DESIGNING AN INTELLIGENT WASTE COLLECTION SYSTEM THAT REDUCES GHG EMISSIONS AND INVOLVES CITIZENS

MARTA JOFRA SORA*, IGNACIO GARCÍA VEGA**, AIDA ANTHOULI°, ILIANA KOUKOSIA°

** ENT Environment & Management, c/Sant Joan 39, 1st, 08800 Vilanova i la Geltrú, Barcelona, Spain*
*** Wellness Telecom S.L., Av. Charles Darwin S/N, Pabellón monorrail, 41092 Isla de la Cartuja, Sevilla, Spain*
° D-Waste Ltd, Acharnon 141A, 10446, Athens, Greece

SUMMARY: Traditional waste collection services cause environmental problems related to Greenhouse Gas (GHG) emissions, and other negative effects such as noise and traffic congestion. In these services citizens usually have a passive role and do not interact with waste managers. Innovation, and Information and Communication Technologies (ICT) tools can help optimize waste collection in order to reduce its negative effects and increase citizen's involvement. This paper examines and analyses the benefits deriving from the implementation of such technologies in cities and regions, and investigates the barriers and opportunities from their implementation. In particular, the paper proposes the application of a methodology that aims at using a combination of ICT tools in order to improve waste management and increase citizen's awareness. The expected results are a reduction of GHG emissions by over 10%, a reduction of noise pollution, economic savings and an increased awareness towards waste prevention and separation.

1. INTRODUCTION

Waste collection services are part of the broader waste management strategy. They consume a large part of the city budget and their suitable delivery is directly linked with the quality of urban governance and citizens' satisfaction.

There is a variety of waste collection systems that exist worldwide (Christensen, 2011). In general, there is not a better or a worst system to use, but the decision on the most suitable methods, technologies, or their combination, in each case, is based on a number of factors such as the town planning.

Collection and transport of waste are the most expensive process of waste management and can reach over 70% of the total waste management budget (de Oliveira and Borenstein, 2007; Tavares et al., 2009; United Nations Environment Programme, 2009). Therefore, it should be as far as possible performed in the most cost-effective way, obtaining at the same time the highest possible yield (in terms of cost per ton collected).

Moreover, waste collection services affect significantly city's life. Increased municipal waste generation affects collection systems in a sense that the waste generated has to be handled in an environmentally and economically sustainable way.

In traditional methodologies trucks normally follow static routes which are usually designed without taking into account real time data of the particular containers, but only using general considerations and historical data. In general, waste is collected following predefined frequencies of collection.

These methodologies might be enough for collecting waste itself in some cases, but they seem not to be sufficiently efficient, and at the same time they produce several problems mainly related to the environment. The collection and transportation of waste generates GHG emissions to the air which are associated with the fuel consumption of collection vehicles (Rodrigues Pereira Ramos et al., 2014). Overall, it is estimated that the waste sector contributes about 3-4% to the global anthropogenic GHG emissions (Bogner et al., 2008).

Another important point is related to citizens' awareness-raising. Information reported by a proper waste collection methodology is a tool that can encourage people to adopt a better attitude towards waste prevention and source separation. Traditional methodologies are not good at reporting concrete information which could be customized for accurate areas.

In general, and following the on-going quick adoption of ICT technologies in the entire domain of a city and the citizens, it is clear that ICT can help improve the situation of waste collection and transportation.

There have been further innovative developments in waste collection systems, especially through IT technologies.

Intelligent Waste Collection is composed by different kinds of technologies and several tools and services based on them. It offers several possibilities for optimizing the process of collection itself and make up a robust solution which is able to use all the data reported in real time.
A complete Intelligent Waste Collection System is made up by the working of different technologies as a whole. Some of them are well known due to his wide presence in systems of daily use, mainly those in charge of communication itself; others are newer or simply less known generally. These technologies are Global Positioning System *(*GPS), Radio Frequency IDentification (RFID), Wireless sensoring, and new communication channels as GSM/GPRS or 3G. This technologies are usually integrated with advanced information systems, enterprise resource planning or logistic software in order to exploit the data captured.

Some of the benefits of these technologies are that the frequency of collection is reduced, and therefore vehicle routes can be improved, reducing the costs of collection, and improving profitability and environmental effects caused by fuel consumption.

New technologies are offering a novel field for innovation, changing the way waste practices are applied as they contribute to more active citizens' involvement and participation.

Through studying data deriving from these systems, in combination with geo-visualization methods, waste managers and citizens can come up with a better understanding of waste management and urban systems in general.

Through its legislation EU has set ambitious targets for recycling and sustainable waste management, especially through the Waste Framework Directive and through the legislative proposal of the Circular Economy Package (CEP), which was presented in July 2014 by the European Commission (COM(2014) 397 final).

According to the above proposal, the current 50% target for waste recycling and preparation for re-use would be increased up to 70% by 2030. For packaging waste, the new target would be 60% by weight of preparation for re-use and recycling by 2020 and 70% for 2025. As regards landfilling, the proposal establishes that recyclable waste (including plastics, metals, glass, paper and cardboard, and other biodegradable waste) should not be accepted in landfills by 1st January 2025, also from 1st January 2025, the amount of waste sent to landfill should not exceed 25% of the total amount of municipal waste generated in the previous year, finally by 1st January 2030, the amount of residual waste sent to landfill should not exceed 5% of the total amount of municipal waste generated in the previous year.

Regarding EU energy targets, by 2020, member states are expected to cut greenhouse gas emissions by 20% compared to 1990 levels, to achieve a 20% share of renewable energy sources in final energy consumption, and to increase energy efficiency by 20%.

Under the above framework, the aim of this paper is to highlight the potential and the benefits of new information technologies (ICT) to optimise waste management & collection, and to promote their wider adoption across Europe. This paper examines and analyses the benefits deriving from the development of such projects in waste management practices of cities and regions, and investigates the barriers and opportunities for their implementation.

More specifically, the paper presents how such technologies contribute to improving the management of natural resources and waste, and to help EU member states reach EU 2020 goals. The paper is emphasising on the importance of energy efficiency and reduction of GHG emissions, noise and traffic congestion during the collection and transportation of waste, and the raise of citizens' awareness through such innovative tools.

The objective of the paper is described in section 2. The methodology proposed is presented in section 3. Chapter 4 investigates the results derived from the application of such technologies in urban waste management infrastructures, namely how these solutions can help improve waste management, the added value they have compared to the existing solutions, the key aspects to be taken into account for the implementation of the solutions, for which fractions and cities is this solution most convenient, the expected reduction of the cost of waste management, and GHG emissions, and other expected results (collection times, separate collection, noise, etc.). Last, conclusions of the research are presented in section 5.

2. OBJECTIVE

The aim of this paper is to set the baseline and motivation on how ICT can be used in the area of waste collection in order to achieve more efficient and controlled urban waste collection methodology in terms of economic, environmental, social and operational improvements by using innovative ICT technologies and involving the whole chain of stakeholders.

The hypothesis is that ICT, per se, do not contribute to improve waste management, but they need to be complemented with user-oriented solutions. The main users in a general level can be identified as the waste collection managers and the citizens. In order to get citizens involved demonstration activities must be performed, involving a representative sample of the users, which is essential for achieving a behavioural change that will lead to less waste, more recycling and less management costs.

From now on, we will refer to ICT applied to waste collection as Intelligent Waste Collection (IWC). IWC is composed of different kinds of technologies and several tools and services based on them. They offer several possibilities for optimizing the process of collection itself and make up a robust solution which is able to use all the data reported while it takes place.

The paper focuses on the combination and integration of existing partial ICT solutions that are able to deliver concrete possibilities offered by an intelligent waste collection system in order to:

- Monitor the performance of waste collection at container level.
- Support the management of waste collection routes and fleet.
- Raise social awareness and communication between the stakeholders.

3. DESCRIPTION OF THE METHODOLOGY

Economic crisis has pushed and increase of efficiency of public services, such as Municipal Solid Waste (MSW) management. Waste managers, in cooperation with private companies, are facing a great challenge to improve their processes and reduce CO_2 emissions and resources/costs to achieve 2020 priority challenges related with waste management strategies.

The methodology proposed is based on the following combination of technologies is proposed:

- A sensing infrastructure (including hardware and communication elements) to be installed on waste containers in order to be able to monitor the fulfilment level of the containers.

- A waste manager platform that allow waste managers to visualize the status of every container on real time and that provides reports for an optimal route planning.

- A citizen platform that provides waste collection users with a solution that has extra added value services related to waste management in their city.

- A cloud hardware infrastructure able to provide the services offered both to the waste managers and citizens and host all the databases.

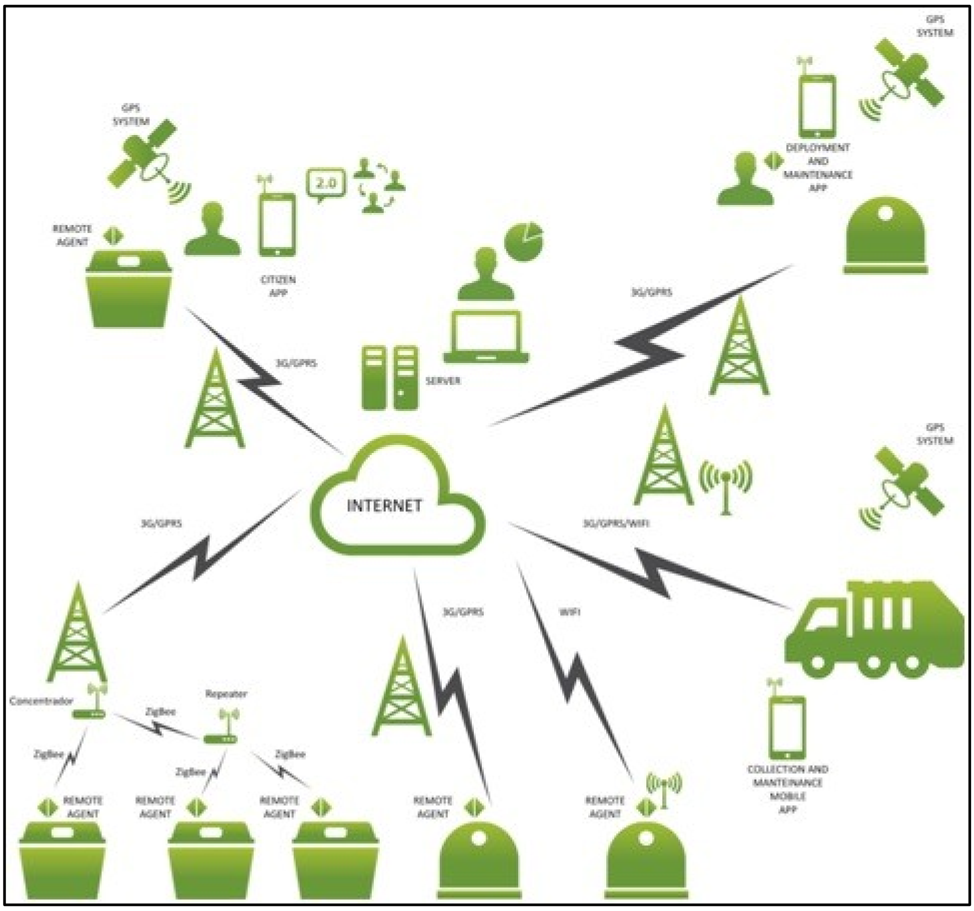
This solutions can be integrated into two platforms: platform A and platform B. Platform A enables the monitoring of the filling level of a container, the calculation of optimal collection routes, savings in fuel, savings in GHG emissions, the elaboration of progress reports and statistics for analysis and audits, the real time tracking of routes, and the management of incidents/alerts. The inputs of this platform come from the sensors installed and from the users of the service, that could interact with the platform.

Platform B is the information management platform. It displays information to both the waste managers and the citizens in a very simple and fast way. This way, the different stakeholders can get information in order to adapt the waste collection methodologies to the real needs both from the real data obtained from the containers and from the citizens. This is a fundamental part for changing the habits from citizens and current non-optimized waste collection methodologies.

The scheme below shows the general technical architecture proposed, where we can differentiate two main parts: one for waste managers and the other one for citizens:

<table>
<tr><td rowspan="3">The Manager Platform</td><td>HW Infrastructure</td><td>Sensorial infrastructure</td><td>Real Time information from the containers</td></tr>
<tr><td rowspan="2">SW Application</td><td>Inventory and Installation</td><td>Inventory and Installation automation using mobile applications</td></tr>
<tr><td>Web Based Management Platform</td><td>Widget based dashboard
Real time events, status, alarms, reports, statistics.
Correlation with other information systems as ERP</td></tr>
<tr><td colspan="3">The Citizen SW Application</td><td>Widget based dashboard
Real time events, status, alarms, reports, statistics.</td></tr>
</table>

The functional architecture of the solution is described on the following image that represents the different elements and communication interfaces between them:



On the following sub-sections,a description of the elements that form the solution is carried out.

3.1 Sensing Infrastructure (Remote agents)

The remote agent is a device able to measure different parameters of a waste container (i.e. measure fulfilment level, temperature, location and vibrations) and to communicate either to a concentrator or directly to the central server of the system. It is leak-proof device.

The average resolution of capturing the data can be adapted to the needs of the final user, but in general the average resolution is one hour. Since it allows remote configuration, the resolution may be adjusted once installed.

The remote agent can be installed easily in different types and sizes of containers, including back loading and side loading, upper hook and underground. It contains a battery and is optimized in terms of energy consumption so that the battery can last.

The communication with the concentrator is done using wireless technologies such as Zigbee, and with the central server via Wi-Fi or GPRS. Battery consumption using Zigbee or Wi-Fi is lower than using GPRS. If the municipality has a Wi-Fi network, it will also be a cheaper option than GPRS. However, with a GPRS system the container can be relocated and it will still work; this is not possible using the Zigbee and Wi-Fi versions.

It is formed by the following components:

• Fulfilment sensor: Ultrasound sensor with a volumetric measurement.

• Temperature sensor: Sensor to measures temperatures from –20 °C to +100 °C.

• Location sensor: Sensor that enable horizontal position accuracy 50 meter at least.

• Vibration sensor: Sensor that enable real-time orientation detection, Static orientation detection (Portrait/Landscape, Up/Down, Left/Right, Back/Front position identification) and freefall detection.

• Battery: High durability batteries (they should provide power to the system at least two years), preferably Lithium thionyl chloride (they give a better response to devices installed outdoors with high autonomy and low maintenance).

• A leak-proof case: The remote agent must support outdoors conditions without any problem which may affect the electronics. Besides it must support the cleaning operations which is usually done at least once a year and is performed with pressurized water.

• Communication module: the communication module will enable zigbee, Wi-Fi or GPRS communication for sending information autonomously.

3.2 Web platform

The Software based implementation is used as the main entry point for the different users and stakeholders. It has different interfaces based on the role and requirements gathered from a first analysis with the stakeholders:

• Administrator Interface: can access all the configuration parameters and information of the platform, can manage the rest of roles and has access to all the functionalities of the rest of the roles of the platform. Moreover, the Admin can manage the award programme (gamification) offered to the citizen.

• Waste Manager Interface: waste managers have full access to the information (containers, routes, reports, incidences, etc.). This interface:

- shows a resume at the home page.
- shows a list of existing monitored containers and enables visualizing and generating historical and statistical reports per container.
- shows a list of existing monitored routes and enables visualizing and generating historical and statistical reports per route.
- shows the alerts and issues reporting. On that list, the technician will be able to monitor the incidents and register the actions and solution proposed for each incident.
- enables real time fulfilment information and forecasting collection date either at container level or route. It enables generating performance reports.

• Citizen Interface. citizens can access with or without being registered.

Non registered users: they can only see general information about the system:

- Location of the containers
- Waste fraction of each container
- Collection planning schedule for the container
- Fulfilling level of the container
- Collection statistics
- Feedback from other users

Registered citizens: they have access to extra services of the specific citizen web platform, e.g.:

- Location of the containers
- Fraction accepted at each container
- Collection planned schedule
- Fulfilling level of the container
- Collection statistics
- Feedback from other users
- Query to locate containers
- Reporting the fulfilling level of a container
- Reporting incidences: lose of a container, damaging of a container, waste outside the container
- Posting comments

3.3 Mobile application

The mobile application allows citizens and waste managers' operators to access to the main services and information from the web platform through mobile phones or tablets.

The main advantage of the mobile application is that users can report incidences easily independently of their location and can even interact by sending pictures from their mobile device. The operational team from the waste manager entity can report incidences on real time.

The app is available for the main mobile Operating Systems (iOs and Android), has an easy and straightforward interface and has several operational roles.

3.3 Cloud infrastructure

In order to be able to provide all the mentioned services, there is a need of hosting the whole backend of these services on the cloud. A software solution following the Software as a Service (SaaS) model is recommended due to the following features:

- Scalability and integration. SaaS applications are available from any computer or any device—anytime, anywhere. Because most people are familiar with using the Internet to find what they need, SaaS apps tend to have high adoption rates.
- Lower Initial Costs. SaaS applications are subscription based. No license fees mean lower initial costs. Having the application provider managing the IT infrastructure will means lower infrastructure costs for hardware, software, and the technicians efforts to manage it all.

- Painless Upgrades. Because the application provider manages all updates and upgrades, there are no patches for customers to download or install.

This methodology will be tested and adjusted on different real waste collection routes of different locations in the Mediterranean regions of Sevilla (Spain) and Chania (Greece), in the framework of the LIFE-EWAS project, financed by the European Commission. These two areas have different conditions (urban area and touristic area respectively). The project will allow to demonstrate the advantages of the innovative models on a practical basis and to have different cases of success on which to support the communication activities.

In order to implement the new methodologies, an already developed platform will be used.

For the demonstration activities two different full-scale pilots will be deployed in two stages:

- In a first stage, the Platform A will be installed. The sensors will be monitored but no action will be planned. The outputs of the innovative system will be used as recommendations and analysis to be assessed before the implementation, in order to verify full operation of the system and check emissions savings achievable in the routes selected for the piloting.
- In a second stage, after having proved the reliability of Platform A and Platform B and after analysing the achievable improvements in the current waste collection methodologies in each pilot, LIFE EWAS will propose optimised routes and logistic as well as social information and services to the stakeholders. At this stage the improvement in costs and emissions will be measured and compared with the previous ones. It will also include communication activities addressed to waste managers, public administrations and citizens in order to inform them about this innovative waste collection methodology.

4. RESULTS AND DISCUSSION

Intelligent Waste Collection has economic, social and environmental benefits, among with:

- A reduction in investment costs for vehicles fleet, thanks to the ability to schedule on-demand pick-ups according to the real needs, with a consequent reduction in the number of vehicles used.
- A reduction in operational costs (fuel, maintenance, etc.) of collection, thanks to the reduction of vehicles, covered distance and stationary load and unload times.
- A reduction of noise, due to the elimination of unnecessary routes (this is especially interesting in urban areas).
- More transparent services, and the involvement of citizens. Waste data is converted into open data and as a consequence can attract the citizen’s participation, a key pillar for the management not only of waste collection services but for most public services.
- An increased involvement of citizens in the waste management cycle. Also, residents can appreciate the benefits derived from the implementation of these methodologies, while information for their contribution and benefits from its proper operation will be emphasised,

offering reliability and confidence to the waste management organizations, thereby regaining trust to local public services.

- Expected reduction of GHG emissions from the use of such technologies, in compliance with the EU 2020 goals. This reduction is the result of eliminating unnecessary stops, which means a reduction of engine emissions, produced both by collection vehicles and traffic congestion. Also, as a result of the reduction of the stop duration: thanks to an automated data capturing system, well integrated in, the network of vehicles will reduce time spent from human operators during the waste collection especially in a kerbside collection model.

The methodology proposed is most convenient for fractions that are collected less often, such as glass, packaging waste or paper. The methodology allows the optimisation of the collection so that only containers that are full are collected. In the case of these fractions, the day of collection can be adjusted to the filling level of the containers. In cities where selective collection of biowaste is carried out, it could also be applied to the collection of refuse.

The methodology is also very convenient for rural municipalities where the routes are very long and some containers are very far away from the main road. In these cases, the methodology could be applied to reduce the distance travelled and the time spent for the collection substantially.

Even in dense cities, if the routes have a fish bone pattern (a main road with no containers and a lot of secondary roads where containers are placed at the end of the road) the application of this methodology could help save quite a lot of time, energy and money.

Waste collection services are, probably, the most “visible” municipal services. They consume a large part of the city budget and their suitable delivery is directly linked with the quality of urban governance and citizens’ satisfaction. Moreover, waste collection performance is directly linked to the citizens’ perception regarding the city’s image affecting at the same time their everyday life.

If waste collection does not apply in right intervals, there is a risk of odours causing nuisance. An efficient collection system should aim at a high level of hygiene, occupational safety and public health having in consideration also measures for achieving environmental safety.

The way that waste materials are collected (and subsequently sorted) determines which waste management options can then be used. Moreover, the selected collection method significantly influences the quality of recovered materials.

Besides reducing the frequency of collection, there are other cost-cutting strategies to increase the efficiency of the collection system, including, for example, implementing dual collection of solid waste and recyclables, and automating collection practices.

Collection frequency is based on the cost as well as requirements of each municipality. Household waste usually contains food and other putrefying materials. Frequent collection of these wastes is desirable for health and aesthetic reasons. Local climatic conditions often have a strong influence in determining the collection frequency. The condition of the containers may create operational problems, affecting even the collection frequency.

From a social point of view, and concerning waste collection, the most important issue is the sitting of bins. Because most people do not want waste bins to be too near, but not too far either. This is often referred to as the “NIMBY” (Not In My Back Yard) factor. When it comes to picking up municipal solid waste and recyclables, less is often best, even though generally acceptance of bins for dry fractions (glass, paper, packaging waste) tends to be higher than for mixed waste and biowaste. Offering collection services less often can, in many cases, decrease costs, and even increase the amount of waste diverted from disposal, as it can include management of different waste streams. At the same time, it cannot be assumed that householders will be interested in whether their waste is dumped illegally or taken to an approved disposal site, provided that it is taken out of the immediate neighbourhood.

Last, waste collection upgrading can bring about benefits in transportation issues as well, through the renewal of the collection fleet, improvements of the vehicle routes, bringing avoidance of traffic jams and decrease in accident rates.

5. CONCLUSIONS

The use of Information and Communication Technologies (ICT) can lead to a more sustainable waste management scheme where the impacts and costs of this activity are reduced compared to the business-as-usual practices.

A complete Intelligent Waste Collection (IWC) system must not only integrate the most innovative ICT solutions, but must combine the most suitable ones in such a way that makes waste management friendly for the users and that involves them in the operation of the service.

It should, therefore, be composed by end-of-pipe technologies, such as volumetric sensors and communication systems, and by solutions that process all the information compiled and make the most of the technologies. A solution that should be user-friendly and accessible from several devices (on board computers, remote systems, mobile phones, etc.).

The implementation of integrated solutions in pilot areas can help prove the capabilities of new methodologies, improve them and monitor the results. The methodology proposed in this paper is foreseen to allow a 10% reduction of GHG emissions.

The widespread of this methodology, if this results are confirmed, could help achieve the EU GHG reduction commitment by 2020.

In a nutshell, according to the findings ICT tools can facilitate the transition to an energy-efficient, low-carbon economy and contribute to the EU objectives in relation to GHG reduction for 2020 in the waste management sector, and improve current waste management practices. Also they can improve people’s quality of life, reduce the environmental impact comparing with current methodologies, increase waste recycling level and citizens’ cooperation, and finally reduce the investment and operational costs, noise and traffic problems.

REFERENCES

Bogner, J., Pipatti, R., Hashimoto, R., Diaz, C., Mareckova, K., Diaz, L., Kjeldsen, P.S., Faaij, A., Gao, Q., Zhang, T., Ahmed, M.A., Sutamihardja, R.T.M., Gregory, R. (2008), Mitigation of global GHG emissions from waste: conclusions and strategies from the Intergovernmental Panel on Climate Change (IPCC) Fourth Assessment Report. Working Group III (Mitigation), Waste Management Research 26: 11-13.

Christensen T. H. (2011), Solid Waste Technology & Management, Blackwell Publishing Ltd. ISBN: 978-1-405-17517-3.

de Oliveira Simmoneto, E., Borenstein, D. (2007), A.decision support system for the operational planning of solid waste collection, Waste Management 27: 1286-97.

Rodrigues Pereira Ramos, T., Gomes, M.I., Barbosa-Póvoa, A.P. (2014), Economic and environmental concerns in planning recyclable waste collection systems, Transportation Research Part E 62: 34-54.

Tvares, G., Zsigraiova, Z., Semiao, V., Carvalho, M.G. (2009), Optimisation of MSW collection routes form minimum fuel consumption using 3D GIS modelling, Waste Management 29: 1176-85.

United Nations Environment Programme (2009), Assessment of current waste management system and gaps therein developing integrated solid waste management plan. Training manual. Division of technology, industry and economics, Osaka/Shiga, Japan; International Environment Technology Centre.