Cloud-based product-service systems platform for household solid waste classification management

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Abstract: The household solid waste (HSW) classification management plays an important role in reducing and recycling urban garbage in current residential community. However, with the rapid development of urbanisation in developing countries and the continuous increase of urban waste, the traditional waste management modes and technologies cannot satisfy the newly emerged needs of collecting and transporting solid waste in the accurate and effective way. Under this background, this research carries out a preliminary study on the HSW classification system and the resource servitisation. According to the HSW classification process, a cloud-based product-service systems (PSSs) platform, targeting on managing those solid waste management resources such as internet of things enabled smart waste bin, is established. The proposed PSS platform will be illustrated from four layers: physical layer, management layer, service layer and application layer. Additionally, the multi-stakeholders’ value analysis of the platform will be provided from five aspects. Finally, a PSS-based real-life case of managing household waste bin is investigated and analysed in order to verify the feasibility of the proposed platform.

1 Introduction
Household solid waste (HSW) management is a great challenge in urban areas around the world [1]. Particularly, for the management of municipal solid waste, the HSW classification management (HSWCM) is the most difficult. A common sense is that, compared with office, school and community, the source separation ratio of community is the lowest [1]. To tackle this problem, waste classification management is widely accepted as a key method due to its ability of minimising waste and enhancing recycling and disposal efficiency [2,3].

In some developed countries, such as Sweden and Japan, they have achieved significant results in waste classification [4, 5]. In recent years, developing countries have also gradually been promoting waste classification [6, 7]. Taking China as an example, as the largest developing country in the world, it began to advocate HSW source separation in eight pilot cities in 2000 and the number of pilot cities for subsequent HSW source separation has increased to 46. The Chinese government has issued a series of laws, regulations and policies to promote source separation, and at the same time investing a lot of money in the field of source separation [1]. However, the source separation pilot programs have resulted in poor results [8].

This study summarises three possible reasons for hard HSWCM in the municipal context(i) residents’ different levels of participation and accuracy in waste classification due to different ages, education levels and income levels, (ii) probable waste bursting due to inadequate input of smart equipment of source separation in the community and (iii) lack of sustainable business models and incentive mechanism. Therefore, how to improve the effect of waste classification management, increase the utilisation rate of solid waste management resource (SWMR) and how to reduce the cost of waste management and improve the efficiency of management are the main problems that researchers need to solve.

In the early stage, Mieszkis and Thomas [9] studied the waste source separation and proposed an effective method to separate useful materials from post-consumer waste. It has gradually attracted the attention of many scholars on the aspect of waste classification management.

From the empirical analysis aspect, Sarbassov et al. [7] studied the impact of gender, income, education level and age on waste classification and recycling, respectively [10–14]. Tai et al. [8] analysed the implementation effect of eight pilot cities in China and pointed out that China’s HSW management system lacked investment in infrastructure. According to the characteristics of residents in the same area and the multi-dimensional perspective of different areas the differences in waste classification among different groups of people were analysed.

From the technical aspect, with the development of industry 4.0 technology, the new generation of smart-enabling technologies has been widely used in manufacturing field [15–18], which opened up a new idea for waste management at the technical level. Thurer et al. [19] proposed a solid waste collection Kanban system based on internet of things (IoT) technology. Meng et al. [20] proposed a multi-agent based HSW separation and recycling system model. Hannan et al. [21] applied radio frequency identification (RFID) and communication technologies to a monitoring system for waste bins and vehicles. Zhang et al. [22] applied smart technology to disaster waste management. Misra et al. [23] proposed a new method of comprehensive sensing to automate the solid waste management process based on IoT and cloud technology. Zhang et al. [24, 25] analysed the drivers and barriers for smart-enabling technologies in waste management. Predictably, smart-enabling technologies will play more important role in waste classification management field.

From the business model and business platform aspect, the Recycle Bank system in the United States has established an environmental protection exchange mechanism. Elia et al. [26] designed a waste management service model based on ‘Pay-As-
needs to go through multiple collection and transfer processes. As From the generation to the final disposal of the waste, it usually increase the enthusiasm of multiple stakeholders to participate in product-service system (PSS) business model also has a wide chain for the interests of involved multiple stakeholders, and into decision information to assist multiple stakeholders to make pay attention to the application of PSS.

edge computing can quickly process and analyse the operating data Bluetooth and 5G provide a guarantee for fast and stable IoT, big data analytics, cloud computing, cyber-physical system [27, 34, 35]. Wireless communication technologies such as RFID, Bluetooth and 5G provide a guarantee for fast and stable transmission of the product operating data. Cloud computing and edge computing can quickly process and analyse the operating data [36–39]. Digital twin, AI and other technologies can transform data decision-optimisation [27, 40]. In the case study aspects, Ness et al. [41] proposed an information and communication technologies enabled PSS for reuse of building components. Seregni et al. [42] analysed the impact of the IoT technologies on product-oriented PSS through the 'home delivery' service case. Smart-enabling technologies are possibly to make many types of PSS more economic and practical. In summary, few articles break the traditional community waste collection network in the existing research, and almost no researchers studied the PSS platform of SWMR such as waste bins, collection vehicles and waste workers. Under this background, this study proposes the following three research objectives:

- Establishing the network of HSWCM system.
- Configuration of hardware and software resources in the network of HSWCM system.
- Building a cloud-based PSS platform for HSWCM.

In order to achieve the established objectives, the study is structured as follows: Section 2 illustrates the current problems of HSW stream process. Section 3 is the introduction of the network of HSW classification system and PSS platform architecture. Section 4 is the multi-stakeholders value analysis of the platform. The case study and conclusion are in Section 5 and Section 6, respectively.

2.1 Household waste bin

The household waste bin is one of the most common products in residents' daily life, which has many kinds of simple functions. The main function of the waste bin is to store the waste, such as food scraps, bottles, e-waste, etc.

China has implemented the pilot project of waste classification for a long time. However, a main reason leading to poor results is that the classification network usually starts from the collection points in a neighbourhood or locality, which is not continent for residents to throw away their waste to community bins placed at the collection points. Obviously, the ideal starting point of waste management is household waste bin.

However, we encounter another problem that traditional waste management networks are usually not able to provide smart waste bins at home, mainly because buying a smart waste bin is more expensive than an ordinary waste bin and choice of the waste bin is always determined by residents’ real needs. What's more, as mentioned above, residents’ attitudes and effects on waste classification are quite different due to their different education levels, ages and income levels. For instance, the elderly and children do not know how to classify waste, while young people know how to classify, but they do not have time to separate, which put forward new requirements for home smart waste bins For example, the function of voice interaction with the elderly and children could be addressed through AI technology to assist residents in identifying waste categories, so that the smart waste bin is able to save time of waste classification and make it more convenient to throw the waste away. For young people, they can also purchase other services, for example, sharing smart waste bins with their neighbours.

2.2 Collection point

In the current HSW classification system, there are four main problems in the collection point. The first is that the price of the smart waste bin is higher than that of the traditional waste bin. The second problem is that the smart waste bin occupies a larger area of land than the traditional waste bin, and the construction cost of the collection point is high. Third, the number of smart waste bins in the current community is insufficient, and the distribution of collection points is unreasonable. These problems may lead to smart waste bins burst during the peak period of dumping. Therefore, introducing more smart waste bins in collection point and managing the status of smart waste bins in real-time is very important for network configuration of the HSW classification system.

2.3 Three-highs problem of smart equipment

New SWMR (such as smart waste bin, smart collection vehicle, smart wearable device etc.) and a new generation of information management technologies (such as IoT, big data analytics, cloud computing etc.) are the key for building an HSW classification system. In the field of manufacturing, smart equipment and new generation information technologies can significantly improve product quality and production efficiency. However, when customers make decisions to purchase smart products, they always face the ‘three-highs’ problem, which includes, the high cost of using smart equipment, the high risk of equipment investment due to the rapid development of technologies, and the high threshold for the use of smart equipment [43].

In the field of environmental sanitation, smart equipment also faces a similar ‘three-highs’ problem. First, the use cost is high. Compared with the traditional waste bin, the price is nearly a hundred times higher. Second, the investment risk is high. Due to the large mobility of residents in the residential area, the types and total amount of waste generated are different, which makes the configuration of the smart waste bins more dynamic. This dynamic makes the return of investments very unstable. Third, the threshold for use is high. For residents, the smart waste bin could dramatically promote life quality. However, for the community or platform manager, the network structure settings and system

Fig. 1 HSW stream process

You-Throw’. Many enterprises have established online recycling platforms and offline recycling networks, such as Germany ALL, United States Waste Management and China Aihuishou. The product-service system (PSS) business model also has a wide application prospect in smart living and smart city [27]. PSS is an innovative business model where a product and its associated services are combined together in a certain proportion and provided to customers in a reasonable way, by selling or renting or even mixing [28, 29]. In terms of waste management, the PSS platform can centrally manage various types of SWMR, establish a value chain for the interests of involved multiple stakeholders, and increase the enthusiasm of multiple stakeholders to participate in waste classification management. PSS mode has been widely used in the production field [30–32]. Elia et al. [33] evaluated the effects of several PSS modes of waste from electrical and electronic equipment. However, from HSW management aspect, few articles pay attention to the application of PSS.

From the smart-enabling technology supported PSS aspect (such smart-enabling technologies include, but are not limited to IoT, big data analytics, cloud computing, cyber-physical system and artificial intelligence (AI) [24]), IoT serves as the fundamental technology to enable ubiquitous connectivity, so as to enable manufacturers or service providers to collect real-time data and offer product-related services based on the product operation data [27, 34, 35]. Wireless communication technologies such as RFID, Bluetooth and 5G provide a guarantee for fast and stable transmission of the product operating data. Cloud computing and edge computing can quickly process and analyse the operating data [36–39]. Digital twin, AI and other technologies can transform data into decision information to assist multiple stakeholders to make decision-optimisation [27, 40]. In the case study aspects, Ness et al. [41] proposed an information and communication technologies enabled PSS for reuse of building components. Seregni et al. [42] analysed the impact of the IoT technologies on product-oriented PSS through the ‘home delivery’ service case. Smart-enabling technologies are possibly to make many types of PSS more economic and practical.

In summary, few articles break the traditional community waste collection network in the existing research, and almost no researchers studied the PSS platform of SWMR such as waste bins, collection vehicles and waste workers. Under this background, this study proposes the following three research objectives:

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2 Problem formulation of current HSW stream process

From the generation to the final disposal of the waste, it usually needs to go through multiple collection and transfer processes. As shown in Fig. 1, there are three levels of HSW stream process: household waste bin, collection point and transfer station.

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pay little attention to the source of household waste, which lead to resident need to first swipe the point card, and the bin door is also configured according to the dynamic recyclable bin (blue), hazardous waste bin (red), food waste bin, and residual waste bin in the collection point. When throwing garbage away, responsible for collecting the waste from the households. The size of the transfer station, as shown in Fig. 2.

A big problem: no regular and effective measures established to enforce the accurate waste separation. That is also why the diversity of communities’ residents makes the effect of HSWCM very different.

Thanks to the latest standards announced by the Ministry of Housing and Urban-Rural Development of the People's Republic of China, which classifies municipal solid waste into four categories: recyclable, hazardous waste, food waste and residual waste, this study is able to establish an updated three-level smart waste bins configuration system of households, the collection point and transfer station, as shown in Fig. 2.

The first level, household waste bin: this level can be divided into two situations. The first one is to arrange a group of smart waste bins based on households. The second is to take the floor as the unit, and several households on the same floor can share a group of smart waste bins. Residents can determine the size and type of bins according to the actual situation of HSW, and they can also configure the smart waste bins according to the dynamic changes. Each group of smart waste bins includes four categories: recyclable bin (blue), hazardous waste bin (red), food waste bin (green) and residual waste bin (grey). Household smart waste bins possess voice interaction, the fullness level monitoring and measurement, dumping reminder and other functions; additionally, data transmission through Wi-Fi, smart gateway and Bluetooth is also permitted which is easy to connect and use the bins for residents.

The second level, collection point: the collection point is dynamically arranged among buildings, which is mainly responsible for collecting the waste from the households. The size of the smart waste bin in the collection point depends on the amount of waste generated by the residents. Each group of smart waste bins includes four categories the same as the household waste bins, which possess the same functions as those in the households. However, these bins in the collection points may be larger than those in the households depending on the actual usage situations.

An interactive terminal for the points is also set up on the smart waste bin in the collection point. When throwing garbage away, resident need to first swipe the point card, and the bin door is automatically opened. The garbage will be analysed first, based on the types and the weight of the waste, corresponding points could be generated and stored in the point card, which could be used to exchange garbage bags or some other things for free, or discount coupons in the partner supermarkets and so on. This is also a good way to motivate the residents fulfill waste separation. Besides, the interactive terminal also can help garbage bags distribution among different households and collection points.

The third level, transfer station: this level is the terminal of waste collection in the community. The second level of waste collection is transported to this level by the collection vehicles. There are also four categories of containers to hold the collected waste. The location of the transfer station is determined according to the community planning based on its area, size, the amount of the waste etc., so as to the number of the stations.

3.2 Cloud-based PSS platform for HSWCM

This platform inherits the AUTOM architecture proposed by Huang et al. [44] and the general cloud resource management architecture [31]. The fundamental purpose of this platform is to provide services to platform users through the PSS model. The platform integrates hardware equipment resources, system management software resources, waste workers and IoT equipment resources together. The resources in the platform are registered and used in the form of cloud resources. Particularly, IoT equipment resources target on real-time data and information collection and transmission through the AUTOM architecture.

As shown in Fig. 3, the cloud-based PSS platform architecture of HSWCM (PSS-HSWCM) includes four layers: (i) physical resource layer; (ii) SWMR management layer; (iii) SWMR service layer; (iv) SWMR application layer.

3.2.1 Physical resource layer: The physical resource layer is the bottom layer of the platform. The main function of this layer is to manage all physical resources that may be involved in the implementation process. The physical resources of this layer mainly include hardware equipment (such as waste bin, collection vehicle, transfer station etc.), software resource (such as SOA, EAI, ESB etc.), waste worker (such as housemaid, sanitation worker, waste picker etc.) and IoT equipment (such as wearable device, RFID terminal, RFID reader etc.). These resources are provided by different resource providers.

3.2.2 SWMR management layer: SWMR Management Layer is the basis of the functional layer of the platform. The main function is to realise the virtualisation and registration of physical SWMR. This layer can provide the upper layer visual SWMR information in the system. The upper layer can call the SWMR in this layer according to requirements.

The service object of this layer is the provider of the physical SWMR, the aim is to provide resource registration and management services for the SWMR providers in the PSS model. The main functions provided in this layer are as follows:

- **Resource virtualisation**: virtualisation is the conversion of physical resources into digital parameter information. Including appearance parameters, function parameters and processing capability parameters of a physical resource, etc.
- **Resource registration**: it is to register virtualised resource information into the platform. The platform provides a dedicated resource registration window. Resource providers can register resources through this window.
- **Resource searching**: by entering certain resource parameters, a related resources list can be searched, and the user can enter more resource parameter information for filtering. After finding the target resource, the user can click to see all the information about the resource.
- **Resource monitoring**: the resource monitoring function is to monitor the running state of resources through IoT devices, such as the fullness level of the waste bin, the vehicle routes, the position of waste workers, etc. And through the information...
network, the implementation data of resources can be collected and stored in the platform database.

3.2.3 SWMR service layer: The SWMR service layer provides independent SWMR services to users in the PSS model. After the user makes a service request, this layer can call the lower-level SWMR management layer to match the service requirements.

This layer provides service functions such as SWMR renting service, waste classification service, Kanban service and ‘points’ service. The main functions are as follows:

- **SWMR renting service**: this function mainly provides customers (households and property management companies) with the SWMR renting service. Including customer demand matching, contract signing, renting payment, resource return and other functions.
- **Waste classification service**: this function mainly provides household waste classification services and household waste dumping services for families who are unwilling to classify and dump waste by themselves. It can also provide waste classification and cleaning services for the property management company.
- **Kanban service**: this function is mainly to provide real-time dynamic monitoring services for a property management company or third-party operating company. It mainly includes the visualisation of the position of the vehicle, the visualisation of the fullness level of the waste bin, the vehicle routes, the visualisation of the position of the vehicle, the visualisation of the vehicle routing and the visualisation of the position of waste workers.
- **‘Points’ service**: each registered resident has a point card named ‘green bank card’. This service is that residents could award workers.

Platform can be found in this system. Users can log in to this system to inquire the SWMR that they want to rent (such as smart waste bin, collection vehicle, IoT equipment, waste worker). System functions include resource configuration, bargaining, contract signing and management and resource reuse.

- **Waste classification service management system**: this system is mainly for users to manage waste classification services. It mainly includes two aspects of the business: one is that residents themselves are unwilling to carry out waste classification and can purchase waste classification services through the system. Second, the property management company can contract the community waste classification business to a third-party company. The main functions include bargaining, contract management and service evaluation.
- **Kanban management system**: this is a system for real-time monitoring of the SWMR. This system can monitor the position and fullness level of the waste bin, the vehicle routes, the position and the movement routes of the waste worker. If the waste bin is full, the system will automatically launch collection request.
- **Points service management system**: the points management system is a financial system used to manage the ‘green bank cards’. This system is not only linked to the collection point interactive terminals, but also to the stores around the community. The main function is to manage the generation and consumption of points in the ‘green bank cards’.

4 Multiple stakeholders value analysis of the platform

The stakeholders of the platform include end customers (residents and property management companies), resource providers and platform operators. From a macro-level, the PSS platform designed in this study can improve the level of HSWCM in the community, so as to reduce the damage of garbage to the ecological environment. It also can provide more jobs for service workers, and it can enhance the residents’ life happiness. From the micro-level, first, the PSS platform can improve the participation of residents in source separation and the accuracy of waste classification. Second, the platform can increase the convenience of waste classification and transportation, which can improve management efficiency and effectiveness. Third, the platform helps resource providers attract more customers and build long-term relationships.

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4.1 Value analysis of residents based on the household waste bin

For the residents of the community, the main consideration should be the functionality and cost of the product. The functions of the smart waste bin can provide better assistance for residents to do the waste classification. However, in order to increase the acceptance of more expensive smart waste bins, the way of providing smart waste bins is very important. In here, three cases renting models are enumerated.

First, the residents rent smart waste bins from the platform. Considering the cost, the platform must price the renting within a range that is easily acceptable for the residents. Stakeholders include residents, smart waste bin providers and platform operators.

Second, the platform provides residents with smart waste bins for free. This is a good promotion method in the early stage of the platform launch. The platform can also make compensation from other stakeholders.

Third, the platform provides smart waste bins to residents for free, but the cost of smart waste bins is borne by third parties, such as property management companies and government departments. Third parties can make a profit by selling useful materials. The stakeholders involved may be residents, smart waste bin providers, platform operators, property management companies and government departments.

This article only lists three business models, and indeed there may be more. Regardless of the business model, the focus is on increasing participation in HSW classification.

4.2 Value analysis of the property management company based on collection point and transfer station equipment

For the property management company, the company's wholly owned purchase of smart equipment will inevitably face the three-highs problem mentioned earlier in this article. Property management companies can dramatically reduce equipment purchase and maintenance costs by renting smart equipment from the PSS platform.

Under the environment of the classification system mentioned in this article, the property management company can recycle more useful materials and increase the company's income. In addition, the property management company can adopt a payment model of residential waste to improve the effect of waste classification management.

4.3 Value analysis of the resource providers based on resource service

The resource provider makes profits by selling more products or services. Under the PSS business model mentioned in this article, resource providers can use the platform to achieve better advertising effects and enhance the visibility and awareness of the company's new products. In particular, after smart waste bins are deployed in residents' homes, it can stably lock more customers for the resource providers.

4.4 Value analysis of platform operators based on platform services

Platform operators are mainly responsible for platform promotion, registrant business negotiation, platform information management updates, system upgrades and routine maintenance. On the one hand, the platform can make a profit by collecting registration fees, intermediary fees, management fees and business commissions. On the other hand, the platform can also purchase products from resource producers, so the platform becomes a provider. The general platform can also be used in both ways.

4.5 Value analysis of other stakeholders

The value analysis of the neighborhood stores: stores around the community can join the ‘green bank card’ system through an agreement to attract customers to shop and providing partial ‘points’ service for customers. Residents can use points in the ‘Green Bank Card’ to redeem goods in stores or use points to redeem product discounts.

The real estate developer: The implementation of waste classification management not only can improve the happiness of residential residents, but also enhance the brand image of the real estate developer.

Government: HSWCM is an important part of urban waste management. HSW is the main source of municipal solid waste. Good classification of residential waste can effectively promote the management of the whole city's domestic waste closer to the goal of ‘reduce, reuse and recycle’.

5 Case study

In order to verify the feasibility of the platform in reality, this section will analyse the case from three aspects, including the analysis of the overall application scenario of the platform, the analysis of the household waste bin PSS case and investigation of potential users of household waste bins.

5.1 Scenario description

This section describes the process of using the platform to complete the HSWCM in the community. As shown in Fig. 4, all steps are arranged according to the logical sequence of the involved operators and activities. This process is common for other workshops and commercial places because the waste separation processes are very similar.

There are ten main steps in this process. Each step is directly initiated by one of the visibility modules downloaded to the corresponding PC and is supported by a tracking capability service running in the background.

Step 1: the property management company rent infrastructure resources of collection point and transfer station from the platform according to the actual needs of the community.

Step 2: the platform configures resources to the community based on the demand of the property management company order.

Step 3: customers search relevant equipment and service resources (such as smart waste bin, waste classification service resource, shared waste bin service resource, etc.) on the platform according to their own needs, and sign a business contract with the platform.

Step 4: the platform configures resources to customers according to their order requirements after optimisation, and the resources are sent directly to customers by the resource providers.

Step 5: when the household waste bin is full, the platform will prompt the resident to send the waste to the collection point. There are two kinds of situations here. The first is that residents themselves dump waste. Second, the provider that is responsible for waste classification service will help residents dump waste.

Step 6: resident or service workers first swipe ‘green bank card’ to interact with the smart waste bin and throw garbage into the corresponding smart waste bins. The smart waste bin of collection point will weigh the garbage and convert it into corresponding points, which will be stored in the ‘green bank card’. 
they are reluctant to pay for too much money for a new smart waste transportation early warning to the related manager.

(ii) They have difficulty understanding the waste classification (30.2%) and occasionally implement waste classification (30.2%).

Step 8: the platform monitors the fullness level of the smart waste bin at the collection point, and provides collection and transportation early warning to the related manager.

(iii) They have no time to implement waste separation by themselves; (iv) They are office workers who rent departments; (v) They are students who have low income and are not willing to pay for smart waste bins.

(i) Their community has implemented household waste bin product service for these customers. The survey results show that 9.5% of the communities are inclined to the housekeeping service company.

(ii) The platform designed in this article will provide a good household waste bin product service for these customers. The analysis of the household waste bin PSS case is shown in Fig. 5.

(iii) The platform Kanban system will monitor the status of the smart waste bin. On the one hand, residents are reminded to dump waste; on the other hand, the relevant maintainer is reminded to perform maintenance and repair of the smart waste bin. Step 6: residents return the smart waste bin or replace the new one.

Under this service model, on the one hand, the resident can rent and return smart waste bins at any time, which increases the flexibility of using smart waste bins. On the other hand, the resident has enjoyed the service of the smart waste bin and made it easier and more convenient for the resident to separate waste.

5.3 Investigation of potential users of household waste bin

In order to verify the feasibility of the smart waste bin product service model proposed in Section 5.2, this study conducted a questionnaire survey to potential users of the smart waste bin. The questionnaires were distributed to the respondents through the online questionnaire system (Tencent Questionnaire). The Chinese language was used in the questionnaire. A total of 70 questionnaires were sent, and 63 valid questionnaires were recovered.

5.3.1 Basic characteristics of respondents: In terms of gender, 73% of the valid samples are men and 27% are women. In terms of age, 1.6% of people are under the age of 20, while 71.4% of people aged 21–30, 20.6% of people aged 31–40, 4.8% of people aged 41–50 and 51–60 accounted for 1.6%. In terms of education, most of the valid samples obtain bachelor degree or above, 19% have doctoral degree, 60.3% have master degree, 12.7% have bachelor degree, 8% have college degree or below. Respondents’ occupations include teachers, students, engineers, company managers, factory workers and civil servants. Respondents were mainly located in Shanghai, Beijing, Guangzhou, Shenzhen, Dongguan, Changsha and Zhuhai.

5.3.2 Descriptive statistical analysis: 38.1% of the communities in which the respondents live have implemented waste classification management, and 61.9% have not implemented waste classification management. However, only 6.3% of the respondents strictly implement classification each time, 58.7% occasionally implement classification and 35% do not classify at all.

Respondents think that the most difficult points to implement classification are as follows: the categories of waste are not easy to distinguish (65.1%), the household waste bins are not conducive to waste classification management (63.5%), the habit of waste classification is not formed (49.2%) and the work is too busy to do waste classification (30.2%).

When answering whether the smart waste bin could assist residents in waste classification, 31.7% of the people think it is very helpful, 63.5% think it is helpful and 4.8% think it is not helpful at all.

When questioning whether they are willing to use smart waste bins by renting, 57.1% of the people accept and 42.9% refuse. In terms of the ways to rent smart waste bins, the survey results are shown in Fig. 6. 81% of the people prefer the PSS platforms specifically for HSWCM, 9.5% of the people prefer waste bin manufacturers and 9.5% of the people prefer physical stores.

In terms of purchasing waste classification services, 61.9% of the people accept while 38.1% of them refuse. In terms of purchase channels, the survey results are shown in Fig. 7. 65.1% of the people are inclined to the PSS platforms specifically for HSWCM, 30.2% are inclined to property management company and 4.7% are inclined to the housekeeping service company.

5.3.2.1 Customer activity cycle analysis in household waste bin PSS case

Step 7: residents exchange points at the collection point for garbage bags.

Step 8: the platform monitors the fullness level of the smart waste bin and the transportation early warning to the related manager.

Fig. 5 Customer activity cycle analysis in household waste bin PSS case

Fig. 6 Percentage of potential users choosing different ways to rent smart waste bin

Step 9: when the smart waste bin of the collection point is full, the manager will send a collection vehicle to collect the waste after receiving the reminder from the platform, or the waste is collected by the waste classification service provider. According to the real-time monitoring information of smart waste bins, the platform can automatically optimise the routes of collection vehicles.

Step 10: after the waste is transported to the transfer station by collection vehicles, it is put into the corresponding smart waste bin, and then feedback is completed to the platform. Thus, a cycle of collection and transportation in the community is completed.

5.2 Household waste bin PSS case

In this case, we focus on residential customers. These customers have the following characteristics:

(i) Their community has implemented or will implement waste source separation management;

(ii) They have difficulty understanding the waste separation knowledge quickly (for example, the elderly and children);

(iii) They have no time to implement waste separation by themselves;

(iv) They are office workers who rent departments;

(v) They are reluctant to pay for too much money for a new smart waste bin.

The platform designed in this article will provide a good household waste bin product service for these customers. The analysis of the household waste bin PSS case is shown in Fig. 5.

Step 1: customer rent smart waste bins through the platform.

Step 2: after the platform accepts the customer’s request, the tripartite service company sends the smart waste bin to the customer’s home.

Step 3: service provider helps fulfil installation and commissioning of the smart waste bin system.

Step 4: the customer uses a smart waste bin as well as its service add-ons, including waste classification, earning points, redeeming points for garbage bags and waste classification service.

Step 5: through the IoT monitoring equipment, the platform Kanban system will monitor the status of the smart waste bin. On the one hand, residents are reminded to dump waste; on the other hand, the relevant maintainer is reminded to perform maintenance and repair of the smart waste bin.

Step 6: residents return the smart waste bin or replace the new one.

Under this service model, on the one hand, the resident can rent and return smart waste bins at any time, which increases the flexibility of using smart waste bins. On the other hand, the resident has enjoyed the service of the smart waste bin and made it easier and more convenient for the resident to separate waste.

5.3 Investigation of potential users of household waste bin

In order to verify the feasibility of the smart waste bin product service model proposed in Section 5.2, this study conducted a questionnaire survey to potential users of the smart waste bin. The questionnaires were distributed to the respondents through the online questionnaire system (Tencent Questionnaire). The Chinese language was used in the questionnaire. A total of 70 questionnaires were sent, and 63 valid questionnaires were recovered.

5.3.1 Basic characteristics of respondents: In terms of gender, 73% of the valid samples are men and 27% are women. In terms of age, 1.6% of people are under the age of 20, while 71.4% of people aged 21–30, 20.6% of people aged 31–40, 4.8% of people aged 41–50 and 51–60 accounted for 1.6%. In terms of education, most of the valid samples obtain bachelor degree or above, 19% have doctoral degree, 60.3% have master degree, 12.7% have bachelor degree, 8% have college degree or below. Respondents’ occupations include teachers, students, engineers, company managers, factory workers and civil servants. Respondents were mainly located in Shanghai, Beijing, Guangzhou, Shenzhen, Dongguan, Changsha and Zhuhai.

5.3.2 Descriptive statistical analysis: 38.1% of the communities in which the respondents live have implemented waste classification management, and 61.9% have not implemented waste classification management. However, only 6.3% of the respondents strictly implement classification each time, 58.7% occasionally implement classification and 35% do not classify at all.

Respondents think that the most difficult points to implement classification are as follows: the categories of waste are not easy to distinguish (65.1%), the household waste bins are not conducive to waste classification management (63.5%), the habit of waste classification is not formed (49.2%) and the work is too busy to do waste classification (30.2%).

When answering whether the smart waste bin could assist residents in waste classification, 31.7% of the people think it is very helpful, 63.5% think it is helpful and 4.8% think it is not helpful at all.

When questioning whether they are willing to use smart waste bins by renting, 57.1% of the people accept and 42.9% refuse. In terms of the ways to rent smart waste bins, the survey results are shown in Fig. 6. 81% of the people prefer the PSS platforms specifically for HSWCM, 9.5% of the people prefer waste bin manufacturers and 9.5% of the people prefer physical stores.

In terms of purchasing waste classification services, 61.9% of the people accept while 38.1% of them refuse. In terms of purchase channels, the survey results are shown in Fig. 7. 65.1% of the people are inclined to the PSS platforms specifically for HSWCM, 30.2% are inclined to property management company and 4.7% are inclined to the housekeeping service company.

To sum up, at present, waste classification is in the stage of vigorously promoting in China. Most of the respondents are young people with higher education, and most of them come from China’s waste classification pilot cities. Most of them know the importance of waste classification. They are the most probable potential users of the scheme proposed in this paper. The survey results show that these potential users agree that smart waste bin can help residents to do a good job in waste classification, and accept the business model of the PSS and agree to rent a smart waste bin and purchase waste classification services through a special PSS platform. It is
predictable that these respondents show more acceptances in the concepts and the PSS platform proposed in this paper in the future. However, waste classification is still confronted with many challenges. For example, the categories of waste are not easy to distinguish; the ordinary waste bins are not conducive to waste classification management; the residents are too busy to fulfil accurate waste classification and so on.

6 Conclusion

Many smart-enabling technologies (e.g. the IoT, cloud computing, big data analytics, etc.) and management strategies (e.g. source separation, standardisation, points rewards, etc.) improve the timeliness and accuracy of waste classification, collection and transportation. Based on a new generation of information technology and the PSS business model, this paper builds a cloud-based PSS platform for HSWCM. The platform can improve the accuracy of waste classification and enhance the enthusiasm of multiple stakeholders to participate in waste classification. SWMR providers register resources information through the platform, residents and property management companies can rent the required resources on the platform. The platform can realise real-time monitoring of resources. When an exception occurs or the waste bin is full, the platform can automatically send a dynamic reminder to the administrator.

This article achieves three main contributions. First, a network of the HSWCM system is constructed for the residents of the communities to classify waste. This network is used to configure the smart waste bins in the residents’ homes so that the waste is accurately classified at the source. Second, the operation and management of the whole network is supported by smart waste bin, smart vehicle, IoT technology and cloud technology. Third, the cloud-based PSS platform not only makes the use of SWMR more flexible but also realises the dynamic configuration of SWMR. Moreover, the efficiency of waste collection and transportation management is greatly improved through visual management. In addition, the platform enables multiple stakeholders to make profits and improve the participation of all social parties in waste classification.

The platform still has certain limitations, which require further research and experimentation. Some practical cases can be used to test the feasibility of network and platform.

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