Urban logistics platform to encourage recycling in smart city

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Abstract
Accessibility of recycling infrastructure is an issue preventing people to recycle. To improve recycling, we propose an urban logistics platform for recyclables collection using empty backhaul from truck deliveries. Two main objectives are helping the household to submit collection requests and helping the recycling company to consolidate and schedule it.

Keywords: urban logistics platform, recyclables collection, empty backhaul

INTRODUCTION

Recycling has become one of the solutions to improve the preservation and conservation of the declining environment (Gamba and Oskamp, 1994). It has been widely encouraged and regulated in several countries such as the UK, Norway, United State of America and Spain (Tonglet et al., 2004; Kipperberg, 2007; Gonzalez-Torre et al., 2003). In Singapore, recycling is also being encouraged to achieve the recycling target rate of 70% in 2030 (Ministry of the Environment and Water Resources, 2015a). The Singapore government has tried different ways to encourage more people to recycle. As an example, waste recycling programs have been introduced to children in early age by teaching the importance of recycling and waste management in schools. Other examples are national campaigns to improve, encourage and maintain recycling awareness for the general public such as Recycling Day started in 2004 and Clean and Green Singapore launched in 2012 (National Environment Agency, 2012). For household recycling, recyclables are collected on a door-to-door basis (Casey, 2009). Recycling bins are also made available for each block of public housing.

From the household recycling study in Singapore, it is cited that inconvenience was one reason for why people did not recycle (Ministry of the Environment and Water Resources, 2013). Although recycling bins are available for each block of public housing, some participants in the study mentioned that recycling bins were hard to locate or inconveniently located. Some of them are also complaining that the recycle bins were not emptied frequently enough. This is a known factor that influence people not to do recycle (Tonglet et al., 2004).

The door-to-door recycle collections in Singapore have been done in a traditional way using “Karung Guni” practice where the “Karung Guni” men visit the resident door-to-door for recyclables for a small amount of money (Neo, 2010; Carroll, 2013; Wong, 2014). The recyclables accepted by the "Karung Guni" men include electronic and electrical waste, newspapers, aluminium cans, cardboard, clothes and toys. The "Karung Guni" man would dismantle and sort the recyclables based on the types before he sells it to the waste wholesaler. This "Karung Guni" practice may not be convenient for all households for two main reasons: the irregularity of the schedule and limitations on the acceptance of recyclable items.

On the other hand, the growth of home delivery parcel services that comes together with Omni-channel shopping is driving demand for goods transport in city areas (DHL Trend Research, 2014; Mitrovic-Minic et al. 2004). Higher volumes and more frequent delivery demands with smaller goods size to the end customers in the cities need to be fulfilled. It increases the usage for all types of freight vehicles such as vans and trucks. Most of the time, after delivering the parcels, trucks or vans would be empty or have lesser truck load (Peetijade and Bangviwat, 2012). It wastes resources and creates inefficiency in the last mile logistics delivery that has a major impact on traffic conditions and threatens the sustainability of the city (Quak and Tavasszy, 2011).

Recognizing this situation, we propose an urban logistics platform as a platform to balance the transportation supply and demand for recycling collection. This proposed platform is aligned with Singapore's Smart Nation vision where most of the information including delivery information can be accessed from many channels through a Smart Nation Platform (Infocomm Development Authority of Singapore, 2014). Assuming that delivery trucks and vans may be empty after delivering their goods to certain areas, these trucks and vans can be used to pick-up the recyclables and deliver it to the recycle plant nearest of the truck and van depots. The platform enables the households to submit collection requests and schedule the collection time windows. Depending on the types of recyclables, the households may get a small amount of money for their recyclables. The platform would consolidate all the requests and bundle it according to the locations. It then publishes the bundle to the carrier companies that have delivery routes around those areas. The platform is also able to access the delivery trucks and vans information and matching it according to the recycle collection requests. The carrier companies can offer their services to collect those recyclables and deliver it to the recycling plant nearest to their depots to get extra income and fulfil their Corporate Social Responsibility (CSR). Our proposed platform is equipped with four components: (1) features to identify recyclable and collection time window selection, (2) bundling recommendation engine to consolidate recycle demand and reduce the amount of transportation needed, (3) auction mechanism with optimal winner determination to promote fairness and transparency for all parties involved and (4) routing engine to optimize travelling time.

In this paper, we design the conceptual design of the platform and then focus on the bundling components. We model the bundling as an optimization problem and use Genetic Algorithm (GA) to solve it. The experiments are conducted using randomly generated data. From the experiment results, it is shown that our bundling component is able to reduce the number of vehicles used up to 90% and the total cost up to 47.35% as compared to a single-collection-vehicle assignment.

The remaining of the paper is organized as follows: Section 2 presents the conceptual design of the proposed urban logistics platform. Next, the bundling component is described in more detail in Section 3. Section 4 presents the experiment result. Section 5 presents the conclusions and future research direction

CONCEPTUAL DESIGN OF THE URBAN LOGISTICS PLATFORM

At a high level, the platform would be supported by four main components: recycling submission, bundling, auction and routing recommendation. The process flows is illustrated in

Figure 1. The households would be able to submit the collection request including the preferred time windows. Based on their location and time windows, the platform matches the requests with the available carriers' delivery information and bundles the requests. It proposes those matching and bundling to the carriers. The carriers would be able to accept the proposed requests or bid on other requests. After the auction is closed, the platform determines the auction winner using a winner determination algorithm by considering certain criteria such as number of trucks or vans, cost, etc. Then, the platform sends the schedule and route recommendation to the carrier. After the carrier accept the schedule, the platform publishes it to the household and recycle plan. When the recyclables are collected and delivered, the household and recycle plan need to confirm that the delivery has been completed. To further encourage household recycling, the platform can also include a *gamification* strategy that would allow the residents to record their recycle patterns and publish it on their social media.

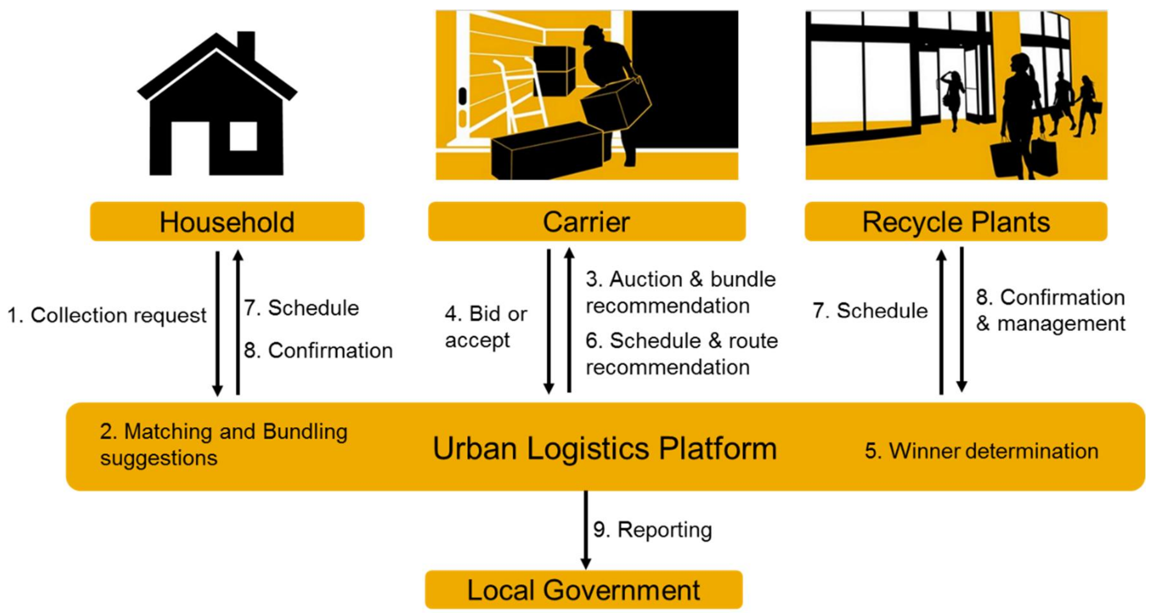

Figure 1 – urban logistics platform

Recycling Submission Component

This component enables the households to check if their items can be recycled and to arrange the collection of their recyclables. It is equipped with an image matching algorithm to compare the image uploaded by the households with a set of recyclable' images in the database as the sample images to determine if the household items are recyclable. The image matching algorithm can be constructed on feature-base matching approach (Wells, 1997; Hsieh et al., 1997; Forstner, 1986; Harris, 1992) or the intensity-based matching approach (Anandan, 1989; Brunelli and Poggio, 1997; Black and Jepson, 1998; Hager and Belhumeur, 1998). The feature-based matching requires feature extraction algorithm to extract a set of features from the image and sample images. It then calculates the corresponding feature to determine the matching. It is considered more robust to deal with incomplete images. While intensity-based matching is primarily based on the sum of squared difference formulation. It does not require feature extraction, but requires more image quality and highly sensitive to illumination changes.

The processes in recycling submission are as follows. The households upload a picture of the items they want to recycle. Based on the picture, the platform would use the image processing algorithm to identify the items. It determines if the items can be recycled and may provide an amount of money they would receive for their recyclables. Alternatively, the households can choose the recyclable items based on the provided list. If they can recycle their items, the households are able to submit their preferred collection times. After the auction process completed, a confirmed collection schedule would be sent to the respective residents using any preferred channel such as email or SMS. The households would also be able to request for collection time changes if needed. It would dynamically change the carrier's routes.

Bundling Component

Collection requests bundling can be useful for both recycling agencies and carriers. For recycling agencies, by bundling packages that go to the same or near origin locations, they can reduce the need for transportation. For carrier companies, package bundling can help them to improve truck utilization and reduce travel distance. The bundling engine can run based on both recycling agencies' and carrier companies' preferences. For recycling agencies, it provides bundle recommendation based on the recyclable types, collection dates and times and recycle plant destination of the items. For carrier companies, the bundling component takes more input parameters. The carrier companies can specify their preferred pick-up areas, preferred recycle types, remaining shipping capacities, then the recommendation component can generate bundles for them to bid together with a suggestion of bidding price.

In our proposed platform, the bundling is modelled as an optimization problem to minimize the collection costs. The collection location, time windows and recycle plan destinations are considered as the hard constraints. The violation of these constraints makes the solutions become infeasible. The detail of this bundling component is discussed in the next section.

Auction Component

The auction engine is used to provide a fair mechanism to assign each collection request to a specific carrier. The assigned carrier needs to complete the collection requests. To determine the auction winner, a set of criteria is used. The criteria may include number of vehicles, time windows and collection cost. It is determined by the platform owner based on his personal interests. For example, if the owner is the recycling agency, the criteria could be to minimize the collection cost. While for the government agency as the platform owner, the criteria could be to increase recycling rates.

There are various auction mechanisms available in the literature (such as Handoko et al., 2014; Van Duin and Kneyber, 2004; Jonkman et al., 2006; Mes et al., 2010; Van Duin et al., 2007). The platform owner can choose any type of auction mechanism that fits his interests best. The recently proposed auction mechanism with a rolling horizon determines the winner using robust optimization techniques (Wang et al., 2015). It considers the uncertainties in parameters such as cost, impose a reasonable ceiling on cost, and maximize the robustness of the resulting solution so that the target can be achieved with high probability. This winner determination mechanism is useful for our proposed platform where the auction environment involves a lot of uncertainties. To protect the information of bidders, a specific auction mechanism can be implemented. One example is a sealed-bid auction (such as Suzuki et al., 2001; Haile et al., 2003). In sealed-bid auction, all the bidder information and identification are encrypted and unknown to the rest. For other open auction types, the bidders are masked by randomly generated ID for each bid they submit.

Routing Recommendation Component

The routing recommendation component is used by the carrier to optimally collect the recyclables. When the auction winners are already determined, the collection jobs that are assigned to one carrier are known. Using the collected information and the individual carrier's preferences, an optimum route is proposed. In most cases, this is a typical vehicle routing problem (such as Toth and Vigo, 2001; Dethloff, 2001; Golden et al., 2008). The machine learning feature can be implemented in this routing recommendation to develop a personalized routing recommendation. Individual route preferences or preferences from other couriers with the similar collection request can be extracted and used as criteria to determine the routes.

BUNDLING MECHANISM

In this section, we describe the bundling component in more detail. Our bundling component aims to minimize transportation cost for collecting the recyclables by matching the collection requests (in term of location and time windows) with the carriers' home delivery schedules.

In the bundling problem, we assume that the number of carrier' vehicles for collecting the recyclables is sufficient enough and even more than needed with homogeneous volume and weight capacity. Let *N* be the set of vehicles. Each vehicle $i \in N$ has a volume and weight capacity Q (i.e. 1040x640x580mm in volume and 15 kg in weight), current location v_i and time windows capacity$[e_i, l_i]$.

M denotes the set of collection requests with delivery load size q_k. Let $P = V \cup U \cup \{u_0\}$ be the set of nodes where $V = \{ v_i \in V \mid i = 1,2, \dots, |N|\}$ represents the vehicle's current locations, $U = \{ u_k \in U \mid k = 1,2, \dots, |M|\}$ represents the collection locations and node u_0 denotes the recycle plant location. Vehicle trip needs to start from the vehicle current location v_i with a set of collection $U_k \subset U$ and end in the recycle plant u_0. For all $i, j \in P$, d_{ij} and t_{ij} represent a non-negative travel distance and a non-negative travel time between *i* and *j*, respectively.

$[f_k, g_k]$ denotes the time window from collections where the collection service at location *i* must take place. If a vehicle *i* reaches location *k* before f_k, it needs to wait w_k time units until f_k to collect the recyclables. A collection route R_i for vehicle *i* is a directed route for a set of collections $U_k \subset U$ under the following constraints:

1. It starts in v_i and ends in u_0
2. Vehicle *i* visits each location *k* exactly once
3. The vehicle load at any one time never exceeds Q
4. The arrival time A_k and departure time D_k of any location *k* satisfy $D_k \in [f_k, g_k]$ where $D_k = \max\{A_k, g_k\}$ and $w_k = \begin{cases} f_k - A_k, & A_k < f_k \\ 0, & A_k \geq f_k \end{cases}$
5. The w_k for each collection in R_i is less than ε. ε is set to a small number (i.e. 30).
6. The start time E_i and end time L_i for each route R_i satisfy $E_i \leq e_i$ and $L_i \leq l_i$

The total collection cost C_i for R_i consists of two components: base and transaction cost. The base cost is a fix cost for using a vehicle i in R_i. While, the transaction cost depends on the travel distances in route R_i calculated by summarizing the non-negative travel distance d_{ij} for all locations $i, j \in R_i$. The objective function of this bundling component is to minimize C_i without violating any constraints.

To generate the routes, we construct a meta-heuristic algorithm, Genetic Algorithm (GA). GA is an algorithm inspired by the "natural selection" that moves from one population of chromosomes (e.g. strings of ones and zeros, or bits) to a new population using genetics-inspired operators of selection, crossover and mutation (Mitchell, 1999). Each chromosome is an integer string of length $|M|$ represents the set of collection requests. Each gene is ordered based on collection's time windows $[f_k, g_k]$ where $k = 1,2, \ldots, |M|$. A gene k in a given chromosome is the vehicle number assigned to fulfil the collection request k. Each gene may have value of 1 to $|N|$ where N is the set of vehicles. The chromosome is illustrated in Figure 2.

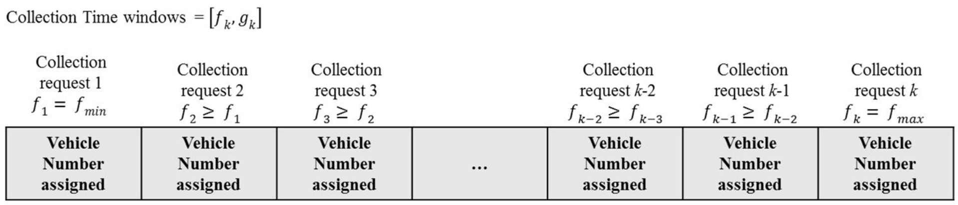

Figure 2 – GA Chromosome

Each chromosome has a fitness function which evaluate how good the routes in term of its objective function for feasible solution and objective function plus penalize value for infeasible solution. Penalize value is set to a fix high number Z. The optimal solution is the one, which is feasible and minimize the fitness function. Initial population is generated using two methods: available-random and random. In the available-random method, we randomly assign a collection request to any vehicle without violating the constraints. This is to make sure that some initial solutions are feasible. While in random method, we random all the assignments. Each method generates half of the population.

Standard genetic operators for selection, crossover and mutation are used. Tournament 2-selection, single-point crossover and uniform random mutation are used for selection, crossover and mutation respectively. In tournament 2-selection, two solutions are randomly chosen and compared. The one with a higher fitness value is selected as a parent. In single-point crossover, we randomly choose one point to exchange part of the parents' chromosome to create new offspring. While in uniform random mutation, we change some genes with random vehicle numbers.

EXPERIMENT RESULT

To test our GA, we randomly generate 10 instances. The locations are extracted from real delivery demand data of a courier company in Singapore. We convert the distance between two customers' location to minutes using a point-to-point routing solution available online (Google Maps, 2015). To simplify the problem, we use the following assumptions, although these can be relaxed in the real-world problems:

1. $|M|$ ranges from 10 to 100
2. Maximum available vehicles $|N|$ is 15

3. The distance between two locations in P is the same in each opposite direction and each collection locations can be visited from all other location, forming an undirected complete graph.
4. The vehicle's capacity Q is homogeneous and set to 100
5. Load size q_k for each collection k is ranged from 5 to 50
6. Collection time windows f_k for each collection k is ranged from 09:00am to 11:00am with duration from 3 to 5 hours.
7. Vehicle time windows e_i for each vehicle i is ranged from 09:00am to 12:00pm with 4 hour duration.
8. Base price = 10
9. Transaction price = 1/distance and 1/time (for waiting)

For GA, we use five parameters, namely: populationSize, crossOverPoint, mutationRate, generationNum and iteration. We set he value for each parameter as described in Table 1. We record the best found solution in each iteration.

Table 1 – GA Parameters

Parameter	Description	Value
populationSize	Population size	500
crossOverPoint	Probability of cross over point	0.7
mutationRate	Probability to run mutation for new offspring	0.03
generationNum	Number of generation	500
Iteration	Iteration	100

Table 2 – GA Comparison Result with single assignment

Number of Customers	Single Assignment		Genetic Algorithm		Decrement	
	Number of vehicles	Total cost	Number of vehicles used	Total cost	Number of vehicles (%)	Total Cost (%)
10	10	327	3	204	70.00	37.61
20	20	756	2	398	90.00	47.35
30	30	1,094	7	722	76.67	34.00
40	40	1,552	7	934	82.50	39.82
50	50	1,866	6	1,004	88.00	46.20
60	60	2,357	6	1,333	90.00	43.45
70	70	2,793	7	1,495	90.00	46.47
80	80	3,021	10	1,753	87.50	41.97
90	90	3,460	15	2,135	83.33	38.29
100	100	3,735	15	2,416	85.00	35.31

We compare our GA result with a single assignment method. In single assignment method, each vehicle serves only one collection request. We use the same assumptions for the base and transaction price. We report the average best found solution from each iteration in Table 2. The result shows that our GA decreases the number of vehicles used up to 90% and the total cost up to 47.35%.

CONCLUSIONS

Recycling has been encouraged to improve the preservation and conservation of the declining environment. This includes household recycling, which is highly influenced by the availability of the recycling infrastructure. The unavailable and inconvenience of the recycling infrastructure becomes one of the reasons for why people did not recycle.

To provide better recycling infrastructure for household recycle, we propose an urban logistics platform for recyclable collection using empty backhaul from truck deliveries. The platform consists of four major components: (1) recycling submission component to identify recyclable and collection time window selection, (2) bundling component to consolidate recycle demand and reduce the amount of transportation needed, (3) auction component to fairly assign the collection request to the bidders and (4) routing recommendation component to optimize travelling time. We describe the conceptual design of the platform and focus more on the bundling component. We model the bundling problem as an optimization problem and design a Genetic Algorithm (GA) to solve it. Our experiment result shows that our GA has up to 90% improvement in term of reducing the number of vehicles and 47.35% in term of reducing total collection cost.

Having a very promising result, we would like to test and validate our approach in the real environment. We are currently developing a prototype that can be used to test and validate our bundling approach.

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