Dynamic data-driven recyclable collection resource allocation in smart cities

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Abstract

Infrastructures and resources are available for household recycling in countries like Singapore. But, the utilization rate of them varies with times and locations. We propose a dynamic data-driven allocation solution to have a better deployment of the resources, improve their utilization rate, encourage recycling, and reduce waste.

Keywords: recyclable collection, resource allocation, smart cities.

INTRODUCTION

The world population will continue to grow until at least 2050 based on the current projections of population growth, and the world population will reach 9 billion in 2040 (United States Census Bureau 2015). As population grows, more and more energy and materials will be consumed. However on the other hand, human being is running out of many unreproducible nature resources. For example according to the BP Statistical Review of World Energy 2015, the global oil reserves will last for only 52.5 years at the current rate of extraction. The same situation is shared by many other natural resources. This resource shortage problem has motivated people to initialize recycling programs at national level in many countries. For example, the LaMiLo (Last Mile Logistics) project is funded by the European Regional Development Fund and it aims to take the last mile delivery fully into consideration in the management of the whole supply chain. In some pilot cities, the delivery trucks also collect recyclable waste from customers and send it to the recycling center. Actually many European countries such as Austria, Germany and Belgium are quite active in recycling to meet the EU-mandated target to recycle 50% of household and similar waste by 2020.

Beside Europe, Asian countries are becoming more and more aware of the importance of recycling. Take Singapore for example. Singapore is a city-state on a small island in the Southeast Asia. It has about 719 square kilometers' land area and 5.5 million residents. With so small land area and high population density, Singapore has almost no natural resources and has to import everything to support its economy. On the other hand land is quite valuable for Singapore and it has to handle waste properly to make good use of the limited land. Due to this reason, Singapore government takes recycling seriously. In the year 2014, Singapore produced enough incinerable solid waste to fill 1,030 football fields to the height of an average person, and the figure will increase dramatically if people do not recycle actively (NEA 2014). The current landfill capacity can only last to 2035 to meet the waste disposal needs of Singapore. To reduce waste disposal and also save limited resources, Singapore government has set the target rate of 70% for recycling to be achieved by 2030 (Ministry of the Environment and Water Resources, 2015a). To achieve this target, Singapore government takes all means to encourage people to recycle. For example, waste recycling programs have been introduced to children in early age by teaching them the importance of recycle and waste management in schools. Another example is 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, and recycling bins shown in Figure 1 are also made available for each block of HDB flats. The acceptable and non-acceptable recyclables are displayed on the front side of the bin. Residents can leave their recyclables in the bin as long as they are not contaminated by food, and do not need to sort the recyclables beforehand. The recyclables are then collected from the recycling bins 3 to 7 times per week. For landed property estates, one recycling bin is available for each house with 1 or 2 times of collection per week (ZeroWasteSG, 2008). The collection is done by appointed Public Waste Collector and the recyclables are brought back to their facility for sorting and further processing. The Public Waste Collectors are selected through an auction mechanism and the government need to pay for their collection and processing services.

One problem with the current operation is that the recycling bins are available for each one of the HDB building and is evenly distributed over the island. Truck schedule for collecting the recyclables are also static and do not change from time to time. Such operation does not consider the actual demand for the recycling facilities. However in reality, how much and how often people recycle in a region is affected by a number of factors such as population density, population structure, residents' living style and mind sets. These differences lead to differences in demand for recycling facilities. It is quite common to observe that some of the recycling bins are always full while at the same time others are quite empty. As pointed out by the household recycling study (Ministry of the Environment and Water Resources, 2013), the recycling bins are not emptied frequently enough. This means that the fix collection schedule may not be efficient enough and a better plan is desirable to improve the efficiency and also reduce the number of trucks and manpower required. This will further reduce the impact on the environment.

Figure 1 Recycling bin under HDB flats

Another limitation of static recycling bin deployment and fixed collection schedule is that it cannot handle seasonal variation of demand for recycling facilities and resources. For example, people tends to purchase a lot and also do recycling before festivals such as Christmas, Deepavali and Chinese New Year. The time and magnitude of the associated peak in demand is predictable based on historical data and appropriate models. Seasonal variation of demand is also subject to some ad hoc events. For example, there are ad hoc sales events offering furniture or electronics appliance. After such events, families that purchase new furniture or electronics appliance may choose to recycle their old ones. The relationship between the ad hoc events and the demand for recycling facility and resources can be established using appropriate models to adjust the demand prediction.

Another factor we notice and would like to consider is the growth of home delivery parcel services that comes together with Omni-channel shopping and boom of e-commerce. The increasing volume of home delivery parcel are driving demand for goods transport in residential areas. Such consumptions is also related to when and how much people recycle. Fortunately, such consumptions can be discovered to certain degree using social media data as people tends to show and share what they purchase with family and friends on Facebook, Tweeter, Weibo and other social media. Since such social media data is available and accessible to all, it could also be utilized to predict the demand for recycling facilities and resources. In the era of big data, crawling and analyzing the data from the social medias is not a difficult technical issue.

Recognizing the above mentioned situations, we propose a Dynamic Data-Driven Recyclable Collection Resource Allocation (3D-Allocation in short) system to predict the demand for recycling facilities and resources and provide optimal plans and schedules for the facilities and resources allocation. In general, the system makes use of the historical data of the demand for recycling resources to predict the trends of future demand, also analyzes social media data and events data to help to adjust the prediction dynamically, and recommends facilities and resources allocation accordingly.

System Description

In general, the system would be supported with four main modules: with (1) historical data analysis, modeling and prediction module, (2) ad hoc events and demand impact analysis module, (3) social media data analysis module, and (4) optimal plan and schedule generating module. The system at the general level is illustrated in Figure 3. Each of the four modules is described in details in the rest of this section.

Historical data analysis, modeling and prediction module: This module takes the historical data of the volume and type of recyclables that is collected at each collection point as input. The module uses machine learning techniques to build an appropriate model which fits the input data best. For different types of recyclables and different locations, different models are built to predict the volume to be collected at that location. When building these models, we will not use complex functions to fit the input data as we only intend to get an estimate or nominal value of the volume of the recyclable to be collected. For example as shown in Figure 2, the dots are historical data points indicating the real volume of recyclables at the same time in earlier months or years. The dashed line is the estimated or predicted trajectory of the volume which is quite smooth and representable by simple functions. The estimated trajectory serves as a baseline of the prediction. However, the real value of the volume may deviate from the baseline. A predicted value of this deviation is to be determined by modules discussed later in this section.

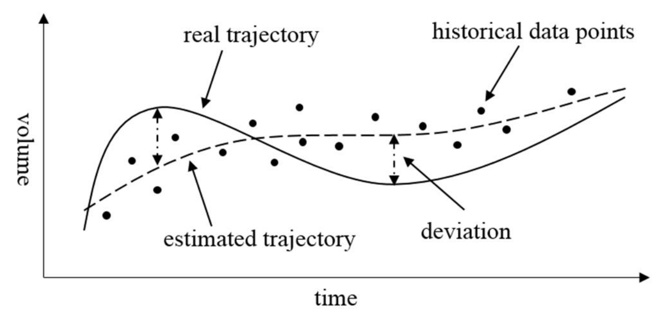

Figure 2 Estimate volume of recyclables and expected adjustment

The above mentioned regression process is done for all possible combinations of recyclable types and locations, which is a typical single input variable regression problem. After this, we can also conduct correlation analysis for the volume of one type of recyclables at any two locations. By doing this, the geographic correlation of recyclable volumes can be discovered and also be used to adjust the prediction using the model developed by other modules. Besides the correlation analysis for same recyclable type at different locations, for example neighborhoods, correlation analysis can also be conducted for different recyclable types at the same location or even combination of different recyclable types and locations. The analysis results can all be used to adjust the prediction by making use of model in other modules.

Besides regression, the data can also be used to discover the recyclable collection hotspot. The location of hotspot and the associate recyclable volume can be taken into consideration in the determination of the locations of sorting and processing centers.

Note that this module predict an estimate or nominal value of the future volume of recyclables. The real value of the volume can deviate from this nominal value as shown in Figure 3. We believe such deviation is due to ad hoc events which may not occur regularly. For example a sales event may encourage the residents to make more purchase and therefore recycle more items. The impact of ad hoc events on the true volume of the recyclables is also taken into consideration by the proposed system. We will use such models to adjust the predicted value of the volume of recyclables to make an accurate estimate of its value. The module to fulfill this functionality is described in details in the following paragraphs.

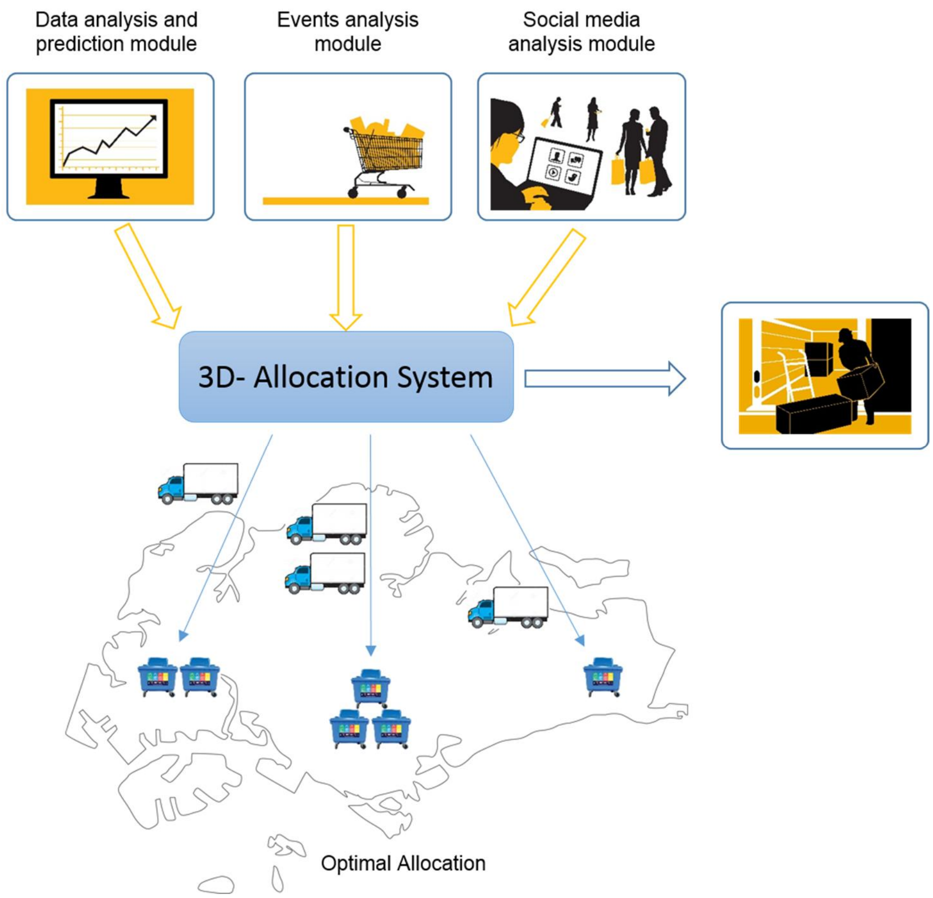

Figure 3 Process Flows of 3D-Allocation System

Events and Demand Impact Analysis Module: As described above, the volume of recyclables to be collected is affected by ad hoc events. The module focuses on big sales events such as IT shows and Warehouse sales and model the impact of such events on the predicted volume of the recyclables. By comparing the real value of the volume and the predicted value obtained by the first module, we can quantify how much the volume is affected by ad hoc events and other factors. This module takes various factors as input, including the content of the event, scale of the event, duration of the event, location of the event, target population and the distribution of such population. The module then establishes appropriate models, using machine learning techniques, to predict how the demand for recycling facilities and resources is affected by the various factors of the event. The model is also continuously updated and modified as the events data becomes available to provide precise adjustment of the final volume prediction.

Besides the sales events, this module can also analyze other events such as education and entertaining events organized by regional community club to identify events that influence people's recycling behavior. Thanks to the highly developed IT technology and software market in Singapore, a number of websites (e.g. www.greatdeals.com.sg, singpromos.com) and apps (e.g. Deals.sg, Qoo10 SG) are available to publish event information. Web crawler can be designed to automatically retrieve the event data from the relevant websites and used as the input to our models. Similarly, social media data from websites such as Facebook and Twitter can also be retrieved using web crawler. Such information can be used to analyze the impact of events and also as an indicator of how the volume of recyclables changes. This is discussed in detail in the next.

Social Media Analysis Module: With web crawler technology, it is possible to continuously retrieve data from social media websites and such data can be used to analyze the behavior of a specific group of people and also to report issues. This module keeps monitoring the social media data including text and multimedia to discover what people has purchased and what they tend to recycle. The analysis result can be presented in the form of certain statistics. For example for certain location, the statistics can show the numbers of posts in social media about certain kind of purchase within a specific distance. The module can discover the relationship between such statistics and the deviation of the real value of recyclable volume and its predicted nominal value, and then use the established model to adjust the predicted value.

The process described above uses the statistics of the analysis result as input and produce adjustment for the predicted value as output. The module can also treat the statistics as the consequence of sales events, and analyze the impact of certain event on the residents' life in certain area. This is helpful for the second module to create a precise model to predict the impact of sales event. This is reasonable as the population structure varies from town to town in Singapore. Some relatively new town can have more young population who are more interested in electronic appliance shows and hence may purchase more during an IT show and recycle more wrapping paper box as a result.

The social media can also be used as a way to collect information about the usage of recycling infrastructures and helps to identify irregular spikes in demand. For example, if a recycling bin is full or there is an extremely large amount of recyclables waiting for collection, residents may take a photo and post to a social media such as STOMP (a local news in pictures sharing app). The module can detect such issues and send ad hoc trucks to collect the recyclables.

Optimal Plan and Schedule Determination Module: Based on the volume prediction and adjustment done by the previous three modules, this model can determine an optimal plan for recycling bin allocation and schedule for collection trucks. This is done by considering all the constraints on number of available trucks, preferred time windows, cost for a collection trip and others. The recycling bin allocation is determined to meet the value of the predicted volume of recyclables. In the case where there is no enough recycling bins to meet all the projected volume, the allocation can be determined to maximize the probability for all the bins to be fully utilized. After the bin allocation plan is obtained, a schedule and rout for collection trucks can be determined. This can be typically modeled by a Periodic Vehicle Routing Problem (PVRP), which is also discussed in the literature of recyclable collection (Teixera et al., 2004; Bommisetty and Jacobs 1998). Efficient algorithms and heuristics for solving PVRP are also available in (Cordeau et al. 1997; Drummond et al. 2001). Interesting readers may refer to the mentioned works and the references therein. Thanks to the available literature, the scheduling problem can be solved without any problem.

One key feature of the module is that when determining the plans and schedules we also consider uncertainties in the future demand, collection cost and other factors. We can model the uncertainty properly and use robust optimization techniques to solve the problem and obtain a solution that is robust against the uncertain factors. As a consequence, the plan and schedule may not require significant changes when the uncertain factors realize.

Given the current plan and schedule, the model also make necessary adjustment to the solution as uncertainty factor become realized. The module consider a moving planning horizon which is composed of several execution periods. For example in Figure 4, the planning horizon is one month and one execution period is one week. The module then determine the plan and schedule for the next four weeks. After the first week of the plan and schedule is executed, the module will consider the volume of the recyclables realized in the first week and solve the planning problem again for the next following four weeks and the make necessary adjustment to the previous plan and schedule. In this way, the uncertainty is considered in a closed-loop decision making process and a more efficient plan can be expected.

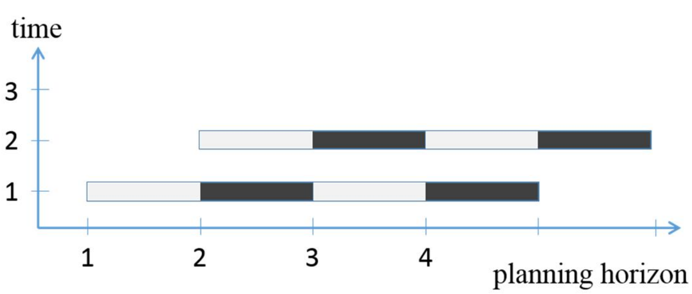

Figure 4 Rolling planning horizon

Potential Impact and Benefits

The system is designed to provide better utilization of the available resources to meet the recycle demand by leveraging the prediction and insight discovered from historical data, events data and social media data. We foresee the system would have four key benefits as follows. First, it would provide better recycle resource availability for residents to recycle their items and improve the household recycling rate. Second, it would help collection carrier companies to improve their truck utilization, reduce operation costs and also impact positively on urban environment. Third, it would help the recycling agencies to have a better picture of when and how much people recycle, and the trends of any changes. It would also help the recycling agencies to do resource planning and scheduling when receive the recyclables in their recycling plants because they would know the arrival schedule beforehand. Last, the system enhance the connection between residents and recycling agencies by providing more channel to communicate.

To further explore the potential impacts and benefits, we use Political, Economic, Social, Technology and Natural environment (PESTN) analysis to identify possible impacts on the macro-environments components.

Political/Legal Factors: Although there is no law that requires the residents to recycle, the Singapore government has announce several programs and campaigns to encourage residents to recycle. In addition to that, Singapore Exchange (SGX) has announce a new guidelines for all Singapore-listed companies to publish their sustainability report to promote CSR (Marusiak, 2011). It is still voluntary now but could become a legal requirement in the future. The system supports these campaigns and guidelines by improve resource availability to residents and efficiency of the whole process.

Economic Factors: Being a small island-country, Singapore has severe resource scarcity problems – including land for recycling plants and resources and labor to handle recyclable items. Using the proposed system, recycling agencies would be able to better utilize their existing resources, improve efficiency and reduce costs. With more items recycled, more land resources will be saved for purpose other than landfill.

Social Factors: Recycling has been promoted to general public through a number of channels. The system links social media, public media and can also be used as a tool to promote recycling habits of residents.

Technology Factors: Residents' lifestyles and living patterns is alternating and becoming diverse by the influence of advanced information and communication technologies such as wireless, real-time, on-demand and wearable technologies and devices. The changing patterns may lead to residents psychological changes, and further impact their recycle habits. Using recent technology, the system can be used to influence their recycle habits.

Nature Factors: One way to minimize the amount of waste that we create is recycling. It is important to cut down the amount of waste and reduce the cost of disposal (Ministry of the Environment and Water Resources, 2015b).

Conclusions and future works

In this paper, a system for recycling resources allocation, planning and scheduling is proposed at the general level. The system is composed of four main modules to 1) predict the nominal volume of recyclables, 2) monitor ad hoc events and predict impact on recyclable volume, 3) crawl social media data to help adjust volume prediction, and 4) determine resource allocation, collection plan and schedule, respectively. The proposed system would be able to encourage residents to recycle by provide better availability of recycling facilities and resources, better and more efficient collection schedules, and therefore the system can help to reduce the operation costs and labor required for recyclable collection. Potential impacts and benefits of the proposed system discussed using PESTN analysis. In the future work, we intend to conduct trial run with local public waste collectors to collect data and verify the idea of the system.

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