±79.71	0.93	0.34
	Tuesday	227.34±91.33	182.9±59.26	211.39±83.28	2.67	0.11
	Thursday	173.19±61.37	136.25±31.65	166±58.35	2.35	0.13
	Friday	166.91±67.62	130.29±28.89	152.03±57.55	3.36	0.08

3.5 Waste generation rate by waste type

By waste amount per station, and statistical data of resident number in that station, authors calculated the waste generation rate by each waste type. For combustible waste, the basic unit was calculated by dividing by 4 days in the first half of the week and by 3 days in the latter half of the week. Waste generation rate for combustible waste was 534 - 608.9 g / person / day. The basic unit of recycled materials in 2 districts was ranged from 2.5 ~ 24.0 g, which was considerably much smaller than combustible waste (Table 3.6). And it was also in line with result from previous study of Ishikawa (Ishikawa, 1996), it was found that waste generation rate of PET bottle in Japan was 3.13 g/person/day.

On the other hand, the total waste generation rate can be calculated by sum up all components and acquired 750 g/cap/day. This value is smaller than results from other reports such as high income countries 2.1 kg/cap/day to middle income countries 1.2 kg/cap/day (Hoornweg et al., 2012), because this waste amount in this study was mostly from household and not include other waste sources (commercial, industrial wastes etc.).

In fact, waste generation rate and composition are also different among countries. For example, waste composition percentage in Poland was estimated to be 10% paper, 25% plastic, 15% organic waste, 15% glass and 35% other mixed waste, whereas in two countries, like France and Germany, waste composition is simply estimated to be 50% organic waste, 25% plastic waste and 25% paper waste. (Singh). The results in this study showed the novelty in demonstration the detail and generation rate of different waste types in collection area.

Table 3.6 Waste generation rate by waste type in two districts

District W			District E		
Waste type	Weight / population	Unit consumption	Waste type	Weight / population	Unit consumption
	kg / person / trip	g / person / day		kg / person / trip	g / person / day
Combustible (Mon.)	2.18	544.1	Combustible (Mon.)	2.36	589.9
Combustible (Tue.)	2.14	534.4	Combustible (Tue.)	2.21	551.3
Combustible (Thurs.)	1.73	576.4	Combustible (Thurs.)	1.83	609.8
Combustible (Fri.)	1.65	549.3	Combustible (Fri.)	1.65	550.5
Newspaper	3.42	114.0	Newspaper / magazine	0.63	21.0
Magazine	0.41	13.8			
Old cloth	0.72	24.0	PET bottle, cloth, cardboard	0.10	3.5
Bottle	0.64	21.3	Bottle	0.49	16.3
Cardboard	0.27	9.0	Cardboard	0.11	3.8
Empty can	0.25	8.3	Can	0.26	8.7
Old cloth / paper pack	0.20	6.5	Cloth	0.31	10.4
Landfill waste	0.15	5.1			
PET bottles	0.07	2.5	PET bottles	0.08	2.6

3.6 Modelling

3.6.1 Modelling on loading time by different waste types

The waste loading operation consists of three steps of (1) stopping, (2) waste loading, (3) departing. Then the truck stops at a new station and restarts a new loading process. In this study, data on the total loading times of (1) to (3) per round trip, the number of stations, and the amount of waste are collected by Tachometer. Then an estimation model of loading time was constructed based on these data. The model was constructed by multiple regression analysis with the loading time as the objective variable, and the number of stations and the waste collection unit as explanatory variables. The results are shown in Table 3.7.

Table 3.7 Estimation model of loading time by item

	Time per weight (hour/t)	Station	n	R2
Combustible waste (District B)	0.156***	0.013***	104	0.977***
Combustible waste (District C)	0.212***	0.007	44	0.958***
Combustible waste (Total)	0.166***	0.012***	148	0.968***
PET bottles	1.130	0.54*	13	0.92**
Newspaper / magazine	0.168	0.016***	7	0.99***
Cardboard	0.859	0.013	12	0.968**
Can	0.267	0.035**	15	0.971***
Bottle	0.922*	0.001	14	0.929**

* $p<0.05$, ** $p<0.01$, *** $p<0.001$

The loading time was estimated to be proportional to the number of stations and waste collection amount. The partial regression coefficient of the number of stations is considered to represent the preparation time before and after loading at station, and the partial regression coefficient of the waste collection amount is the loading time per 1 ton.

3.6.2 Modelling on moving velocity for waste transport and collection

Regarding on transport velocity, there was no significant difference among area, and the average transport velocity of trucks was 26.1 km/h. In previous studies, because of insufficient data, there were many components of collection system were assumed with the constant values, such as hauling velocity (40km/h) both in the City And suburban areas (Sonesson, 2000).

Regarding on the moving velocity between stations, it is expected that the moving velocity varies depending on the region. The regional factor in this study was demonstrated as population density by town. Therefore, authors decided to categorize the area by cluster analysis using two variables of average moving velocity and population density by town ,because the important variables would have high impact on the clustering solution (Sarstedt et al., 2014). Clustering is the classification of objects into groups called clusters. Objects from the same cluster are more similar to one another than objects from different clusters (Böhm et al., 2013). For cluster analysis, the process can be shown in a dendrogram, which is used to illustrate the arrangement of the clusters produced (Saraf et al., 2016). Similar characteristics objects are in the same cluster, and between each cluster there is a large distance (Sarstedt et al., 2014). This method of cluster analysis was also applied in other studies for categorizing samples (Mosler et al., 2006; Zhou et al., 2014; Žičkienė et al., 2005).

The dendrogram obtained by cluster analysis in this study was shown in Figure 3.2.

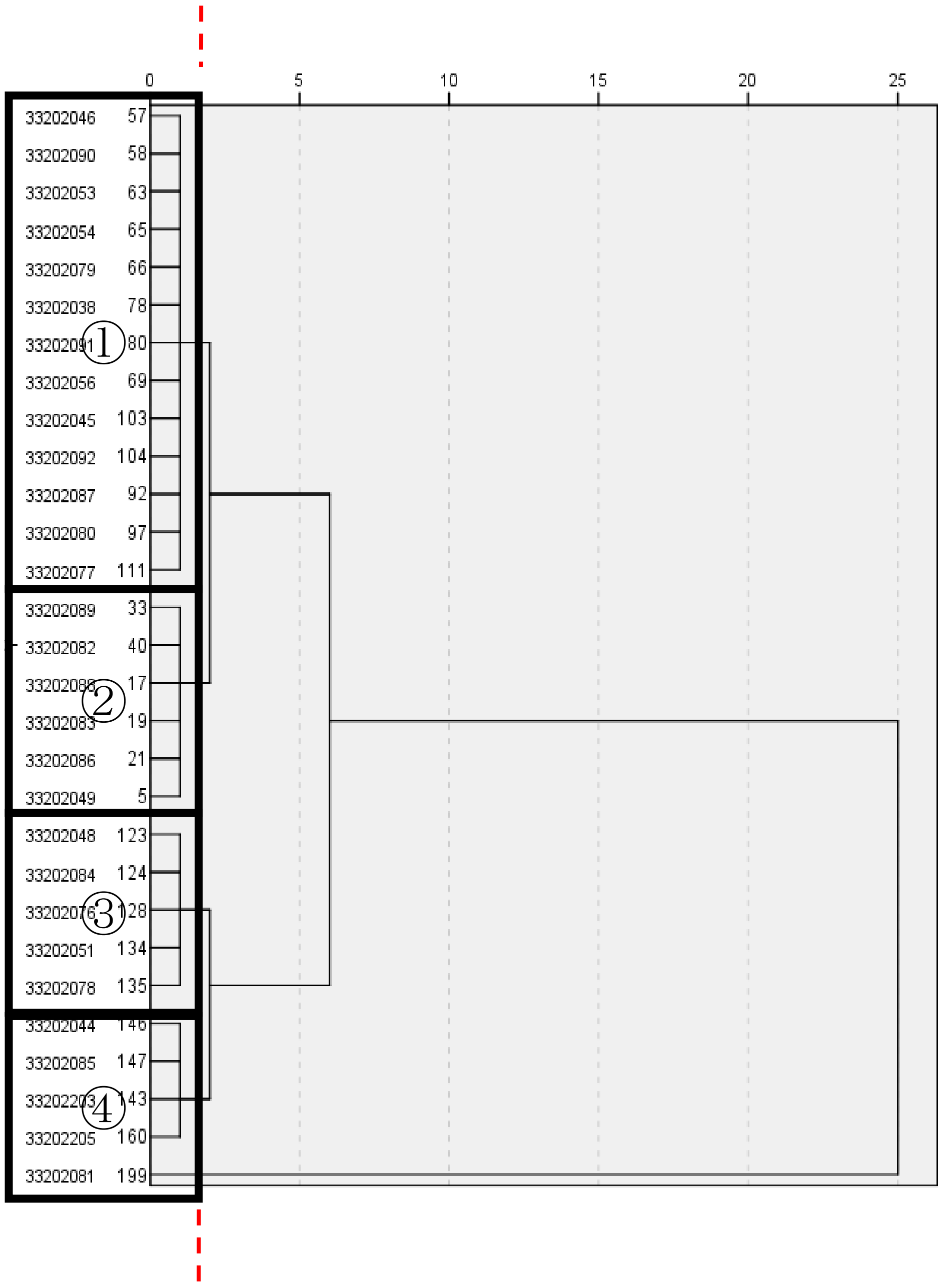


Figure 3-2 Dendrogram obtained using average moving velocity and population density by town

According to the results depicted in the image of dendrogram, it was classified into 5 groups, but there was only one area in one group corresponding to the highest level in the population density, authors decided to integrate it into the group with the fourth population density.

Next, the results of calculating the average moving velocity for each of the 4 groups are shown in Table 3.8. As a result of the multiple comparison, since there was no significant difference between Group 3 and Group 4, authors decided to consolidate these two groups and categorize the area into three groups of Group 1, Group 2, Group 3.

Table 3.8 Average moving velocity by group

Group	n	Average value	Standard deviation	F	p
1	338	17.2	6.4	131.7	0.000
2	1,571	11.9	5.3		
3	685	10.8	5.1		
4	600	11.0	4.6		
Total	3,194	12.1	5.6		

As for the moving velocity, it is also thought that the distance between the collection stations also has influences (B. G. Wilson et al., 2001). The results of examining the correlation of distance between collection stations and the moving velocity were shown in Table 3.9. Correlation was found between the moving velocity and the distance between the collection stations, and it was showed that the correlation coefficient is higher for logarithmically transformed of distance between collection stations.

Table 3.9 Correlation analysis result of moving velocity and distance between collection stations

		Moving Velocity
Distance between collection points	Pearson	0.518
	p	0.000
	N	3195
Distance between collection points logarithmically transformed	Pearson	0.638
	p	0.000
	N	3158

This result revealed that the moving velocity was affected by the distance between stations. Next, authors constructed an estimation model of moving velocity using two factors as distance between stations and population density. The model was constructed by multiple regression analysis with the moving collection velocity Are the objective variable, and explanatory variable candidates were logarithmic transformation distance and dummy variables of group 1 and group 2, which are indicators of regional characteristics. The results were shown in Table 3.10. The moving velocity of vehicle in target area then can be estimated based on distance between collection stations and population density group.

Table 3.10 Estimation model of moving velocity

n	Constant	Log transformed distance	Variable 1	Variable 2	R^2
3195	1.008***	7.937***	3.859***	0.341*	0.669***

3.7 Conclusion for section 3

In this study, authors tried to combine the data of district W and E in City A together to examine the relationship between working efficiency and regional factors. Authors also statistically studied the relationship between collection efficiency and regional factors and built estimation models. The results from models were applied in an optimal scenario for waste collection.

The main results of this research are as follows.

(1) From the digital tachograph and the daily work report, data on work categories, distance, collection time of collecting vehicles for combustible and resource waste was prepared. In addition, basic units such as time, distance for each operation categories were also received.

(2) Regarding on operation time, the average working hours per day and breakdown by work categories did not differ much between W and E districts. Average working time per day in 2 districts was 7:35:45 to 7:42:09. By operation classification, the highest percentage was transport time, accounting for nearly 40% of the total.

(3) Regarding waste separate collection, in W and E districts, the significant difference in collection time per weight of combustible waste per trip was found in. The combustible waste was the smallest at 1.02 hours / t, and the PET bottle was the longest at 10.41 hours / t.

(4) In the comparison of unit of collecting combustible waste per day in two districts, a significant difference was found among the total time and total distance per 1 ton except Tuesday. For combustible waste, the basic unit was calculated by dividing by 4 days in the first half of the week and by 3 days in the latter half of the week. Waste generation rate for combustible waste was 534 - 608.9 g / person / day. The basic unit of recycled materials in 2 districts was ranged from 2.5 ~ 24.0 g, which was considerably much smaller than combustible waste.

(5) A prediction model was constructed with regard to loading time, and moving velocity, taking regional characteristics into consideration.

(6) By the optimized route in GIS, the collection time and distance were reduced in comparison to current status in district.

(7) This separate collection system can be introduced for other waste collection system in developing countries to increase collection efficiency as well as recyclable waste collection enhancement, also can reduce the financial burden by low frequency collection.

Reference for section 3

Abarca-Guerrero, L., Maas, G., & Hogland, W. (2015). Solid waste management challenges for cities in developing countries. Revista Tecnología en Marcha, 28(2), 141-168.

Abdulai, H., Hussein, R., Bevilacqua, E., & Storrings, M. (2015). GIS Based Mapping and Analysis of Municipal Solid Waste Collection System in Wa, Ghana. Journal of Geographic Information System, 7(02), 85.

Agarwal, R., Chaudhary, M., & Singh, J. (2015). Waste Management Initiatives in India for human well being. European Scientific Journal, ESJ, 11(10).

Ahmed, S. A., & Ali, S. M. (2006). People as partners: Facilitating people's participation in public–private partnerships for solid waste management. Habitat International, 30(4), 781-796.

Allesch, A., & Brunner, P. H. (2014). Assessment methods for solid waste management: A literature review. Waste Management & Research, 32(6), 461-473.

Apaydin, O., & Gonullu, M. (2007). Route optimization for solid waste collection: Trabzon (Turkey) case study. Global NEST Journal, 9(1), 6-11.

Apaydin, O., & Gonullu, M. (2011). Route time estimation of solid waste collection vehicles based on population density. Global NEST Journal, 13(2), 162-169.

Aremu, A. S., Mihelcic, J. R., & Fatai Sule, B. (2011). Trip time model for municipal solid waste collection applicable to developing countries. Environmental technology, 32(15), 1749-1754.

Arribas, C. A., Blazquez, C. A., & Lamas, A. (2010). Urban solid waste collection system using mathematical modelling and tools of geographic information systems. Waste Management & Research, 28(4), 355-363.

Beliën, J., De Boeck, L., & Van Ackere, J. (2011). Municipal Solid Waste Collection Problems: A Literature Review.

Bhambulkar, A. V. (2011). Municipal solid waste collection routes optimized with arc gis network analyst. International Journal Of Advanced Engineering Sciences And Technologies Vol(11), 202-207.

Bodansky, D. (2016). The legal character of the Paris Agreement. Review of European, Comparative & International Environmental Law, 25(2), 142-150.

Böhm, K., Smidt, E., & Tintner, J. (2013). Application of multivariate data analyses in waste management Multivariate analysis in management, engineering and the sciences: InTech.

Briš, M. (2007). Sensitivity analysis as a managerial decision making tool. Paper presented at the Interdisciplinary Management Research.

Canter, L. W., Canter, L. W., Canter, L. W., & Canter, L. W. (1996). Environmental impact assessment.

Chalkias, C., & Lasaridi, K. (2009a). A GIS based model for the optimisation of municipal solid waste collection: The case study of Nikea, Athens, Greece. technology, 1, 11-15.

Chalkias, C., & Lasaridi, K. (2009b). Optimizing municipal solid waste collection using GIS. Paper presented at the 5th International Conference on Energy, Environment, Ecosystems and Sustainable Development/2nd International Conference on Landscape Architecture, Greece. In: Proceedings of Energy, Environment, Ecosystems, Development and, Landscape Architecture.

Choi, H. C., & Turk, E. S. (2011). Sustainability indicators for managing community tourism Quality-of-life community indicators for parks, recreation and tourism management (pp. 115-140): Springer.

D'Onza, G., Greco, G., & Allegrini, M. (2016). Full cost accounting in the analysis of separated waste collection efficiency: A methodological proposal. Journal of Environmental Management, 167, 59-65.

Dahlén, L. (2008). Household waste collection: factors and variations. Luleå tekniska universitet.

David, A. (2013). Technical document on municipal solid waste organics processing: Environment Canada= Environnement Canada.

Demirbas, A. (2009). Political, economic and environmental impacts of biofuels: A review. Applied energy, 86, S108-S117.

Dincer, I. (2000). Renewable energy and sustainable development: a crucial review. Renewable and sustainable energy reviews, 4(2), 157-175.

DO-PHAM, C., & Tran-Nam, B. (2004). The Vietnamese economy: Awakening the dormant dragon: Routledge.

Doğan, K., & Süleyman, S. (2003). Report: Cost and financing of municipal solid waste collection services in Istanbul. Waste Management & Research, 21(5), 480-485.

Ebreo, A., Hershey, J., & Vining, J. (1999). Reducing solid waste: Linking recycling to environmentally responsible consumerism. Environment and Behavior, 31(1), 107-135.

El-Fadel, M., Findikakis, A. N., & Leckie, J. O. (1997). Environmental impacts of solid waste landfilling. Journal of Environmental Management, 50(1), 1-25.

Eriksen, M., Lebreton, L. C., Carson, H. S., Thiel, M., Moore, C. J., Borerro, J. C., . . . Reisser, J. (2014). Plastic pollution in the world's oceans: more than 5 trillion plastic pieces weighing over 250,000 tons afloat at sea. PloS one, 9(12), e111913.

Essien, O. E., & Udo, J. (2013). Estimating Time Loss Effects On Municipal Solid Waste Collection Using Haul Container System In Uyo Nigeria. American Journal of Engineering Research.

Ezeah, C., Roberts, C., & Phillips, P. S. (2010). Evaluation of public health impacts of scavenging in Abuja, Nigeria using Q Methodology. International Journal of Environmental Health Research, 300-310.

Ghisellini, P., Cialani, C., & Ulgiati, S. (2016). A review on circular economy: the expected transition to a balanced interplay of environmental and economic systems. Journal of Cleaner Production, 114, 11-32.

Ghose, M., Dikshit, A. K., & Sharma, S. (2006). A GIS based transportation model for solid waste disposal–A case study on Asansol municipality. Waste management, 26(11), 1287-1293.

Greco, G., Cenciarelli, V. G., & Allegrini, M. (2017). Tourism's impacts on the costs of municipal solid waste collection: Evidence from Italy. Journal of Cleaner Production.

Haas, W., Krausmann, F., Wiedenhofer, D., & Heinz, M. (2015). How circular is the global economy?: An assessment of material flows, waste production, and recycling in the European Union and the world in 2005. Journal of Industrial Ecology, 19(5), 765-777.

Hong, S.-Y. (1995). Marine policy in the Republic of Korea. Marine Policy, 19(2), 97-113.

Hoornweg, D., & Bhada-Tata, P. (2012). What a waste: a global review of solid waste management.

Ishikawa, M. (1996). A logistics model for post-consumer waste recycling. significance, 2, 0.679.

Issahaku, I., Nyame, F. K., & Brimah, A. K. (2014). Waste Management Strategies in an Urban Setting Example from the Tamale Metropolis, Ghana. Journal of Waste Management, 2014.

Kallel, A., Serbaji, M. M., & Zairi, M. (2016). Using GIS-Based Tools for the Optimization of Solid Waste Collection and Transport: Case Study of Sfax City, Tunisia. Journal of Engineering, 2016.

Karadimas, N. V., & Loumos, V. G. (2008). GIS-based modelling for the estimation of municipal solid waste generation and collection. Waste Management & Research, 26(4), 337-346.

Kathiravale, S., Yunus, M. N. M., Sopian, K., Samsuddin, A., & Rahman, R. (2003). Modeling the heating value of Municipal Solid Waste☆. Fuel, 82(9), 1119-1125.

Klass, D. L. (1998). Biomass for renewable energy, fuels, and chemicals: Elsevier.
Kubo, K., & Leader, P. T. (2014). Recycling in Japan. Application of Reclaimed Asphalt Pavement and Recycled Asphalt Shingles in Hot-Mix Asphalt, Vols. TR Circular E-C188, 60-66.

Lebreton, L., Slat, B., Ferrari, F., Sainte-Rose, B., Aitken, J., Marthouse, R., . . . Levivier, A. (2018). Evidence that the Great Pacific Garbage Patch is rapidly accumulating plastic. Scientific reports, 8(1), 4666.

Lehmann, S. (2010). Resource recovery and materials flow in the city: Zero waste and sustainable consumption as paradigms in urban development. Sustainable Dev. L. & Pol'y, 11, 28.

Lohri, C. R., Camenzind, E. J., & Zurbrügg, C. (2014). Financial sustainability in municipal solid waste management–Costs and revenues in Bahir Dar, Ethiopia. Waste management, 34(2), 542-552.

Longe, E., & Williams, A. (2006). A preliminary study of medical waste management in Lagos metropolis, Nigeria. Iran J Environ Health Sci Eng, 3(2), 133-139.

Lusher, A., Hollman, P., & Mendoza-Hill, J. (2017). Microplastics in fisheries and aquaculture. Status of knowledge on their occurrence and implications for aquatic organisms and food safety. FAO Fisheries and Aquaculture Technical Paper, 615.

Malakahmad, A., Bakri, P. M., Mokhtar, M. R. M., & Khalil, N. (2014). Solid waste collection routes optimization via GIS techniques in Ipoh city, Malaysia. Procedia Engineering, 77, 20-27.

McAllister, J. (2015). Factors influencing solid-waste management in the developing world.

Mosler, H. J., Drescher, S., Zurbrügg, C., Rodriguez, T. C., & Miranda, O. G. (2006). Formulating waste management strategies based on waste management practices of households in Santiago de Cuba, Cuba. Habitat International, 30(4), 849-862.

Mourad, M. (2015). France moves toward a national policy against food waste. Natural Resources Defense Council.

Nguyen, T. T., & Wilson, B. G. (2010). Fuel consumption estimation for kerbside municipal solid waste (MSW) collection activities. Waste Management & Research, 28(4), 289-297.

Okuwaki, A. (2004). Feedstock recycling of plastics in Japan. Polymer Degradation and Stability, 85(3), 981-988.

Olukanni, D., Adeleke, J., & Aremu, D. (2016). A Review of Local Factors affecting Solid Waste Collection in Nigeria. Pollution, 2(3), 339-356.

Organisation, A. P. (2007). Solid waste management, issues and challenges in Asia. AP Organisation, Tokyo Google Scholar.

Pan, C., Lu, J., Wang, D., & Ran, B. (2008). Data collection based on global positioning system for travel time and delay for arterial roadway network. Transportation Research Record: Journal of the Transportation Research Board(2024), 35-43.

Pappu, A., Saxena, M., & Asolekar, S. R. (2007). Solid wastes generation in India and their recycling potential in building materials. Building and environment, 42(6), 2311-2320.

Peters, G. P., Weber, C. L., Guan, D., & Hubacek, K. (2007). China's growing CO2 emissions a race between increasing consumption and efficiency gains: ACS Publications.

Premakumara, D., Abe, M., & Maeda, T. (2011). Reducing municipal waste through promoting integrated sustainable waste management (ISWM) practices in Surabaya city, Indonesia. WIT Transactions on Ecology and the Environment, 144, 457-468.

Qdais, H. A. (2007). Techno-economic assessment of municipal solid waste management in Jordan. Waste management, 27(11), 1666-1672.

Rauch, J. N., & Newman, J. (2008). Research and solutions: zeroing in on sustainability. Sustainability: The Journal of Record, 1(6), 387-390.

Rezaee, R. (2014). Estimation of gas emission released from a municipal solid waste landfill site through a modeling approach: A case study, Sanandaj, Iran. Journal of Advances in Environmental Health Research, 2(1).

Sankoh, F. P., Yan, X., & Tran, Q. (2013). Environmental and health impact of solid waste disposal in developing cities: A case study of granville brook dumpsite, Freetown, Sierra Leone. Journal of Environmental Protection, 4(07), 665.

Saraf, R., & Patil, S. (2016). Market-Basket Analysis using Agglomerative Hierarchical approach for clustering a retail items. International Journal of Computer Science and Network Security (IJCSNS), 16(3), 47.

Sarstedt, M., & Mooi, E. (2014). A concise guide to market research. The Process, Data, and.

Sasikumar, K., & Krishna, S. G. (2009). Solid waste management: PHI Learning Pvt. Ltd.

Schüch, A., Morscheck, G., Lemke, A., & Nelles, M. (2016). Bio-waste recycling in Germany–further challenges. Procedia Environmental Sciences, 35, 308-318.

Seyring, N., Dollhofer, M., Weißenbacher, J., Herzog, M., McKinnon, D., & Bakas, I. (2015). Assessment of separate collection schemes in the 28 capitals of the EU. Final report, Nov.

Shahmoradi, B. (2013). Collection of municipal solid waste in developing countries: Taylor & Francis.

Sharholy, M., Ahmad, K., Mahmood, G., & Trivedi, R. (2008). Municipal solid waste management in Indian cities–A review. Waste management, 28(2), 459-467.
Shinohara, M. (2010). Maritime cluster of Japan: implications for the cluster formation policies. Marit. Pol. Mgmt., 37(4), 377-399.

Singh, N. Waste Separation at Household Level: Comparison and Contrast Among 40 Countries.

Sonesson, U. (2000). Modelling of waste collection–a general approach to calculate fuel consumption and time. Waste Management and Research, 18(2), 115-123.

Stahel, W. R. (2016). The circular economy. Nature News, 531(7595), 435.

Tai, J., Zhang, W., Che, Y., & Feng, D. (2011). Municipal solid waste source-separated collection in China: A comparative analysis. Waste management, 31(8), 1673-1682.

Talebbeydokhti, N., Amiri, H., Shahraki, M. H., Azadia, S., & Ghahfarokhi, S. G. (2013). Optimization of Solid Waste Collection and Transportation System by Use of the TransCAD: A Case Study. Archives of Hygiene Sciences Volume, 2(4).

Tavares, G., Zsigraiova, Z., Semiao, V., & Carvalho, M. d. G. (2009). Optimisation of MSW collection routes for minimum fuel consumption using 3D GIS modelling. Waste management, 29(3), 1176-1185.

Thanh, N., Matsui, Y., Ngan, N., Trung, N., Vinh, T., & Yen, N. (2009). GIS application for estimating the current status and improvement on municipal solid waste collection and transport system: Case study at Can Tho city, Vietnam. Asian Journal on Energy and Environment, 10(02), 108-121.

Thanh, N. P., Matsui, Y., & Fujiwara, T. (2011). Assessment of plastic waste generation and its potential recycling of household solid waste in Can Tho City, Vietnam. Environmental Monitoring and Assessment, 175(1-4), 23-35.

Tin, A. M., Wise, D. L., Su, W.-H., Reutergardh, L., & Lee, S.-K. (1995). Cost—benefit analysis of the municipal solid waste collection system in Yangon, Myanmar. Resources, conservation and recycling, 14(2), 103-131.

Troschinetz, A. M., & Mihelcic, J. R. (2009). Sustainable recycling of municipal solid waste in developing countries. Waste management, 29(2), 915-923.

Tukker, A. (2015). Product services for a resource-efficient and circular economy–a review. Journal of Cleaner Production, 97, 76-91.

Wilson, B. G., & Baetz, B. W. (2001). Modeling municipal solid waste collection systems using derived probability distributions. I: Model development. Journal of environmental engineering, 127(11), 1031-1038.

Wilson, D. C. (2007). Development drivers for waste management. Waste Management & Research, 25(3), 198-207.

Wilson, D. C., Araba, A. O., Chinwah, K., & Cheeseman, C. R. (2009). Building recycling rates through the informal sector. Waste management, 29(2), 629-635.

Wilson, D. C., Velis, C., & Cheeseman, C. (2006). Role of informal sector recycling in waste management in developing countries. Habitat International, 30(4), 797-808.

Yadav, S. K. (2013). GIS Based approach for site selection in waste management. International Journal of Environmental Engineering and Management, 4, 507-514.

Yolin, C. (2015). Waste management and recycling in Japan opportunities for European companies (SMEs focus). EU-Japan Center for Industrial Cooperation: Tokyo, Japan.

Zall Kusek, J., & Rist, R. (2004). Ten steps to a results-based monitoring and evaluation system: a handbook for development practitioners: The World Bank.

Zaman, A. U., & Lehmann, S. (2011a). Challenges and opportunities in transforming a city into a “zero waste city”. Challenges, 2(4), 73-93.

Zaman, A. U., & Lehmann, S. (2011b). Urban growth and waste management optimization towards ‘zero waste city’. City, Culture and Society, 2(4), 177-187.

Zamorano, M., Molero, E., Grindlay, A., Rodríguez, M. L., Hurtado, A., & Calvo, F. J. (2009). A planning scenario for the application of geographical information systems in municipal waste collection: A case of Churriana de la Vega (Granada, Spain). Resources, conservation and recycling, 54(2), 123-133. doi: http://dx.doi.org/10.1016/j.resconrec.2009.07.001

Zhou, H., Meng, A., Long, Y., Li, Q., & Zhang, Y. (2014). Classification and comparison of municipal solid waste based on thermochemical characteristics. Journal of the Air & Waste Management Association, 64(5), 597-616.

Zhuang, Y., Wu, S.-W., Wang, Y.-L., Wu, W.-X., & Chen, Y.-X. (2008). Source separation of household waste: a case study in China. Waste management, 28(10), 2022-2030.

Žičkienė, S., Tričys, V., & Kovierienė, A. (2005). Municipal solid waste management: data analysis and management options. Environmental research, engineering and management, 3(33), 47-54.

Zsigraiova, Z., Semiao, V., & Beijoco, F. (2013). Operation costs and pollutant emissions reduction by definition of new collection scheduling and optimization of MSW collection routes using GIS. The case study of Barreiro, Portugal. Waste management, 33(4), 793-806.

Zurbrügg, C., Caniato, M., & Vaccari, M. (2014). How assessment methods can support solid waste management in developing countries—a critical review. Sustainability, 6(2), 545-570.

4 SCENARIO ANALYSIS

4.1 Scenario definition and calculation condition

First, the author defined 3 representative scenarios based on the current 3 practices in Da Nang City As follows:

Scenario 1: Door-to-door collection by tricycle and transport by truck,

Scenario 2: Door-to-door collection and transport by truck,

Scenario 3: Dustbin collection and transport by truck

In addition, the author also defined a scenario for separate collection of bio-waste as the most prospective scenario in the near future. In reference to Japanese practices for bio-waste separation, the author assumed that the waste was separated into 2 categories, i.e., bio-waste and other waste, to be collected by plastic bags at the station.

Scenario 4: Separate collection and transport of bio-waste by plastic bag

The unit loading time for plastic bags for other waste and bio-waste bags in Scenario 4 was referred from Japanese operation data [Matsui Y., 2009].

Table 4.1 Unit loading time for Scenario 4

Waste bag	Unit loading time (second/bag)
Other waste	3.15
Bio-waste	5.97

Moreover, to understand widely about separate collection system for different waste type, author applied the data from City A to construct one scenario in Da nang city to clarify the operation efficiency as well as cost estimation. There were 6 types of trucks to collect separately 6 types of waste: combustible waste, newspaper/magazine, PET bottle, cardboard, can, glass bottle. The basic data for estimation was referred from Da Nang waste collection system and loading time per station by different waste type in City A.

Scenario5: separate collection for different waste types

The data for cost comparison from Da Nang URENCO in term of operation cost, investment cost, maintenance cost of vehicle, personnel, and facilities. The cost for informal sector was achieved from Hue city, Vietnam in 2010 with related to purchase price of informal sector for recycle wastes.

Based on the abovementioned analytical results on MSW collection and transport operation from 2 cities in previous sections, the author intended to compare the operation efficiencies of some representative alternatives by scenario analysi and the effects of influencing factors such as collection frequency, truck capacity, transport distance and waste separation system.

The definition of the scenario was shown in Table 4.2. The target area for scenario analysis was Hoa Cuong Nam ward in Hai Chau district, which was surveyed, and the basic data for scenario analysis are summarized

Figure 4-1 Map of target area for scenario analysis

Table 4.2 Definition of Scenario and applied vehicle

Scenario		Function	Applied vehicle	Loading capacity (ton/trip)
1	Door-to-door collection by tricycle and transport by truck	Collection	Tricycle	0.21
		Transport	9t truck	8.7*
2	Door-to-door collection and transport by truck	Collection and transport	3.5t truck	3.2*
3	Dustbin collection and transport by truck	Collection and transport	9t truck	8.7*
		Distribution and collection of empty dustbin	Mini-truck	-
4	Separate collection and transport of bio-waste by plastic bag	Collection and transport of bio-waste	9t truck	8.7*
		Collection and transport of other waste	9t truck	8.7*

*The loading capacity of truck was assumed to be full capacity - 300 kg.

Table 4.3 Basic data for scenario analysis

Item	Value	Note
Population	20,360 persons	Population in Hoa Cuong Nam ward (Da Nang Statistical data, 2014)
Area	2.11 km^2	Area in Hoa Cuong Nam ward
Number of households	4,952 households	Households in Population in Hoa Cuong Nam ward
Average household size	4.1 persons/household	Calculated from abovementioned data
Waste generation rate	0.55 kg/cap/day	Waste generation rate in Section 3.1
Waste generation amount	11.2 tons/day	Calculated from abovementioned data
Percentage of bio-waste	68.40%	MONRE, 2011
Separation rate of bio-waste	50.00%	Assumption based on Japanese practice
Distance from landfill site to target area	12.8km	Actual measurement on map
Collection frequency	Everyday	Current status

4.2 Dustbin allocation and collection distance

Practice 1 was actually applied to the target area, while Practice 3 had not been applied yet. For the estimation of Scenarios 3 and 4, the author needed to assume the position of dustbin, and calculate the needed number of dustbins and the distance for collection in the target area.

By using the GIS software and database on land use and street, the author conducted the following works to calculate the collection route for Scenarios 3 and 4 in the target area:

1) Clarify the collection area (excluding green, official, sport areas) and passable street by truck (4m width or wider)

2) Allocate dustbins at intersections and uncovered areas by 100 m buffer area from the intersections

3) Build Thiessen (Voronoi) Polygons by the abovementioned dustbin positions (Abdulai et al., 2015). Thiessen polygons are polygons whose boundaries define the area that is closest to each point relative to all other points. They are mathematically defined by the perpendicular bisectors of the lines between all points. The boundary of collection area was also considered to construct the polygons.

4) Based on the area of each poligon, calculate the corresponding population by population/km^2 in the target collection area, then estimate the waste generation amount by 0.55 kg/cap/d as well as the number of needed dustbins.

5) Calculate the optimum route for traveling around all the points of allocated dustbins by Network Analyst of ArcGIS 10.1 (Chalkias et al., 2009b), and measure the total distance for collection in the target area.

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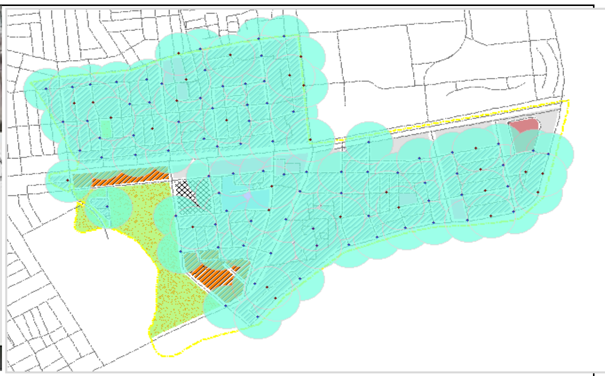
<td></td>
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<tr>
<td>(1) Clarify the collection area and passable street by truck</td>
<td>(2) Allocate dustbins at intersections and uncovered area by 100 m buffer area from the intersections</td>
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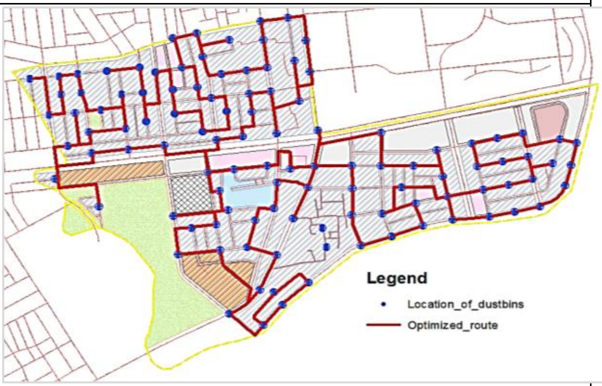
<td>
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<tr>
<td>(3) Build Thiessen (Voronoi) Polygons by the abovementioned dustbin positions

(4) Based on the area of each poligon, calculate the corresponding population, waste generation amount and number of needed dustbins</td>
<td>(5) Calculate the optimum route for traveling around all the points of allocated dustbins by Network Analyst of ArcGIS software, and measure the total distance for collection. Two dustbins located along narrow streets were assumed to be moved to the neighbor points along passable street by the residents.</td>
</tr>
</table>

Figure 4-2 Outline of estimation of fixed time dustbin collection

Then all the achieved data from previous sections were synthesized and applied for scenario analysis.

Number of fixed time dustbin and optimized collection distance

For dustbin allocation and collection distance for Forklift truck 9t in Scenario 3, the results was estimated by Network Analyst in GIS. The target area needs 217 dustbins at 110 points, and the collection distance is 16.6km

Table 4.4 Conditions of system by estimation

Need dustbin	Collection point	Collection distance (km)
217	110	16.6

4.3 Uncertainty and Sensitivity analysis

In solid waste collection system, the impact factors can concern with uncertainties of the system. Uncertainty analysis is performed in order to describe the range of possible outcomes given a set of inputs which obtained from survey data analysis. A full quantitative uncertainty assessment is so far too time consuming to be applied on each model. The realization of the Monte Carlo simulation itself does not demand so much time, due to the use of the special software package. Crystal Ball software which was used to analysis in this study is an analytical tool that helps executives, analysts, and others make decisions by performing simulations on spread sheet models.

Moreover, a model is very useful for determining the impact of a change in any input variable in a sensitivity analysis. Many studies have applied sensitivity analysis to clarify the appropriate solution in the process of decision making (Briš, 2007). Sensitivity analysis can establishes feasible collection routes or scenario by comparing to evaluate the potential impact, the efficiency and cost among results (Arribas et al., 2010). For that reason, sensitivity analysis is performed in order to describe how sensitive the outcome variables are to variation of individual input parameter and help the managers to decide where they should focus data collection efforts.

4.4 Operation parameters for scenario analysis

For the scenario analysis, the author intended to estimate the needed person-hours/t as the representative indicator for operation efficiency. In reference to the abovementioned analytical results on operation, the author extracted the needed operation parameters applied for scenario analysis. Based on the definition, basic data and operation paremeters for scenario analysis, the author calculated the person-hours/t for waste collection and transport.

Table 4.5 Operation parameters applied for scenario analysis

		Component for calculation	Unit	Scenario 1		Scenario 2	Scenario 3		Scenario 4	
Function				Collection	Transport	Collection and transport	Collection and transport	Distribution and collection of empty dustbin	Collection and transport of other waste	Collection and transport of bio-waste
Type of Vehicle				Tricycle	9t truck	3.5t truck	9t truck	Mini-truck	9t truck	9t truck
Number of workers				1	3	3	3	2	3	3
Moving forward/backward		Moving distance/trip	km/trip		25.6	25.6	25.6		25.6	25.6
		Moving velocity	km/hour		33.82	33.82			33.82	33.82
		Moving time/trip	hour/trip	0.11			(Apply model)		(Apply model)	(Apply model)
Collection	Total collection time	Collection time/trip	hour/trip	0.45	1.18					
		Collection time/waste amount	hour/ton			0.86				
	Preparation	Preparation time/station	second/station				7.5		7.5	7.5
		Number of station/day	station/day				110		110	110
	Loading	Loading time/dustbin	second/dustbin				23.2	59.34		
		Number of dustbin/day	dustbin/day				217			
		Other waste: Loading time/bag	second/bag						3.15	
		Other waste: Number of bag/day	bag/day						4925	
		Bio-waste: Loading time/bag	second/bag							5.97
		Bio-waste: Number of bag/day	bag/day							4925
	Moving between points	Moving distance/day	km/day				16.6		16.6	16.6
		Moving Velocity	km/hour				(Apply model)		(Apply model)	(Apply model)
Unloading		Unloading time/trip	hour/trip	0.09	0.24	0.24	0.24		0.24	0.24
Other		Other time/trip	hour/trip	0.11	0.16	0.16	0.16		0.16	0.16

The parameter moving velocity for Scenario 3 was also applied by model of moving velocity and transport velocity achieved in Section 3. The moving time was calculated by each road from road category and moving distance. This moving distance was from GIS Network Analyst.

Moving velocity

The moving velocity was calculated by each road in this area which had been optimized the collection routes. The require data to calculate velocity on each road was road category and moving distance on each road to apply to model. Finally, moving time was computed by moving distance divide for moving velocity. The total moving time in this target area was total moving time on roads. The results showed that the truck took 1.15 hour/day for moving all the roads to collect waste.

Transport velocity

The distance from landfill site to target area in this section was 12.8 km, then it took 25.6 km for transpot forward and backward. The transport velocity was calculated by each road on the transport route. The require data to calculate transport velocity on each road was road category and transport distance on each road to apply to transport model. Finally, transport time was computed by transport distance divide for transport velocity. The total transport time in this target area was total transport time on roads. The results showed that the truck took 1.22 hour for transport waste forward and backward in a day.

4.5 Operation efficiency by scenario

Table 4.6 indicates the operation efficiency of each scenario and some relevant values for the scenario analysis.

Among the current 3 practices, Scenario 1 “Door-to-door collection by tricycle and transport by truck” had the lowest efficiency of 4.37 person-hours/t, the tricycle needed larger number of trips because of the small loading capacity, and spent a longer collection time (39.46 h/d) than other scenarios. The operation efficiency of Scenario 2 “Door-to-door collection and transport by truck” was 3.65 person-hours/t, which was slightly better than Scenario 1. Scenario 3 “Dustbin collection and transport by truck” achieved the highest efficiency of 2.10 person-hours, which was less than half of Scenario 2. The contribution of mini-truck applied to empty dustbin contribution and collection was 59.34 s/dustbin, which was not ignorable in total human resources. It also demonstrated that DB collection had higher efficiency than door-to-door collection.

Regarding the separate collection of bio-waste, the operation efficiency of Scenario 4 was 3.40 person-hours/t. It was better than door-to-door collection scenarios, which means Scenario 4 would be a feasible alternative that can replace Practices 1 and 2.

Table 4.6 Operation efficiency by Scenario

	Unit	Scenario 1		Scenario 2	Scenario 3		Scenario 4	
		Pedal tricycle	Forklift truck	Compactor Truck	Forklift truck	Mini-truck	Forklift truck	Forklift truck
Total waste amount	ton/day	11.20	11.20	11.20	11.20	11.20	3.81	7.39
Loading capacity	ton/trip	0.21	8.70	3.20	8.70		8.70	8.70
No. of trips	trip/day	53.32	1.29	3.50	1.29		0.44	0.85
Total time	hour/day	39.46	2.99	13.64	4.25	3.58	5.98	6.69
Efficiency	Person-hour/ton	3.57	0.80	3.65	1.14	0.96	4.71	2.72
Total efficiency	Person-hour/ton	4.37		3.65	2.10		3.40	

4.6 Uncertainty analysis

Other transport length had high impact to collection efficiency (68.9%) made high contribution to the collection efficiency. This could be suggested to think about transfer station instead of transporting waste directly waste from collection area to landfill site with a long distance. Moving collection distance and the other time during collection also have some impact on collection efficiency (10.5and 10.3%, respectively). The other time in collection consists many other activities such as: break time, coffee time, truck broken… To reduce the other time, it is necessary to monitor and control the collection trip properly in term of schedule, time, and distances. In addition, maintenance of vehicles is also needed to be implemented regularly.

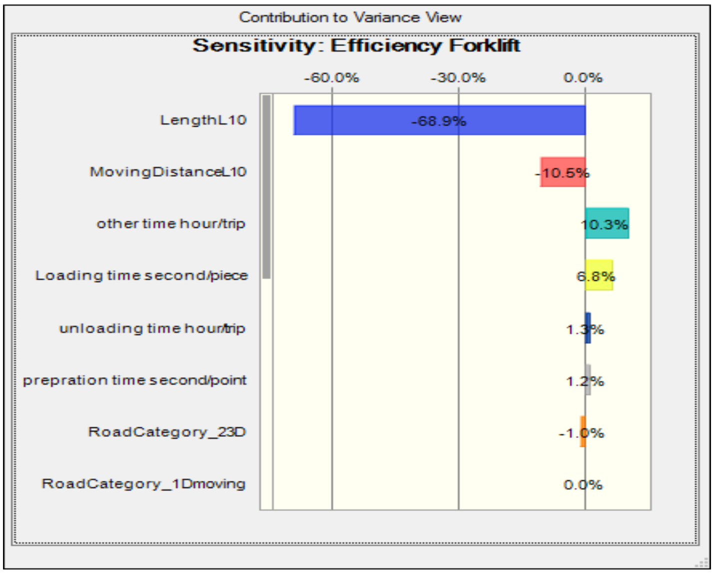

Figure 4-3 Uncertainty analysis of operation parameters in Scenario 3

4.7 Sensitivity analysis

The design variables of waste collection and transport would affect the operation efficiency. The author focused on Scenario 3 as the best practice, and conducted sensitivity analysis to clarify the effects of influencing factors on operation efficiency such as collection frequency, truck capacity, and distance to landfill site. The collection frequency affects the collection area for one day, e.g., the collection area of “Once per week” is one seventh of that of “7 days per week”. It thus affects the collection time. The truck capaCity Affects the needed number of trip, and the distance to landfill site affects the distance of moving forward and backward. Thus these 2 factors affect the transport time.

In addition, the author focused on Scenario 4 as the most prospective practice in the near future, and conducted sensitivity analysis by collecting frequencies and separating the rate of bio-waste.

Sensitivity of collection frequency and truck capacity for Practice 3

The author analysed the operation efficiency of Scenario 3 in the target area in Hai Chau district by various collection frequencies and truck capacities as shown in Table 4.7. The other parameters were same as the abovementioned scenario analysis. Firstly, the author considered the collection frequency from 1 to 7 times per week, and truck capacity from 4.5 tons to 9 tons. The best efficiency was 0.64 person-hours/t achieved at “Once per week and 9t”, and the worst efficiency was 2.52 person-hours/t at “7 times per week and 4.5t”. The range of efficiency by collection frequency from “Once per week” to “7 times per week” was 1.46 person-hours/t, while the ranges by truck capacity from “4.5t” to “9t” were from 0.42 person-hours/t to 0.63 person-hours/t.

Table 4.7 Range of operation efficiency for Scenario 3 by collection frequency and truck capacity

		(time/week)				
		1	2	3	7	Range by frequency
Truck capacity (ton)	4.5	1.06	1.76	2.31	Worst: 2.52	1.46
	5	0.97	1.65	2.18	2.43	
	7	0.75	1.36	1.85	2.21	
	9	Best: 0.64	1.20	1.68	2.10	
	Range by capacity	0.42	0.56	0.63	0.42	Total range 1.88

Sensitivity of distance to landfill site for Practice 3

Da Nang is a big city, and the distance of moving forward and backward was different among the collection areas. The distance of the nearest collection area, Hoa An ward in Cam Le district, is 4.9 km; and that of the farthest collection area, Hoa Hai ward in Ngu Hanh Son district, is 22.0 km. The author intended to explore the impact of distance to landfill, and analysed the range by capacity of the truck in these 2 wards. The ranges of operation efficiency by truck capacity from “4.5t” to “9t” were 0.25 person-hours/ton in the nearest Cam Le district, and 0.62 person-hours/t in the farthest Ngu Hanh Son district.

To improve the collection efficiency, the expected impact of collection frequency was larger than that of truck capacity, even in the farthest collection area.

Sensitivity of collection frequency for Practice 4

The author analysed the operation efficiency of Scenario 4 in the target area in Hai Chau district by various combinations of collection frequencies of bio-waste and Other waste. The applied truck capacity was defined as 9t, and the other parameters were same as the scenario analysis. The best efficiency was 0.90 person-hours/t achieved at “Once per week for 2 waste categories”, and the worst efficiency was 3.47 person-hours/t at “7 times per week for 2 waste categories”. In some conditions shown by green cells in Table 4.8, e.g., “7 times per week for bio-waste and once per week for Other waste”, the person-hours/t were smaller than that of Scenario 3. In order to introduce separate collection of bio-waste without too much increase in person-hours/t, it is indispensable to consider proper collection frequency.

Table 4.8 Range of operation efficiency for Scenario 4 by combination of collection frequency

<table>
<tr><td colspan="2" rowspan="2"></td><td colspan="5">(time/week)</td></tr>
<tr><td>1</td><td>2</td><td>3</td><td>7</td><td>Range by Other waste frequency</td></tr>
<tr><td rowspan="5">Collection frequency for Bio-waste (time/week)</td><td>1</td><td>Best: 0.82</td><td>1.20</td><td>1.50</td><td>2.14</td><td rowspan="4"><u>1.31</u></td></tr>
<tr><td>2</td><td>1.15</td><td>1.53</td><td>1.82</td><td>2.46</td></tr>
<tr><td>3</td><td>1.41</td><td>1.79</td><td>2.09</td><td>2.73</td></tr>
<tr><td>7</td><td>2.08</td><td>2.46</td><td>2.76</td><td>Worst: 3.40</td></tr>
<tr><td>Range by Bio-waste frequency</td><td colspan="4"><u>1.26</u></td><td>Total range <u>2.57</u></td></tr>
</table>

Note: The person-hours/t in green cells were smaller than 2.10 person-hours/t of Scenario 3 shown in Table 4.6.

Sensitivity of separation rate for Practice 4

The author focused on the operation efficiency of “7 times per week for bio-waste and once per week for Other waste”, of which person-hours/t was nearly equal to that of Scenario 3, and analysed the operation efficiency by various separation rates from 0% to 100%. When the separation rate of bio-waste increased, the number of bag for bio-waste increased, and consequently the total collection time increased. The operation efficiencies were 1.06 person-hours/t at “0%”, and 3.26 person-hours/t at “100%”, which is shown in Table 4.9. The ranges of operation efficiency by separation rate was 2.20 person-hours/t, which was the largest range among those of influence factors considered in the sensitivity analysis. This demonstrated that separation rate is a critical factor on operation efficiency, and should be carefully considered for planning separate collections.

Table 4.9 Range of operation efficiency for Scenario 4 by separation rate of bio-waste

Separation rate	0%	50%	100%	Range
person-hour/ton	1.06	2.16	3.26	2.20

4.8 Separate collection for different waste types in Da Nang city

Recycling is a key component of current waste reduction and plays an important role in preventing the waste of useful materials and the reduction of landfill.

Moreover, for example, to recycle paper and compost the left-over food in solid waste stream, they must not be mixed together. Therefore the requirement for recyclable waste recovery is separate collection. And to improve the quality of recycle material, it should be collected separately for each type of waste.

Disadvantages to source separation are that it may require the use of special vehicles or modification of existing vehicles to keep the materials separate. This adds to the expense of the program. However, the amount of recyclable waste discharged daily is relatively small compare to combustible waste, therefore implement lower frequency collection for recyclable waste is feasible

On the other hand, on regular basis, recyclable wastes in Da nang city is often collected by informal sector which exist in parallel with official municipal. These include recyclables for sale and leftover food waste for farmers to feed animals. Scavengers in Informal sector often face up with risky problems such as diseases, public health and environmental hazards, especially in the landfill site (Ezeah et al., 2010). Integrating the informal sector to formal sector in waste management is an important option to consider when attempting to create a sustainable city in developing countries (Baud et al,. 2001).

In this scenario, each recyclable waste was collected separately with frequency varied from 1 collection time per day to 1 collection time per 30 days. The data of operation were not different with above analysis, except loading time unit for recyclable wastes was referred from City A. Recyclable waste in this target area in Da Nang city will be collected in separation by each waste type with low to high collection frequency. The operation efficiency in term of person-hour/ton and cost/ton will be estimated to understand the applicability and potential of this separate waste type collection system.

The data of loading time/waste (hour/ton) of different type of waste in City A was referred from Table 4.6 in previous section and apply in Da Nang city. In here, author assumed that this loading time unit is proportional to waste amount, therefore it could be feasible to apply the Japanese data into Vietnam scenario to estimate the loading time of recyclable waste

Table 4.6. Estimation model of loading time by item

	Time per weight (hour/t)	Station	n	R2
Combustible waste (District B)	0.156***	0.013***	104	0.977***
Combustible waste (District C)	0.212***	0.007	44	0.958***
Combustible waste (Total)	0.166***	0.012***	148	0.968***
PET bottles	1.130	0.54*	13	0.92**
Newspaper / magazine	0.168	0.016***	7	0.99***
Cardboard	0.859	0.013	12	0.968**
Can	0.267	0.035**	15	0.971***
Bottle	0.922*	0.001	14	0.929**

* $p<0.05$, ** $p<0.01$, *** $p<0.001$

4.8.1 Operation efficiency

The results showed that collection efficiency of all recyclable waste types was reduced when decreasing collection frequency. The efficiency in person-hour/ton of this system was person-hour/ton with 7 times/week for combustible waste collection, and 1 times/month for separate collection each other recyclable waste type. With 50% separation rate, the collection cost for each waste type was calculated. It can be understood that lower collection frequency can decrease the operation and personnel cost significantly in the system. Moreover, this different waste type separate collection system does not need the investment cost for dustbins, but only designate stations with plastic bags.

Table 4.10 Sensitivity analysis for collection efficiency for different recyclable waste

		Person-hour/ton				
		Newspaper	PET bottle	Cardboard	Can	Glass Bottle
Collection frequency (day/collection)	1	15.69	37.73	106.84	83.38	114.36
	2	9.91	21.14	54.73	42.42	60.95
	7	5.79	9.28	17.52	13.15	22.81
	14	4.96	6.91	10.07	7.30	15.18
	30	4.52	5.65	6.10	4.18	11.11

And when the collection frequency is reduced, unit cost/ton by each type of recyclable waste was also declined sharply when reduce collection frequency.

Table 4.11 Sensitivity analysis for cost/ton for different recyclable waste when adjust collection frequency

		Cost/ton				
		Newspaper	PET bottle	Cardboard	Can	Glass Bottle
Collection frequency (day/collection)	1	1,236,322.70	2,905,502.71	7,860,041.01	6,178,513.79	7,753,544.11
	2	854,820.99	1,715,545.20	4,124,320.75	3,241,111.83	4,226,015.77
	7	582,319.77	865,575.55	1,455,949.13	1,142,967.57	1,706,352.68
	14	527,819.52	695,581.62	922,274.81	723,338.72	1,202,420.06
	30	498,752.72	604,918.19	637,648.50	499,536.66	933,655.99

4.8.2 Comparison with informal sector

In addition, author compared the cost of this collection system with revenue of informal sector. The results below indicated that this separate collection system does not cost as much as revenue for informal sector with the same amount of recyclable wastes.

Table 4.12 Cost component of recyclable waste separate collection system

Cost (VND)	Newspaper/ Magazine	PET bottle	Cardboard	Can	Glass Bottle
Vehicle/year	6,925,149	3,540,881	1,219,064	1,061,114	1,839,229
Salary/year	7,386,826	3,209,803	1,105,080	961,898	1,961,844
Fuel/year	9,581,151	3,334,344	1,062,105	1,350,761	1,036,200
Total/year	23,893,126	10,085,027	3,386,249	3,373,773	4,837,273
Cost/ton	498,753	604,918	637,649	499,537	933,656
Person-hour/ton	4.52	5.65	6.10	4.18	11.11

Table 4.13 Collection efficiency of informal sector (reported in Hue)

Unit	Waste picker	Junk buyer
kg/person-hour	1.98	5.71
person-hour/ton	505	175

Last but not least, this waste type separation collection system also achieved higher efficiency in term of operation compare to informal sector. Efficiency of recyclable waste was ranged from 4.18 person-hour/ton for can to 11.1 person-hour/ton for glass bottle, which was much more efficient if compared to the operation efficiency of waste picker and junk buyer, equivalent to 175-505 person-hour/ton.

Authors also compared the efficiency of this separation waste type system and the efficiency of informal sector in term of financial aspect. The collection cost was compared with the purchase cost of junk buyers for recyclable waste in Hue city, Vietnam 2013.

	Cost of recyclable waste (Report in Hue, 2013)				
Recyclable waste	**Newspaper**	**PET bottle**	**Cardboard**	**Can**	**Glass Bottle**
Cost (VND/kg)	2,808	4,541	2,500	16,298	1,537

Regarding on the collection cost per ton, with once per month frequency, the cost for recyclable waste collection was ranged from about 500,000 – 930,000 VND per ton, which is much lower than the cost if selling to junk shops which was from 1,500,000 to 16,000,000 VND per ton. The revenues by selling the recyclables were 3.0 – 17.5 times larger than the collection cost.

Table 4.14 indicated that for 1 ton of PET waste, it costed about 500,000 VND to collect, however, informal sector can receive more than 2,800,000 VND from their daily work if collect this amount.

Table 4.14 Cost comparison of separate collection system and informal sector

	Unit	**Newspaper**	**PET bottle**	**Cardboard**	**Can**	**Glass Bottle**
Annual collection amount	Ton/year	47.9057562	16.6717213	5.310526082	6.75380495	5.181001056
Total cost/t of collection system	VND/ton	498,753	604,918	637,649	499,537	933,656
Revenue/t from informal sector	VND/ton	2,808,235	4,540,707	2,500,000	16,298,268	1,537,000

Simultaneously, author pointed out that the efficiency of informal sector is very low. From the report on informal section in Hue city, one waste picker can perceive 1.98 kg waste in 1 hour, equivalent to 505 person-hour/ton. In comparison to the collection efficiency of recyclable waste by separate collection system in Table 4.12, these two values have a big gap. For example, it consumes less than 6 person-hour/ton for collecting one type of recycle waste by one truck, but it might take 505 person-hour to collect 1 ton in case of waste picker. Hence, decision makers should consider apply collection system by trucks with waste separation and low frequency instead of junk buyers and informal sector.

The efficiency in person-hour/ton of this system was person-hour/ton with 7 times/week for combustible waste collection, and 1 times/month for separate collection each other recyclable waste type. With 50% separation rate, the collection cost for each waste type was calculated. It can be understood that lower collection frequency can decrease the operation and personnel cost significantly in the system. Moreover, this different waste type separate collection system does not need the investment cost for dustbins, but only designate stations with plastic bags.

4.9 Conclusion for section 4

In this section, the author focused on the scenario analysis of operation efficiency and sensitivity analysis of decision factors of waste collection and transport practices used in Da Nang City And City A, Japan. The author intended to estimate the operation efficiencies of these practices, and clarify the impacts of policy factors such as truck capacity and collection frequency. In addition, the author also tried to estimate the operation efficiency of separate collection of bio-waste as the most likely alternative in the near future. The major findings were as follows:

1) Using scenario analyses in Hoa Cuong Nam ward in Hai Chau district, the operation efficiency of “Door-to-door collection” was 4.37 person-hours/t, which was lowest among the current 3 practices, and that of “Door-to-door collection and transport by truck” was 3.65 person-hours/t. “Fixed time dustbin collection and transport by truck” achieved the highest efficiency of 2.10 person-hours, which was less than half of “Door-to-door collection and transport by truck”.

2) The operation efficiency would be affected by truck capacity and collection frequency. By sensitivity analysis on “Fixed time dustbin collection and transport by truck”, the best efficiency was 0.64 person-hours/t achieved at “Once per week and 9t”, and the worst efficiency was 2.52 person-hours/t at “7 times per week and 4.5t”. The variation range of operation efficiency by collection frequency from “Once per week” to “7 times per week” was 1.46 person-hours/t, while the ranges by truck capacity from “4.5t” to “9t” were from 0.42 person-hours/t to 0.63 person-hours/t. To improve the collection efficiency, the expected impact of collection frequency was larger than that of truck capacity, even in the farthest collection area.

3) The operation efficiency of separate collection of bio-waste by plastic bag was 3.40 person-hours/t. It was better than door-to-door collection scenarios, which means it would be a feasible alternative that can replace door-to-door collection practices.

4) As sensitivity analysis of separate collection of bio-waste by plastic bags, the operation efficiencies by various combinations of collection frequencies of bio-waste and Other waste were assessed. The best efficiency was 0.82 person-hours/t achieved at “Once per week for 2 waste categories”, and the worst efficiency was 3.40 person-hours/t at “7 times per week for 2 waste categories”. The author found some conditions with better efficiencies than “Fixed time dustbin collection and transport by truck”, e.g., “7 times per week for bio-waste and once per week for Other waste”. The variation range of operation efficiency by separation rate was 2.20 person-hours/t, which was the largest range among those of influence factors considered in the sensitivity analysis. To introduce separate collection of bio-waste, it is indispensable to consider proper collection frequency. Separation rate is a critical factor on operation efficiency, and should be carefully considered for planning separate collection

5) By propose one scenario for separate waste types collection, the results showed this system can achieved well efficiency not only in operation but also financial aspects compare to informal sector’s revenue.

Reference for Section 4

Chalkias, C., & Lasaridi, K. (2009). A GIS based model for the optimisation of municipal solid waste collection: The case study of Nikea, Athens, Greece. Technology, 1, 11-15.

Matsui, Y. (2009). Comprehensive report in FY 2008 for waste management research grant on "Cost-Effectiveness and Cost-Benefit Analyses on separate collection and junction transport". Ministry of the Environment, Japan. (in Japanese)

Anghinolfi, D., Paolucci, M., Robba, M., & Taramasso, A. C. (2013). A dynamic optimization model for solid waste recycling. Waste management, 33(2), 287-296.

Ministry of the Environment (2018). Regarding plan for regionalization of waste disposal、
https://www.env.go.jp/hourei/11/000138.html (received on 20/01/2018).

5 CONCLUSION

In this study, the author focused on the major alternatives of waste collection and transport practices used in Da Nang city, Vietnam and City A, Japan. In Da Nang city, GPS devices and a GIS software were used to survey and analyse detailed tracking data on 3 current practices, “Door-to-door collection by tricycle and transport by truck”, “Door-to-door collection and transport by truck”, and “Fixed time dustbin collection and transport by truck”. Meanwhile, in City A, Japan, data on waste collection and transport system was collected by Tachometer. The author intended to estimate the operation efficiencies of these practices, and clarify the impacts of policy factors such as truck capacity and collection frequency. In addition, the author also tried to estimate the operation efficiency of separate collection of bio-waste, and different waste type separate collection as the most likely alternative in the near future. The major findings were as follows:

In section 3,

By using the data for the 3 current practices on operation time, operation distance, and collected amount, key statistics for each parameter were calculated. The operation efficiency indicators such as unit operation time, person-hours/t and operation velocity were calculated by the detail operation category: Moving forward and backward, waste collection, waste unloading and other activities. Using multi-regression analysis, the author estimated the unit loading time and the unit waste amount for 4 types of containers, 240-L dustbin, 280-L dustbin, 660-L dustbin and Handcart.

Models of operation parameters (moving velocity, transport velocity) were also constructed in related to area factors and characteristics as population density, road width, road material. However the current problems of waste collection system in Da Nang A are still remained: the mixed waste system collection is implemented daily, and all the waste stream comes to landfill site while landfill capacity is limited. Also, a large quantity of recyclable waste was not recovery due to this combine collection system, and this might burden on the landfill capacity and demonstrate the inefficiency in material recovery. Besides, the waste separation collection as well as impact factors have not been strongly considered in designing the system. Therefore, waste separation collection could be examined in developing countries to solve these problems, however to reduce the cost, the impact factors by system and area characteristic should be also approached and researched.

In section 4

(1) From the digital tachograph and the daily work report, data on work categories, distance, collection time of collecting vehicles for combustible and resource waste

was prepared. In addition, basic units such as work categories, work categories time, work distance, etc. were constructed.

(2) As the current status of collection and transportation, the average working hours per day and breakdown by work categories did not differ much between T and C districts.

(3) Sorted Collection By comparison, in T and C districts, the significant difference in collection time per combustible waste and combustible refuse per trip was found in units of work per unit of work.

(4) In the unit of collecting workable combustible waste per day, in the comparison of the two districts, a significant difference was found among the total time per 1 t and the total distance per 1 t other than Tuesday.

(5) With regard to collectable time per unit of waste type, combustible waste was not much different between Monday and Thursday in both districts, Tuesday and Friday. Also, when comparing resource waste and combustible waste, the basic unit of resource waste was much less than combustible refuse.

(6) A prediction model was constructed with regard to loading time, and moving speed, taking regional characteristics into consideration.

(7) Results showed that this separation waste type collection system could be a feasible solution for developing countries in term of operation efficiency and recyclable material recovery as well as aesthetic of the city by informal sector reduction.

In section 5,

Using scenario analyses in Hoa Cuong Nam ward in Hai Chau district, the operation efficiency of “Door-to-door collection” was 4.37 person-hours/t, which was lowest among the current 3 practices, and that of “Door-to-door collection and transport by truck” was 3.86 person-hours/t. “Fixed time dustbin collection and transport by truck” achieved the highest efficiency of 2.10 person-hours, which was less than half of “Door-to-door collection and transport by truck”.

The operation efficiency would be affected by truck capacity and collection frequency. By sensitivity analysis on “Fixed time dustbin collection and transport by truck”, the best efficiency was 0.64 person-hours/t achieved at “Once per week and 9t”, and the worst efficiency was 2.52 person-hours/t at “7 times per week and 4.5t”. The variation range of operation efficiency by collection frequency from “Once per week” to “7 times per week” was 1.46 person-hours/t, while the ranges by truck capacity from “4.5t” to “9t” were from 0.42 person-hours/t to 0.63 person-hours/t. To improve the collection efficiency, the expected impact of collection frequency was larger than that of truck capacity, even in the farthest collection area.

The operation efficiency of separate collection of bio-waste by plastic bag was 3.40 person-hours/t. It was better than door-to-door collection scenarios, which means it would be a feasible alternative that can replace door-to-door collection practices. Separation rate is a critical factor on operation efficiency, and should be carefully considered for planning separate collection. The results showed that this separate waste collection system for 5 different types of waste achieved well results not only in operation efficiency but also in financial aspects compare to informal sector.

Recommendation for future researches

This dissertation dealt with survey and evaluation of the solid waste collection system, operation and collection efficiency with relative factors in Da Nang city, Vietnam and City A, Japan. Some shortcomings with regard to data and method identified, and future research of these was recommended. Moreover, based on the current results, the future researches will be suggested and improved. Some recommendations were given out for future researches, listed as follows:

- Regarding the sampling points, the survey process should be conducted with more areas with different collection methods. The number of survey trip should be larger to increase the reliability of results.
- The study should collect more information on target area such as household size, commercial density, road length, road with. The data can be examined the correlation with collection components for further modelling.
- During data collection process, the author should focus on interval part, measurement on site for each collection parameter in each interval for the target modelling and estimation.
- It should be considered more factors for scenario analysis as well as the sensitivity of each factor in system. This could be helpful for decision makers to understand and focus on target component in waste collection system.

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