Application of RFID Technology in Facilitating REE Collection and Recycling in Hong Kong

Final Report to Hong Kong Institute of Surveyors

(a) Household Pick-up Service

(b) Private Housing Estate Disposal

(c) Community Green Station

Prepared by:

Prof. Winco K.C. Yung

Cheung Ka Ming; Mak Kin Lun; Sze Yee Kei

1 Feb 2018

Table of Contents

Chapter 1 - Background introduction and issues

Air-conditioners, refrigerators, washing machines, televisions, computers, printers, scanners and monitors are collectively referred to as regulated electrical equipment or REE. The handling and disposal status of REE is depicted in Figure 1. It is estimated that more than 70,000 tonnes of REE are discarded every year in Hong Kong. 80% of REE are shipped overseas to Africa or Southeast Asia while the remaining 20% of REE are directly disposed to landfill in Hong Kong. Concerning the waste disposal of WEE to landfill, the Hong Kong Environmental Protection Department (EPD) proposed and implemented Waste Producer responsibility scheme (WPRS) which prohibits the public from illegal disposal of REE.

Figure 1 Handling and Disposal of REE

What is WPRS?

Producer Responsibility Scheme (PRS) is a key policy tool on waste electrical and electronic equipment (WEEE). The Scheme requires the recycling and proper disposal of REE started **effectively from August 2018)**. In general, a consumer, a seller, a supplier and a recycler will be involved in the handling process of WEEE. Their duties

are described as follows (Figure 2): A consumer considers how to properly handle waste equipment that requires disposal. A seller provides the removal service plan, arranges free statutory removal service for consumer and provides the recycling label. A supplier submits an application to EPD to become a registered supplier, pays a recycling levy, and provides the recycling label. A recycler requires a permit for the import and export of e-waste.

Consumer	Seller	Supplier	Recycler
consider how to properly handle waste equipment requiring disposal	removal service plan	submitting an application to EPD to become a registered supplier	a permit will be required for the import and export of e-waste
	arrange free statutory removal service for consumer	pay a recycling levy	
	providing recycling label	providing recycling label	

Figure 2 Group of people involved in the handling process of WEEE

Chapter 2 - Stakeholders and their interest

The licensed REE recyclers and types of REE recycled are shown in Table 1. It can be seen that **Computers, Printers/Scanners are most favorable recyclers, Air-con and Refrigerator are least favorable.** Among all the recyclers, Only ALBA IWS (HK) Limited provides free pick-up service.

Table 1 Licensed REE recyclers and types of REE recycled

	Storage	Treatment	Reprocessing	Recycling
Air-con	1,3,6	1	1	1
Computer	1,2,3,4,5,6,7,8	1,2,3,4,5,6,7,8	1,2,3,4,5,6,7,8	1,2,3,4,5,6,7,8
Monitor	1,3,4,6,7	1,4,6,7	1,4,6,7	1,4,6,7
Printer	1,2,3,4,6	1,2,3,4,6	1,2,3,4,6	1,2,3,4,6
Refrigerator	1,3,6	1	1	1
Scanner	1,3,4,6	1,3,4,6	1,3,4,6	1,3,4,6
Television	1,3,4,6	1,4,6	1,4,6	1,4,6
Washing Machine	1,2,3,6	1,2	1,2	1,2

1 Industry **Leader:** ALBA IWS (HK) Limited
(歐綠保綜合環保(香港)有限公司)
=================================
SME Recyclers:
2 Chiho Eco Protection Limited
(齊合綠色環保有限公司)
3 E.Tech Management (HK) Limited
(億達再生資源有限公司)
4 Li Tong (H.K.) Telecom Company Limited
(俐通(香港)有限公司)
5 Tong Shing Technology Company
(東成科技公司)
6 Vannex International Limited
(科域國際有限公司)
7 Wing Kai Destruction & Recycle Co.
(永佳環保處理公司)
8 H2O & AU ENVIRONMENTAL RECYCLING CO. LTD
(富元再生資源有限公司)

*** **Only ALBA** IWS provides **free pick-up** service

For the roles and interests in REE recycling, there are four different stakeholders, namely, public, Government, Recycler (Industry leader) and Recycler (SMEs). For the public, they expect the Government to **provide free REE Collection with a short waiting time**. They also expect to have free collection service and fast collection from both the Recycler (Industry leader) and the Recycler (SMEs). For the Government, they encourage the public to have **REE reduction and recycling and not to dispose e-waste illegally.** They request both the Recycler (Industry leader) and the Recycler (SMEs) to collect and recycle any kinds of REE legally. For the Recycler (Industry leader), they prefer to collect REE in batches and high recycle value REE from the public. They expect from the Government to provide them more support and capacity in REE recycling. For the Recycler (SMEs), they also prefer to collect REE in batches and high recycle value REE from the public. However, they are looking for "equal opportunities" to be given from the Government so that they can receive the same support as the Recycler (Industry leader).

2.1 Free removal service -- Current situation

There is a commitment from HKSAR government EPD via ALBA that free statutory removal services will be within 3 working days after the purchase of new appliance.

2.2 Timeline of WPRS

Timeline of WPRS is shown in Figure 3. The enabling legislation for the PRS on WEEE (WPRS), namely the Promotion of Recycling and Proper Disposal (Electrical Equipment and Electronic Equipment) (Amendment) Ordinance 2016 was passed by the Legislative Council in March 2016. During the first stage of WPRS in August 2016, All REE suppliers and sellers should fulfill the statutory obligations that providing recycling labels, **arranging free removal service** to customers. In September 2018, there was some report on illegal disposal of REE. Due to limited and un-timely collection service, many REE are disposed at roadside and un-licensed shops. In October 2018, there were complaints from the public. 57 complaints about WPRS has been received since Aug 2018. 19 out of 57 are directly related to ALBA's collection service. The Second stage of WPRS started in December 2018. The **disposal licensing control**, **import and export permit control** and **landfill disposal ban** in respect of abandoned REE commenced. The WPRS legislation says:

a)   Abandoned REE will **no longer** be accepted for disposal at the **landfills** and other designated **waste disposal facilities**

b)   Any person who is engaged in the storage, treatment, reprocessing or recycling of e-waste **must obtain a "waste disposal license"**.

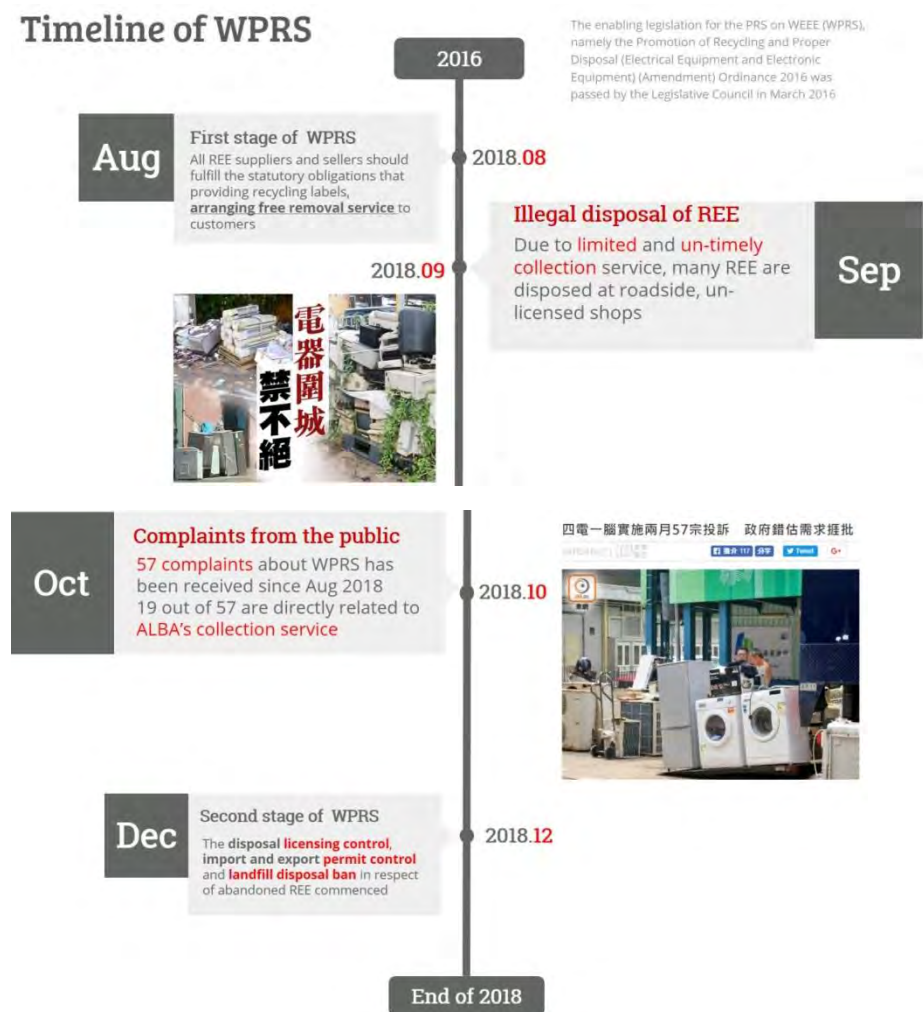Unfortunately, many thrift storeowners do not have the waste disposal license.

Figure 3 Timeline of WPRS

2.3 Three (3) general approaches to dispose e-waste

As shown in Figure 4, there are three general approaches to dispose e-waste. They are (a) Household Pick-up Service, (b) Private Housing Estate Disposal, and (c) Community Green Station.

Figure 4 Three general approaches to dispose e-waste

Chapter 3 - Problems and possible solutions enabled by RFID

3.1 Household collection

3.1.1 Current Situation

As shown in Figure 5, there are four steps for E-waste Logistics Flow, which the retailers initiated. In Step 1, the Consumer purchases REE and makes a request for the removal service. In **Step 2,** the Retailers must arrange the free statutory removal service for consumer. In **Step 3,** Alba, the only contractor appointed, provides free statutory removal service. In **Step 4, they** remove an old REE of the same class from the premises designated by the consumer.

Step 1: Consumer purchases REE and makes a request for the removal service

Step 2: Retailers must arrange the free statutory removal service for consumer

Step 4: Remove an old REE of the same class from the premises designated by the consumer

Step 3: Alba, The only contractor appointed provide free statutory removal service.
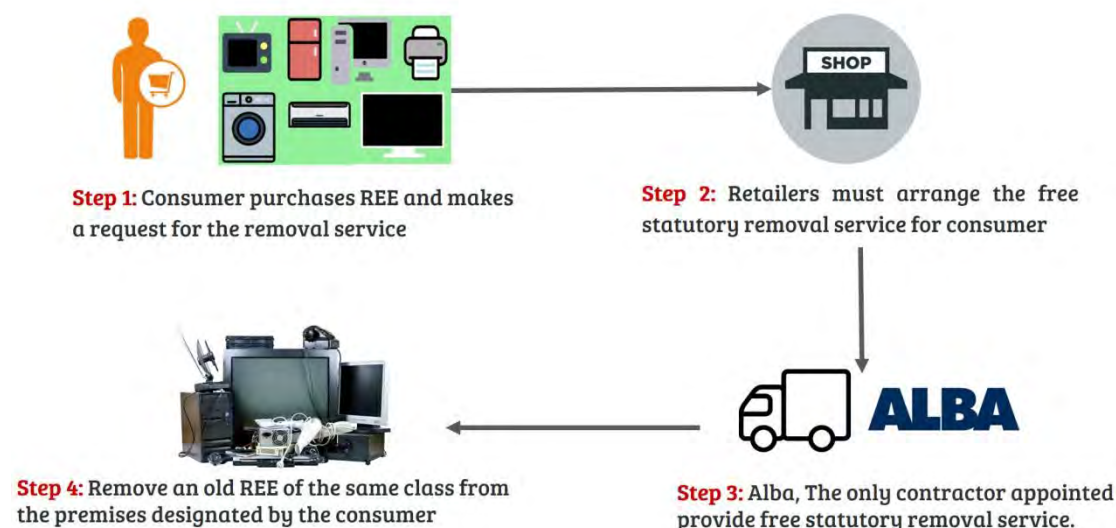
Figure 5 Four steps for E-waste Logistics Flow (Retailers Initiated)

As shown in Figure 6, there are three steps for E-waste Logistics Flow, which the consumers initiated the collection. In Step 1, the Consumer can request removal service by hotline and email to arrange collection.
In **Step 2,** Alba, the only contractor appointed, provides free statutory removal service.
In **Step 3,** Alba, the only contractor appointed, provides free statutory removal service.
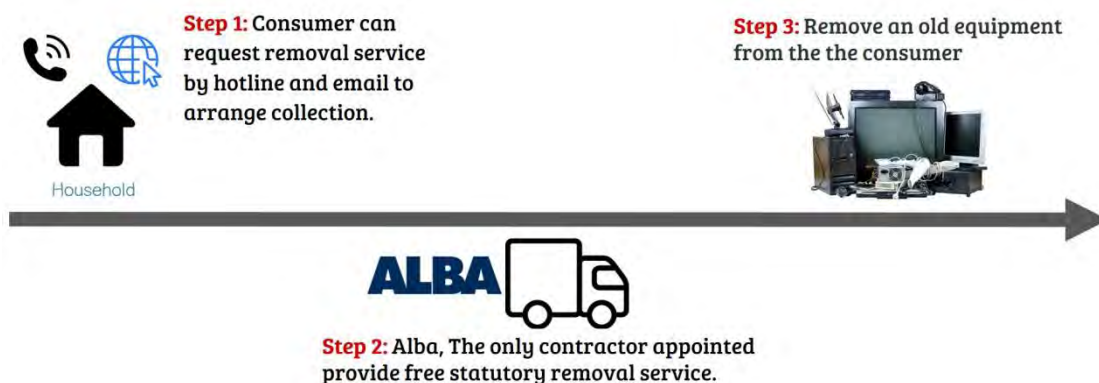In **Step 4, they** remove old equipment from the consumer.

Figure 6 Three steps for E-waste Logistics Flow (consumers initiated the collection)

3.1.2 Problems

As shown in Figure 7, there are different problems related to Recyclers, Consumers in Household, and Retailers. For Recyclers, they have the Problem 1. For Consumers in Household, they have the Problems 2a, 2b and 2c. For Retailers, they have the Problem 3. Details about the Problems 1, 2a, 2b, 2c and 3 are described as below:

Figure 7 different problems related to Recyclers, Consumers in Household, and Retailers

For Problem 1 (Figure 8), it is related to unutilized resources. There are seven REE disposal licensed recyclers updated as of 31 January 2019 but there is one free statutory removal services. Not providing sufficient free statutory removal services is equivalent not to provide the storage service of REE. It will result in (a) the elimination of the capability of other 7 recyclers, (b) the increase the collection difficulties of Alba, (c) the imbalanced development on recycle industry.
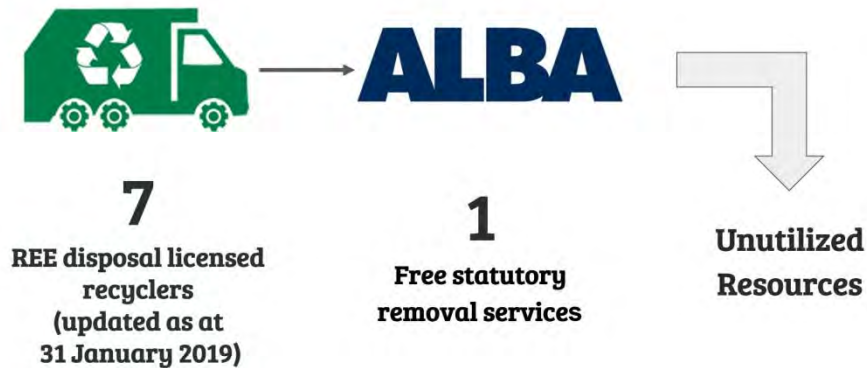
Figure 8 Problem 1 (unutilized resources)

For Problem 2a (Figure 9), the delivery and collection processes of New REE and Old REE are not seamless. It will be difficult to have the same day delivery and collection of those REE items.

Figure 9 Problem 2a (delivery and collection processes of New REE and Old REE)

For Problem 2b (Figure 10), it is related to inconvenience caused. New and old appliances exist at same time will create concern of (a) Moving area, (b) Pollutants, and Cause of home accidents
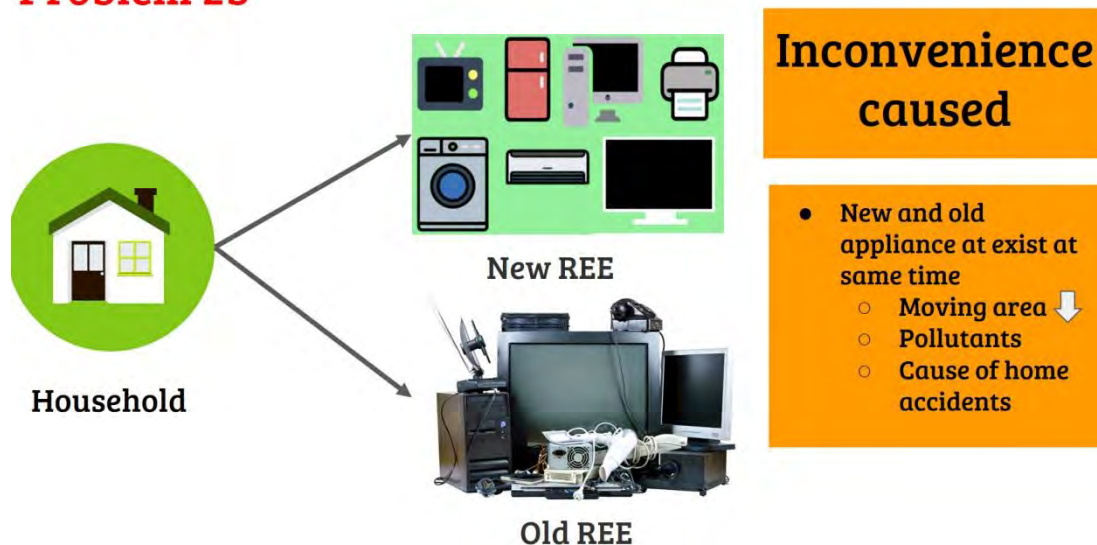
Figure 10 Problem 2b: inconvenience caused

For Problem 2c (Figure 11), it is related to illegal disposal and handling. Some consumers dispose their REE illegally to the Garbage collection station. Also, some Thrift store owner handled the old REE illegally. It was started form December 31, 2018

Under Second stage of WPRS, it should be noted that:
Abandoned REE will **no longer** be accepted for disposal at the **landfills** and other designated **waste disposal facilities**
Any person who is engaged in the storage, treatment, reprocessing or recycling of e-waste **must obtain a waste disposal licence**.

Unfortunately, large percentage of thrift storeowners does not own the waste disposal license.

Figure 11 Problem 2c: illegal disposal and handling

For Problem 3, there are two aspects for the current situation on the handling procedure of REE. One aspect is a complicate application process. As shown in Figure 12, the Retailers need to fill in the REE Collection Service Application Form for customers in the first step. In the second step, they will e-mail or fax the application form to Alba. The other aspect is an inflexible recording process. Sellers must keep records (refer to Figure 13) for all the requests for removal service for a period of not less than one year, in order to facilitate inspection and serve as a proof of the consumer's choice of removal service in case of dispute.

Figure 12 Problem 3: Complicate application process
REE Collection Service Application Form for customers

Figure 13 Problem 3: Problem 3: Complicate application process
Seller – RSP Arrangement Record

3.1.3 Research Objectives

Refer to Figure 14, the research objectives of this project include:
(1) To establish a system that can benefit the stakeholders among Recyclers, Consumers in Household, and Retailers.
(2) To find out a solution that can solve the above problems.
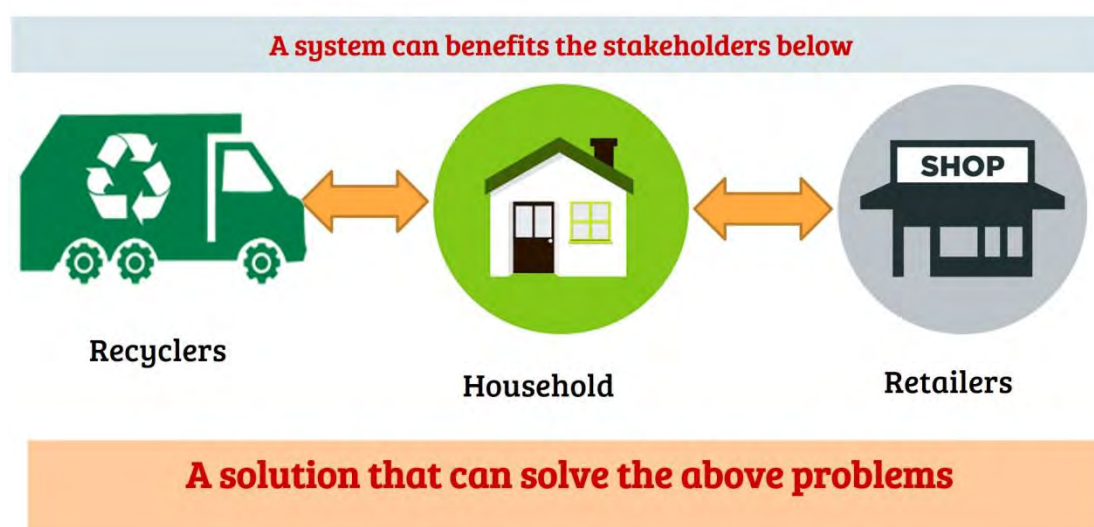
Figure 14 Research Objectives of the project

3.1.4 Solutions

(a) Automatic booking system

An automatic booking system with RFID Technology is suggested to be a solution to the above problems. The automatic booking system can be referred to
Figure 15. It can (i) Increase customer satisfaction and achieve the goal of seamless, (ii) Use Records for further data analysis, (iii) Reduce human processing time and error, (iv) Increase efficiency.

Figure 15 Automatic booking system

There are five steps for the automatic booking system.

For the first step (Figure 16), all First Hand REE are tagged with a recycling label.

In the second step (Figure 17), all recycling label are tagged with RFID Tag.

In the third step (Figure 18), the RFID tag is given by unique electronic product code to specify the product type. A shared database and system is used to arrange the Alba free removal service schedule and accumulate quantity of REE purchase in shop.

In the fourth step (Figure 19), Consumer purchases REE and makes a request for the removal service. Shop operators can scan the recycling label that **shows Alba's Regional Collection Centre Collection schedule**.

In the fifth step (Figure 20), Consumer can determine what the best solution is. If selecting ALBA, **Schedule can be automatically registered and the** delivered date will be the same as the collection date. If not selecting Alba, they **can choose No Preference**. It will reduce the waiting time for the collection process.

Figure 16   First step for the automatic booking system

2nd Step:

All recycling label are tagged with RFID Tag

Figure 17   Second step for the automatic booking system

3rd Step:

01.0000389.000162.000169740

Unique Electronic Product Code

Product's type

3rd Step:

ALBA

Alba free removal service schedule

Accumulate quantity of REE purchase in shop

Shared database and system
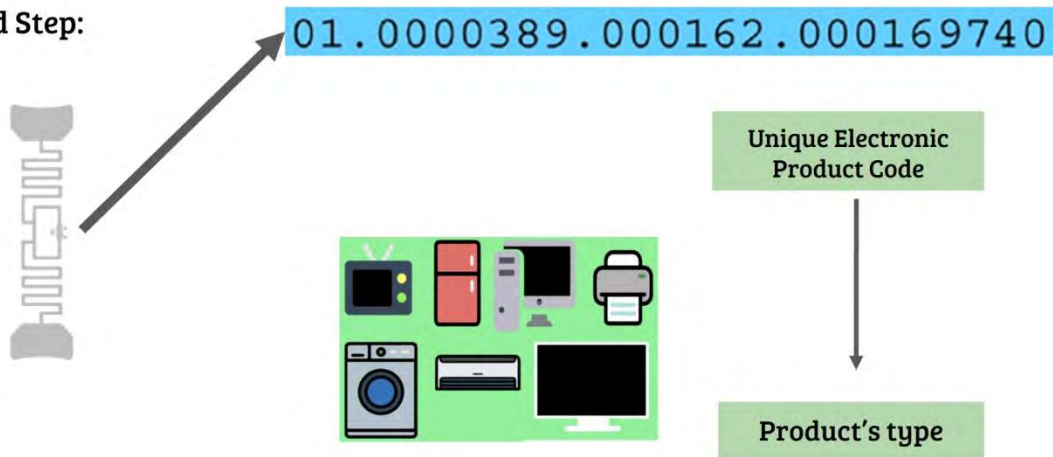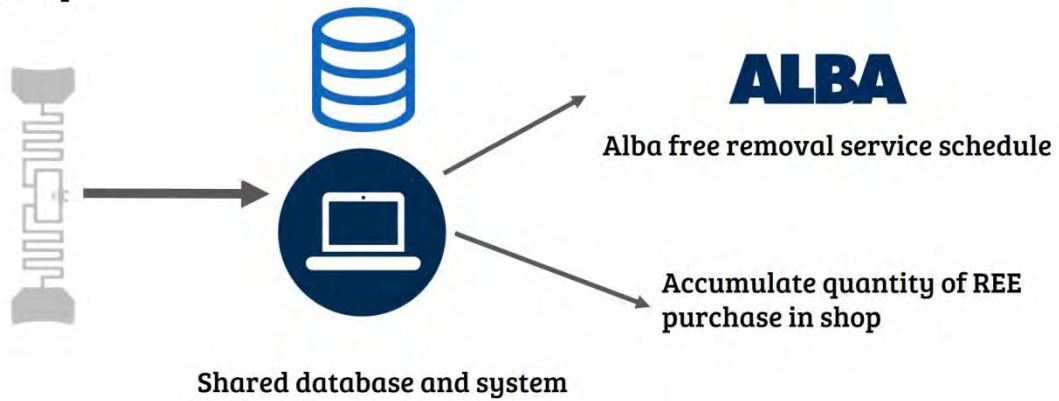
Figure 18   Third step for the automatic booking system

17

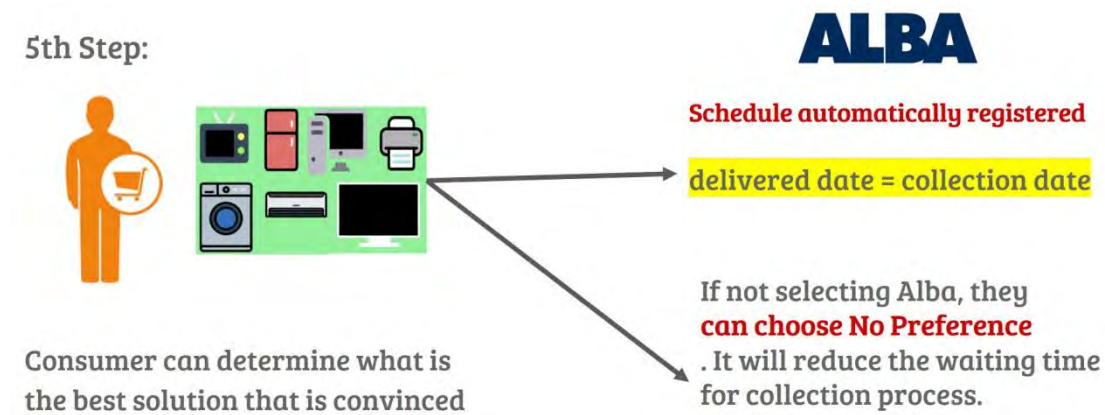Figure 19　Fourth step for the automatic booking system

Figure 20　Fifth step for the automatic booking system

(b) Application

The layout of software system is shown in Figure 21. The time availability for Alba's Schedule, Stores' status can be checked. The delivery and collection date with Recycler can also be selected.

Figure 21 Layout of software system

(c) Flow Chart

The flow chart of the system is shown in Figure 22.

Firstly, Shop operators use RFID Scanner to scan the selected product. Secondly, System can show the RFID Tag Code of product and the category of REE that need to collect. Thirdly, Customers fill in the required Personal Information. Fourthly, the system shows the Real-Time scheduling of Recycler A and other recyclers.

Based on this work flow, Customers can take their preference to choose either "Recycler A" or "No preference". For choosing "Recycler A", A booking will automatic registered to Alba's collection schedule. Information will be stored at Cloud database with share with Alba. A confirmation letter will be sent out through SMS and Email to customers. For choosing "No preference", the order with indicate "NO preference". The order will be accumulated in the Store's Status which within a same district. If reaching a specific quantity, collection request will be sent out to the recyclers. Again, a confirmation letter will be sent out through SMS and Email to customers.
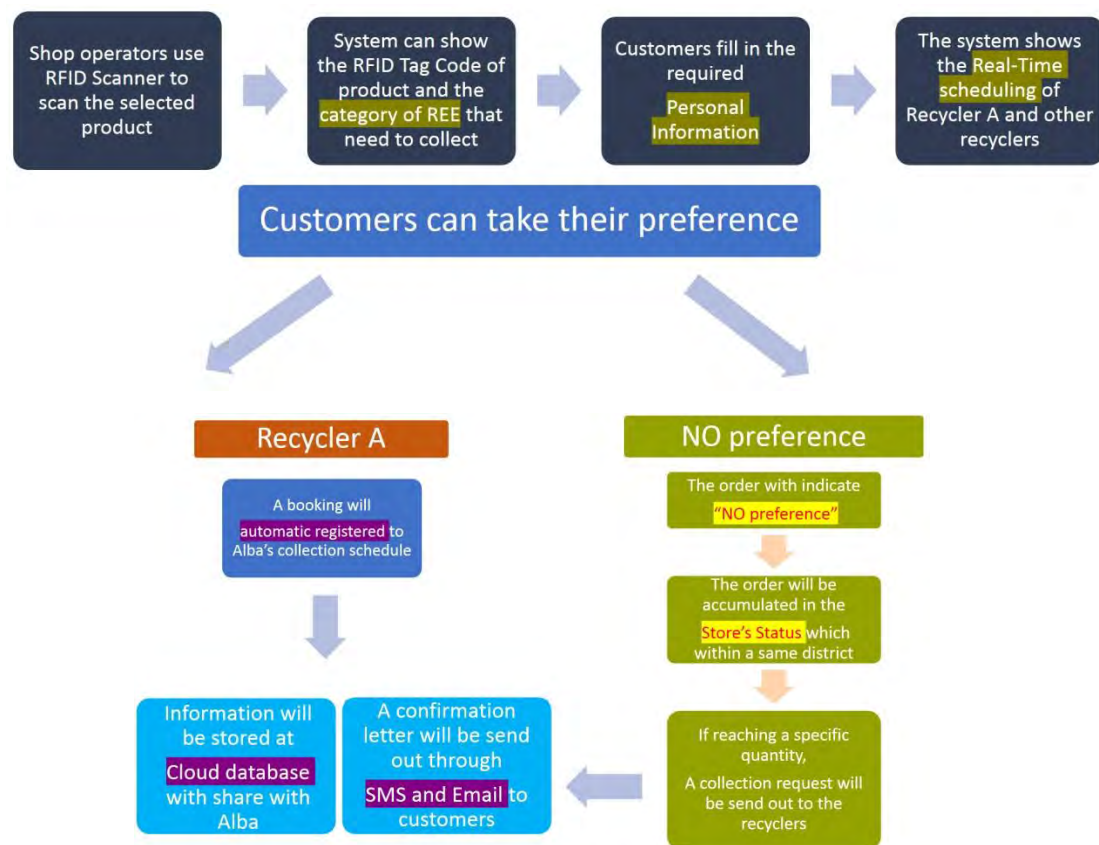
Figure 22 Flow Chart

Functionality of the software system:

The Functionality of the software system is listed as below:

(1) One stop solution for retailers

It can arrange collection and delivery date.

It can save Records.

(2) Real-Time scheduling

It can identify the REE by RFID technology automatically.

It can involve Less human works.

It can increase Efficiency.

(3) A confirmation can be send by SMS and Email

It can provide a solution for customers to track the process.

(4) A better alternative for customers

It can select not only Alba but also other alternative.

(d) Demonstration

As shown in Figure 23, shop operators use RFID Scanner to scan the selected product. System can show the RFID Tag Code of product and the category of REE that need to collect. Customers fill in the required Personal Information.

Figure 23 Demonstration: Step 1 - Collection Request Form

As shown in Figure 24, the system shows the Real-Time scheduling of Recycler A and other recyclers. Information will be stored at Cloud database with share with Alba.

As shown in Figure 25, the order will be accumulated in the Store's Status which within a same district. If reaching a specific quantity, a collection request will be send out to the recyclers

As shown in Figure 26, a confirmation letter will be send out through SMS and Email to customers.
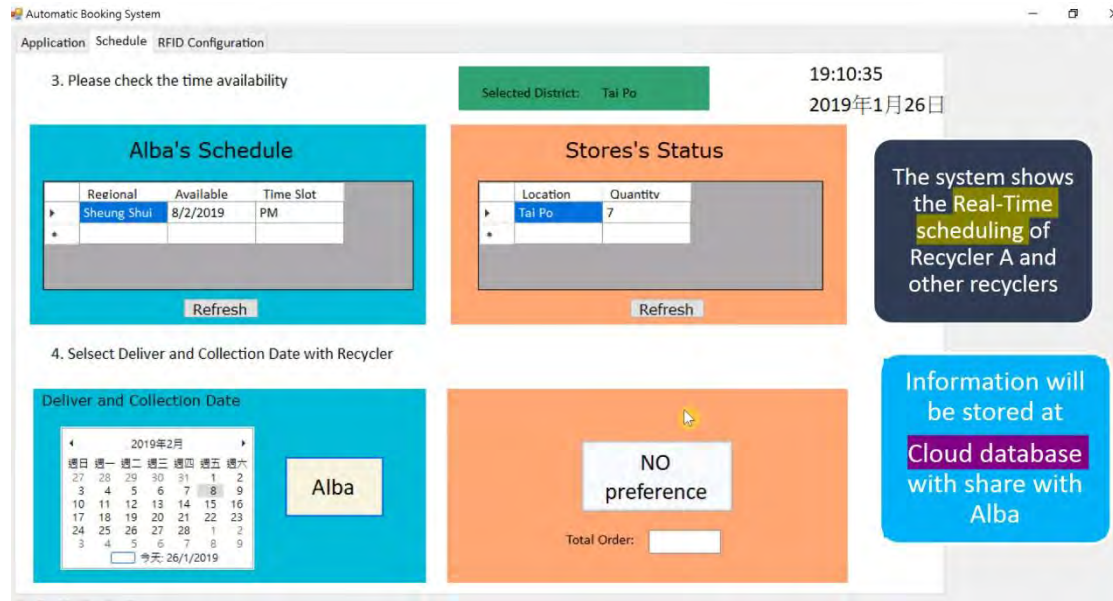
Figure 24 Demonstration: Step 2 – Real-time scheduling and cloud database
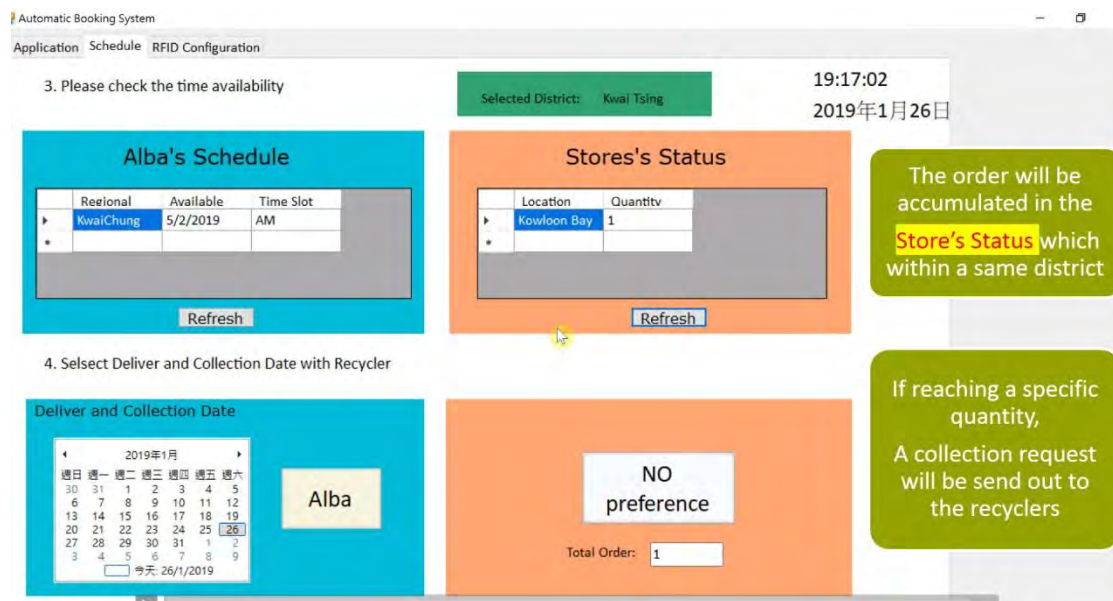
Figure 25 Demonstration: Step 3 – Collection request
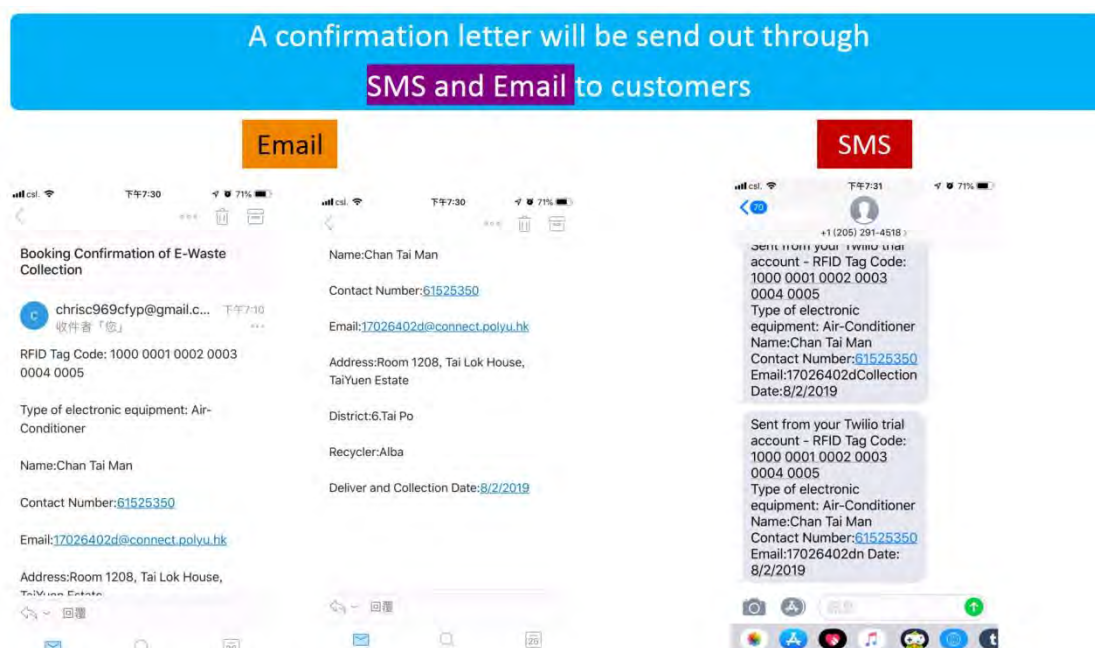
Figure 26 Demonstration: Step 4 – Confirmation letter

(e) Expected Benefits

For the customers in household, the benefits include:
(a) Ensure the collection and delivery process are at same day. The Collection can be in the morning (at A.M.) and the delivery can be in the afternoon (at P.M.).
(b) Inconvenience Reduced
    No new and old appliance will exist at same time.
(c) More alternatives to choose
    (i) Not only Alba.
    (ii) Other E- waste disposal licensed recyclers can be chosen.

For the retailers, the benefits include:
(a) Simplify the booking process.
(b) Reduce human error.
(c) Real- time information sharing.
(d) All application information can be stored in database perfectly.
(e) Instead of storing paper works.
(f) Increase customer's satisfactions.

For the recyclers, the benefits include:
(a) From the Microscopic view,
    (i)   Transparency on scheduled tasks.
    (ii) Better planning on transportation.
    (iii) Data management can be done easily.

(b) From the Macroscopic view:
  (i)   Benefits in Recycle industry.
  (ii)   Resources are utilized.
  (iii) Increase the opportunities to cooperate and communicate between recyclers.

3.2 Private Housing Estate Disposal

(a) Problems

There are two problems. For the first problem, the arrangement of collection services is not efficient and thus waiting time for REE pick-up is too long as illustrated in Figure 27. As for the second problem, REE collection flow in housing estates is lacking the Medium-sized recyclers to collect REE from housing estates as depicted in Figure 28.

Figure 27 **Problem 1**

Lacking Medium-sized recyclers to collect REE from housing estates

Figure 28 Problem 2

Research objectives and Solutions/Studies
For addressing the above two problems, there are two approaches.
(1) Design a user-friendly collection bin that can safely collect REE.
(2) Build up a system to monitor the filling status of collection boxes and send a signal to cloud database to require collection.

(b) Case Study

According to Table 2, the Computer Monitor is a suitable case study in private housing estates among other REE (e.g. Air-conditioner, Printer, Refrigerator, Scanner, Television and Washing Machine).   This is because the Computer Monitor is easy to store and do not involve personal information.

Table 2 Case Study

	Size	Privacy Information
Monitor	1	1
Computer	2	5
Air-con	3	1
Printer	3	2
Refrigerator	5	1
Scanner	4	2
Television	5	1
Washing Machine	4	1

Least 1 ⟺ 5 Most
Level

(c) Questionnaire Result

A number of questionnaires has been designed and distributed to the concerned parties. Based on the questionnaire results shown in Figure 29, the findings are described as below:

1. The monitors' ownership rate of private housing estate is higher than public housing estate.
2. Private housing estate is more suitable as the first experiment target.
3. The Target for below 24'' LCD monitors is about 81%.
4. The frequency at which each household discards the screen: 4.46 years. For example, there are 11 monitors discarded each month in a private housing estate that have 800 households.
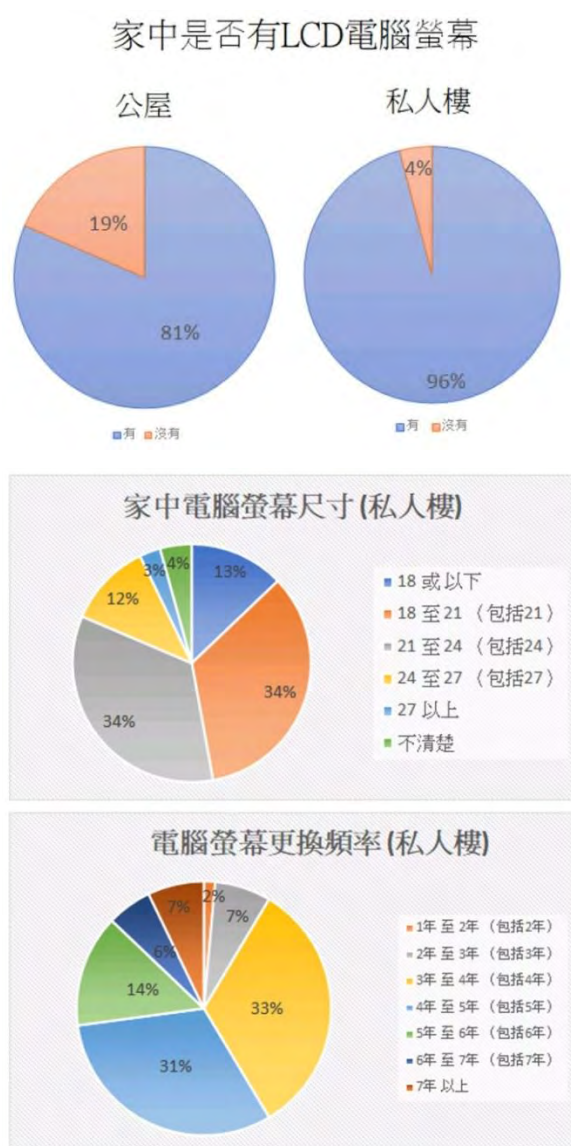
Figure 29 Questionnaire Result

(d) Designed Flow

The designed flow is shown in Figure 30. The steps are
1. Connect the LCD Monitor Collection System (Property Management Office)
2. Take out the protection from the collection bin and set the protection for the monitors (Residents)
3. Put the monitors with protection into the collection bin (Residents)
4. UHF-RFID is used to detect monitors and filling status
5. RFID reader is used to detect the quantity of tags at each setting time
6. Check whether the Bin is full or not. Or, check whether a signal has been sent in half year or not? If no, Keep storing the monitors. If yes, Send a signal to cloud database to require the collection of monitors.
7. After checking the above steps, the designed flow is finished.
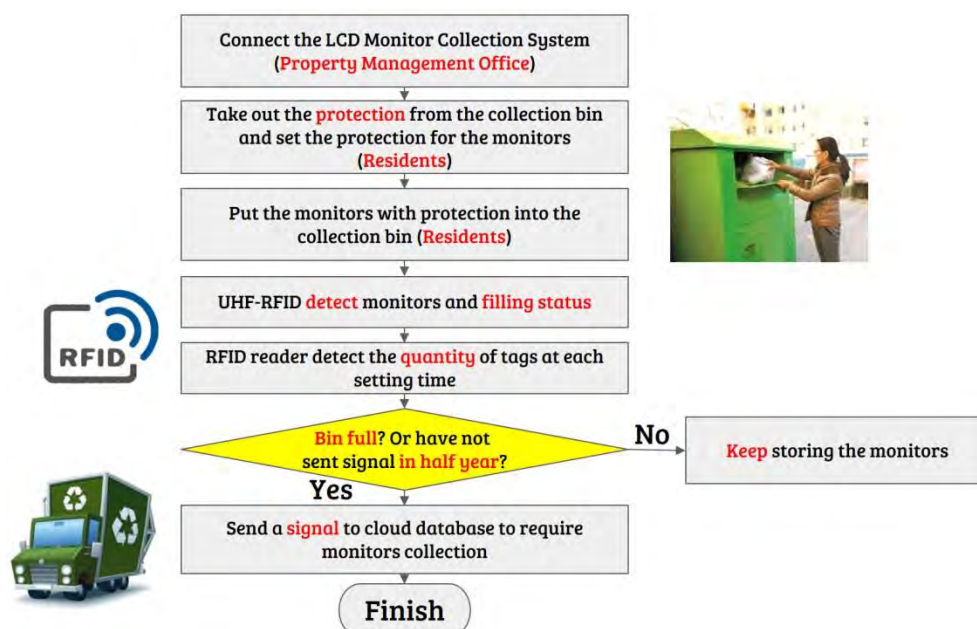
Figure 30 Designed Flow

(e) Solutions

Solution 1 – Collection Bin

Refer to Figure 31, one of the solutions in handling of REE is to design a user-friendly collection bin which can safely collect computer monitors. This can **Increase efficiency** on REE collection. The design requirements should satisfy (a) Easy Maintenance, and (b) The recognized European standard for REE containers of varying capacities and specifications.

Figure 31 Solution 1 – Collection Bin

Refer to Figure 32, the collection bin design should be able to (a) prevent monitors from being stolen, and (b) store the protection of monitors.
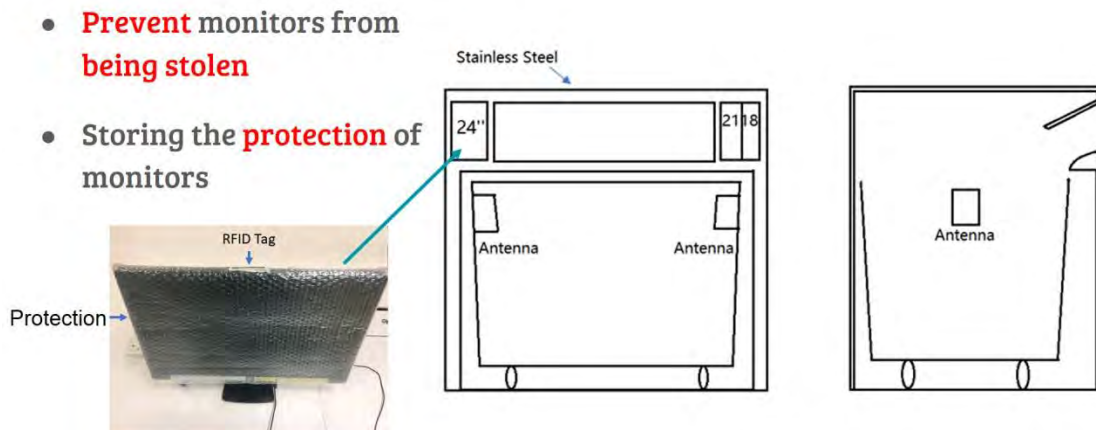
Figure 32 Collection Bin Design

Refer to Figure 33, the collection bin process involves (a) Push collection bin into cabinet, (b) Take out the protection and set the protection for monitors, (c) Put the monitor into the cabinet.

Figure 33 Collection Bin Process

Advantages:

The advantages of the collection bin are:

1. Easily to put monitors into the collection bin.
2. Safely to keep the computer monitors.
3. Protection can be reused.

Solution 2- LCD Monitors Collection System

The second solution in handling of REE is to build up a RFID system to monitor the filling status of collection bins

1. Monitoring and showing the status of the box.
2. According to status of the collection bin, sending a signal to cloud database to require collection.

The LCD Monitors Collection System consists of the following operation steps:

(a) Open the software. (Figure 34)
(b) Set the information of program. (Figure 34)
(c) Click the Connect button and Connect the RFID reader. (Figure 35)
(d) Click the Read button to start the system. Figure 36)
(e) The RFID reader detects the quantity of tags at each setting time. (Figure 36)
(f) If they are equal or more than the quantity setting, the program will send the signal to cloud database. (Figure 37)
(g) After collection, click the Reset button to reset the data. (Figure 38)

Figure 34 LCD Monitors Collection System: Steps (a) and (b)

Figure 35 LCD Monitors Collection System: Step (c)

Figure 36 LCD Monitors Collection System: Steps (d) and (e)

Figure 37 LCD Monitors Collection System: Step (f)
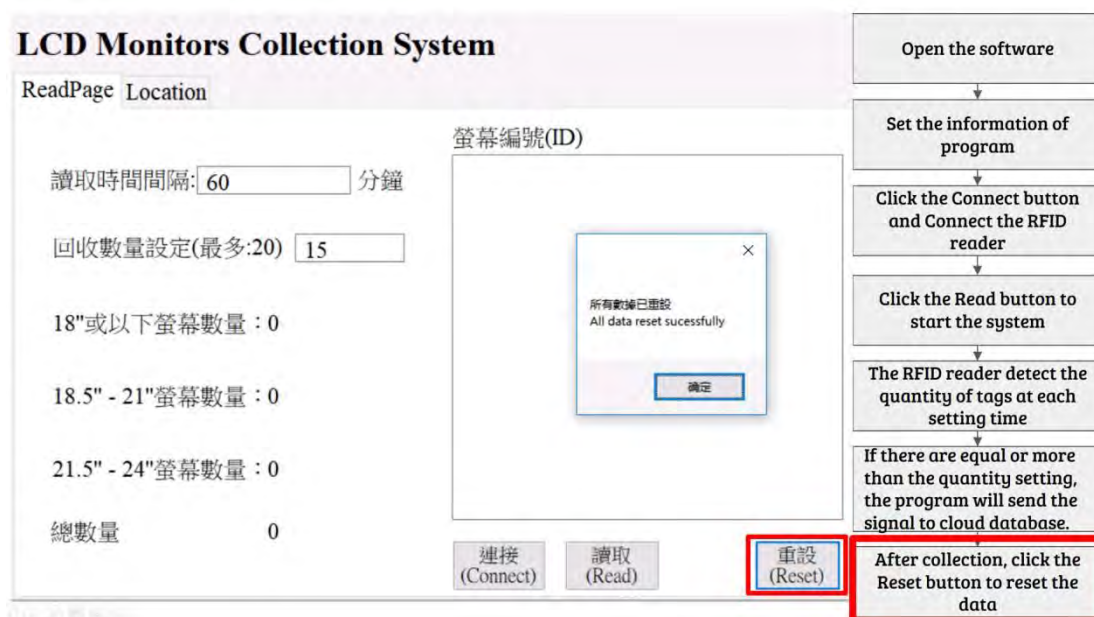
Figure 38 LCD Monitors Collection System: Step (g)

(f) Advantages

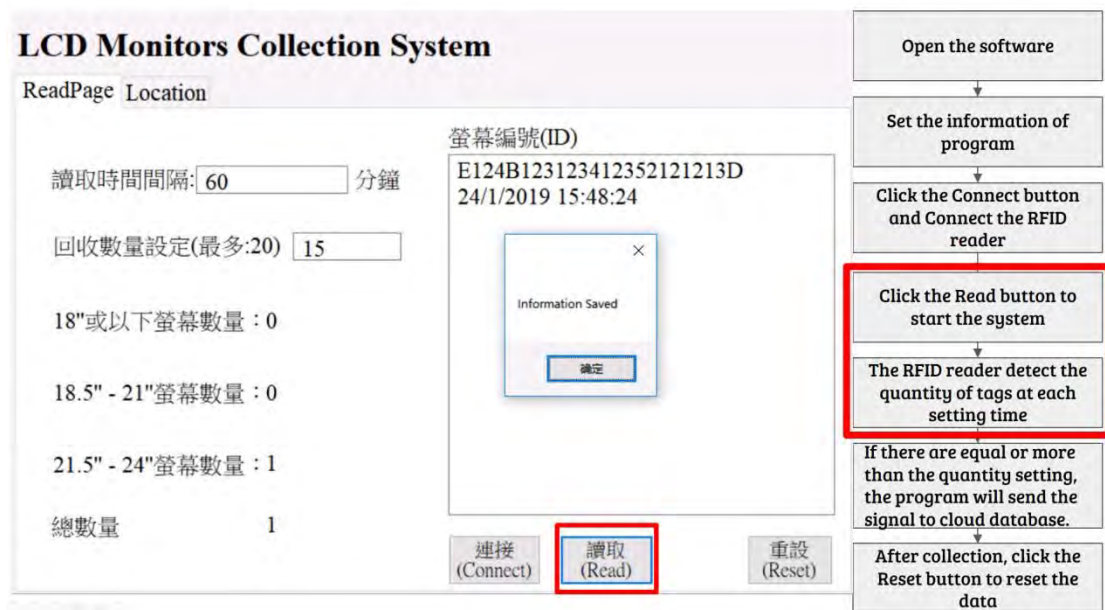The advantages of the LCD Monitors Collection System are:
1. Easy to handle.
2. Less manual operation.
3. Updated information to cloud database at regular intervals.

31

(g) Expected Benefits

The expected benefits for the housing estate are
1. Provide a place to store monitors.
2. Easily and safely to store the computer monitor.
3. Reduce waiting time for collection.

The expected benefits for the Recyclers are
1. Relieve collection service pressure.
2. Increase efficiency to collect REE.
3. Strengthening the relationship between private housing estates and recyclers.

3.3 Community Green Station

(a) Normal flow of REE

The normal flow of REE recycle between disposer and recycler can be referred to Figure 39. A disposer sends the pick-up request to the recycler. The recycler provides the pick-up service for the disposer. The recycler sends the logistic team to the required point. The logistic team picks up REE and transports it to recycler's collect point. Basically, there is a request for disposal in the normal flow of REE recycle. However, due to the limited Collection Capacity of recycler and low logistic efficiency, there may be two most serious cases. (a) Need to wait for around 2 MONTHS and (b) The disposer may dispose the REE illegally.

Normal flow of REE recycle between Disposer and Recycler

① Disposer send the **pick-up request** to the recycler

Disposer

Recycler

② Recycler provide the **pick-up service** for the disposer
Send the logistic team to the required point, pick up REE and transport to recycler's collect point

Figure 39 normal flow of REE recycle between disposer and recycler

Another flow of REE recycle between disposer and recycler can be referred to Figure 40. A disposer disposes the old REE to REE collection point. The REE collection point will provide temporary store REE and send the pick-up request to recycler. The recycler provide the pick-up service for the Collection Point. This can reduce the chance that the disposer dispose REE illegally.

Figure 40 Another flow of REE recycle between disposer and recycler
        REE Collection Point

The REE collection points (Figure 41) include **Community Green Stations (綠在區區)**, Housing Estate' inventory etc.

Figure 41 REE Collection Point

(b) Community Green Station (CGS)

The Environmental Protection Department (EPD) established a CGS network in the community as shown in Figure 42. It can
(a) enhance the public awareness of green living, and
(b) help the local communities to collect recyclables (including REE).

Figure 42 Community Green Station (CGS)

(c) Problems

As depicted in Figure 43, there are 2 problems. The first problem is that the placement of REE is not in well-planned storage. The current storage of REE is messy and is not classified properly. The second is that there is no instant connection and instant information flow between the inventory area and collection point office.

34
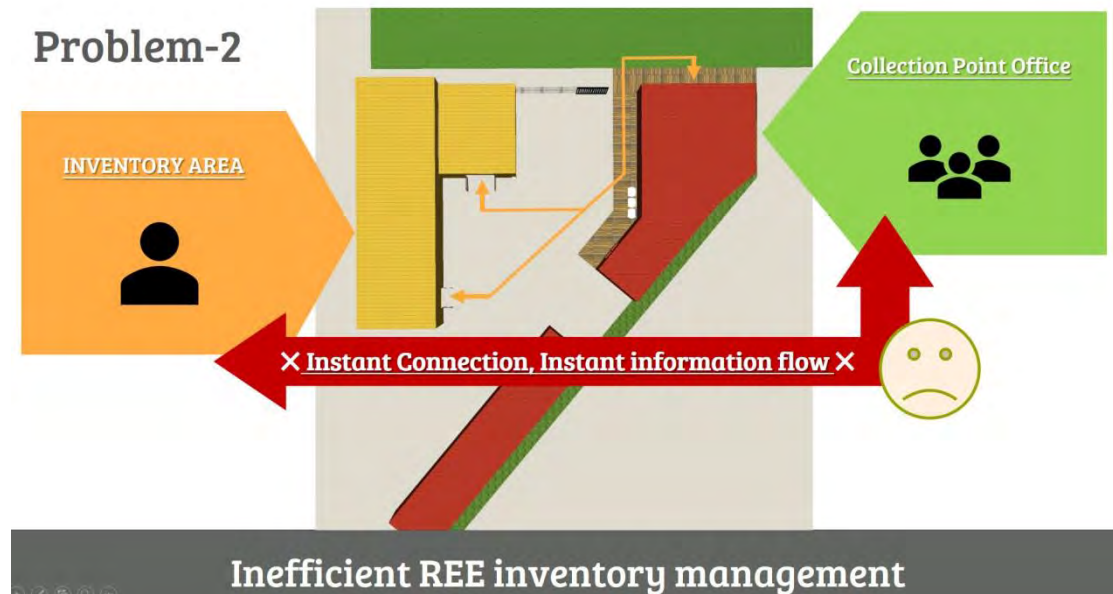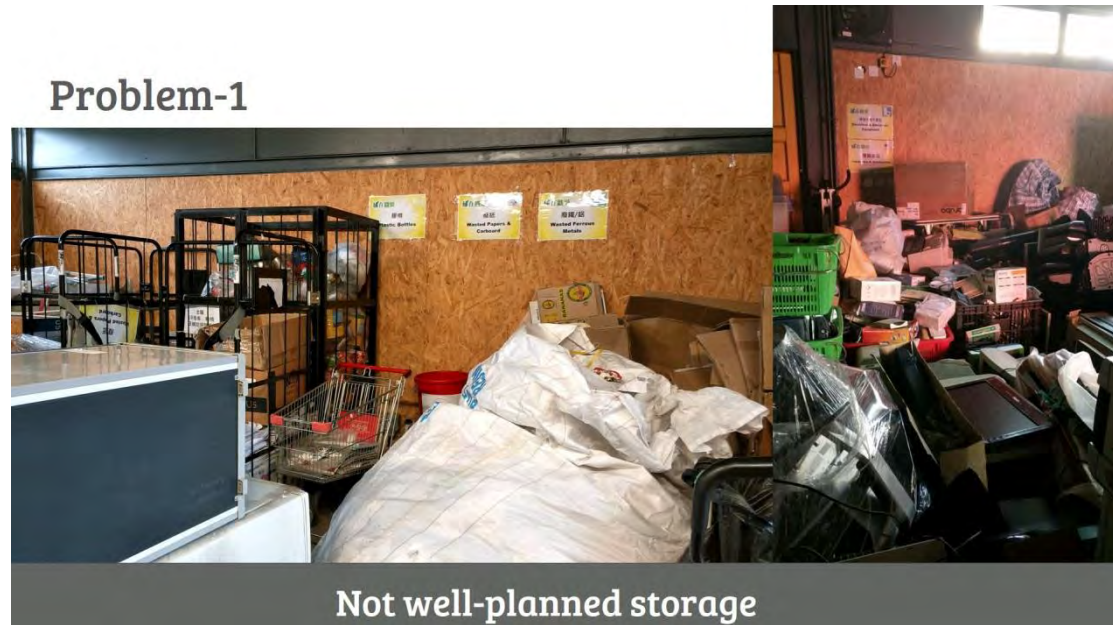
Figure 43 Two problems in the storage of REE

(d) Research objectives

The research objective is to develop a systematic E-waste inventory management system. The system will consist of the following features:

1. Increase the internal process efficiency
It can reduce the repeated works.

2. Detailed Record of the inventory
It can be easy to manage the inventory.

3. Able to analyze the trends of REE collection
It can be easy to apply suitable strategy for e-waste collection.

4. Increase logistic flow efficiency when interacting recycler
It can save time and save cost.

(e) Proposed solution

The proposed solution is to use RFID technology to develop a systematic E-waste inventory management system. The solution will consist of the following features:

1. Instant monitoring of space utilization
It can increase the internal process efficiency.

2. Structural database of collected REE
It can display detailed Record of the inventory.

3. Detailed Statistical Data
It can analyze the trends of REE collection.

4. Instant update information to cloud database
It can increase the logistic flow efficiency when interacting with recycler.

(f) Equipment used

The equipment used is an "Alien Multi-Port General Purpose" RFID reader with model number of ALR 9800 and the required quantity for the RFID reader is 1. The detailed specification for the RFID reader is shown in Figure 44. The other equipment used is a "Small-size UHF" RFID reader and the required quantity for the RFID reader is 1. The

detailed specification for the RFID reader is shown in Figure 45. For the Alien RFID reader, the required quantity for the antenna in Figure 46 is four (or 2 pairs). For the UHF RFID reader, the required quantity for the UHF RFID passive tag in Figure 47 is many (more than 4).

RFID Reader

Name	Alien Multi-Port General Purpose RFID Reader
Model Number	ALR 9800
Architecture	Point-to-multipoint reader network, multi-static
Operating Frequency	902.75 MHz – 927.25 MHz
Hopping Channels	50
Channel Spacing	500 KHz
Channel Dwell Time	< 0.4 Seconds
RF Transmitter	< 30 dBm at the end of 6 m LMR-195 cable.
Modulation Method	On Off Keying (OOK)
20 db Modulation Bandwidth	< 400 KHz
RF Receiver	2 Channels
Power Consumption	45 Watts (120 VAC at 600 mA)
Communications Interface	RS-232 (DB-9 F), TCPI/IP (RJ-45)
Inputs/Outputs	2 or 4 coax antenna, 4/8 optically isolated, com port, LAN, power
Dimensions	(L) 9.0" (22.9 cm) x (W) 11" (28 cm) x (D) 2.22" (5.6 cm)
Weight	Approximately 1.8 kg (4 lb)[d1]
Operating Temperature	0°C to +50°C (+32 °F to +122°F)
LED Indicators	Power, Link, Active, Ant0-3, CPU, Read, Sniff, Fault (red)
Software Support	APIs, sample code, executable demo app (Alien Gateway)
Compliance Certification	FCC Part 15 (Pending)

Alien RFID Reader: 1

Figure 44 Equipment used (Alien RFID Reader)

丨极限参数

项目	符号	数值	单位
电源电压	VCC	16	V
工作温度	TOPR	-10~+60	°C
贮藏温度	TSTR	-25~+80	°C

丨规格

除特别说明，所示规格取自TA=25°C及VCC=+5V工作条件下

项目	符号	小	典型	大	单位
电源电压	VCC	4.5	5	5.5	V
工作电流	Ic		90	150	mA
工作频率	FREQ	902		928	MHz
有效距离*	DIS	0	12	18	cm

Small-size UHF RFID Reader: 1

Figure 45 Equipment used (Small-size UHF RFID Reader)

RFID Reader External Circular Polarized Antenna

Model	ALR-9610-BC
3 dB Beamwidth	E-plane: 65 degrees • H-plane: 65 degrees
Frequency	902-928 MHz
Gain (dBi)	5.73 dBi
Polarization	Circular
RF Connector	6 m LMR-195 with Reverse-Polarity TNC
VSWR	1.5:1
Dimensions	(cm) 22 x 27 x 4 • (in) 8.5 x 10.5 x 1.65
Weight	.57 kg • 1.25 lb

Alien RDID Antenna: 2 pairs (4)

Figure 46 Equipment used (Alien RFID Antenna)

ALN-9554 RFID Inlays

> EPC Class 1 Gen 2 / ISO 180006C

> Exception omni-directional range

> High-speed programming for seamless manufacturing integration

> Operates at all global frequencies (860-960MHz)

> Available in high-yield, high-capacity rolls for high-volume converting processes

> Alien Higgs™-2 IC

RFID	
ISO/IEC 18000-6C	
EPC Class 1 Gen 2	
Integrated Circuit	Alien Higgs-2
EPCglobal Certificate	9501101260000001091
Operating Frequency	840–960 MHz
EPC Size	96 Bits
Access Password	32 Bits
Kill Password	32 Bits

UHF RFID Passive Tag: Many

Figure 47 Equipment used (UHF RFID Passive Tag)

(g) System Design

The software design for the E-Waste Inventory Management System is shown in Figure 48. In the menu bar, there are options (e.g. Record Sheet, Inventory Situation, Current Inventory Details, Graphical Statistic Data and Clear Record) to be selected. There are five steps as specified below:
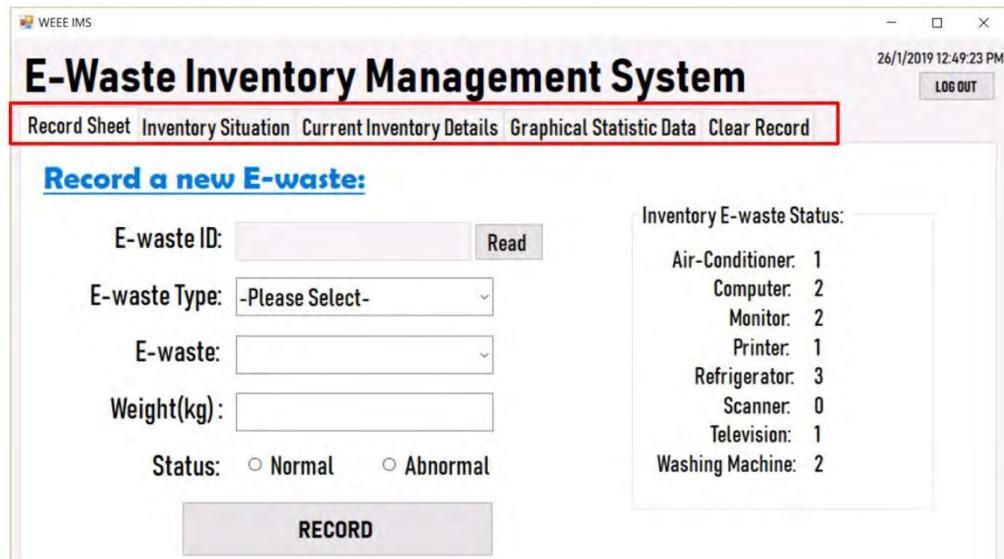
Figure 48 Software design for the E-Waste Inventory Management System

Step 1: System Design- Record Sheet (Stock-in)
For recording the REE data, it is separated into two parts in Figure 49.
1: REE information record area
2: Showing the instant amount of REE in the inventory

Figure 49 Step 1: System Design- Record Sheet (Stock-in)

Step 2: System Design- Inventory Situation (Manage)
In order to show the instant situation of the inventory, it is separated into three parts in Figure 50.
1: REE inventory area floor plan
2: The numbers of the REE now in inventory

3: Area for searching a particular REE
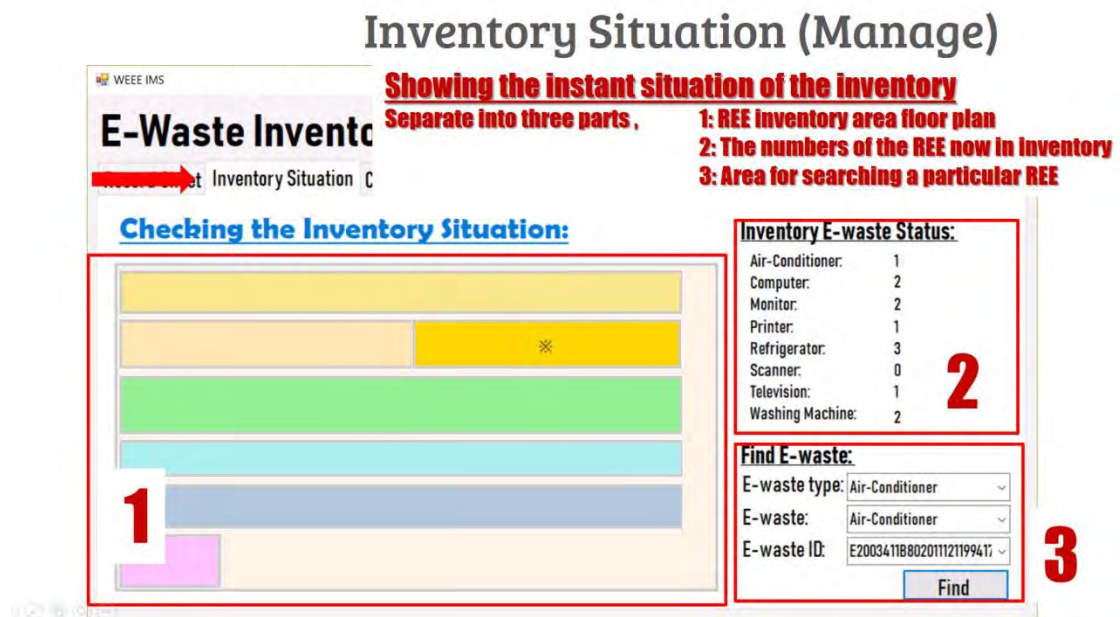
Figure 50 Step 2: System Design- Inventory Situation (Manage)

Step 3: System Design- Current Inventory Details (Manage)
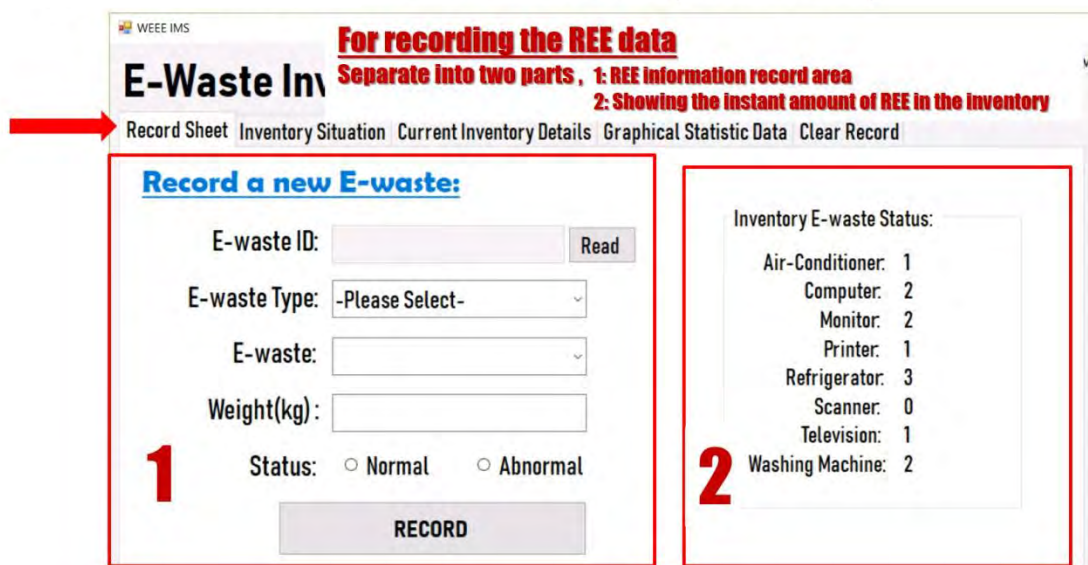
For checking the instant inventory in details, it is separated into two parts in Figure 51.

1: Checking inventory status area

2: The amount of REEs in inventory
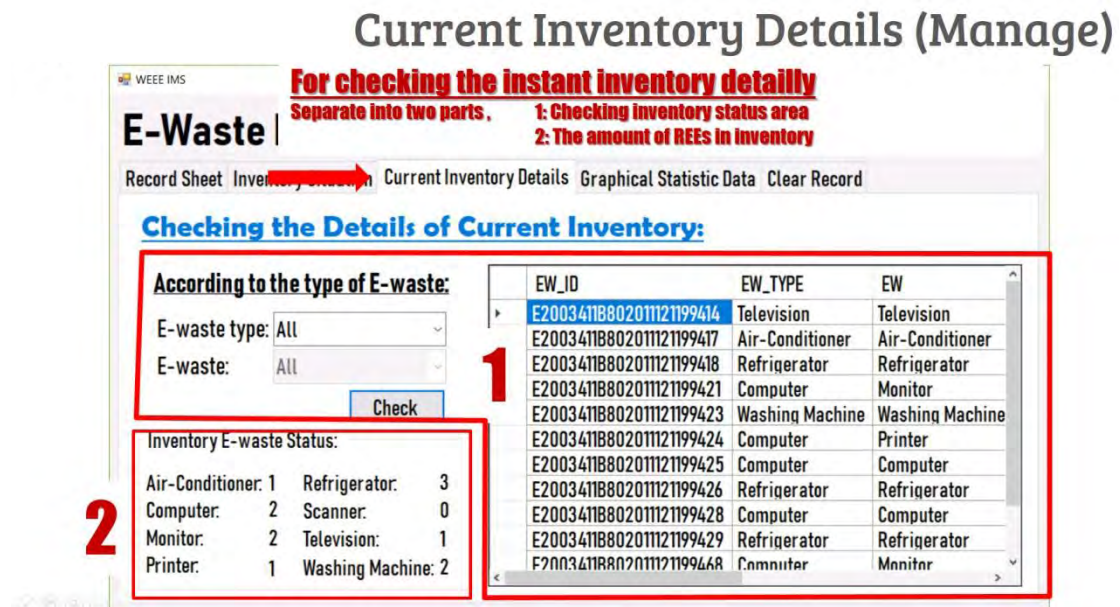
Figure 51 Step 3: System Design- Current Inventory Details (Manage)

Step 4: System Design- Graphical Statistic Data (Manage)

To check the statistical data, there are two factors in Figure 52 to be considered:

1: Type of REE & Name of REE

2: Time period (1day/ 7days/ by month/ by year]
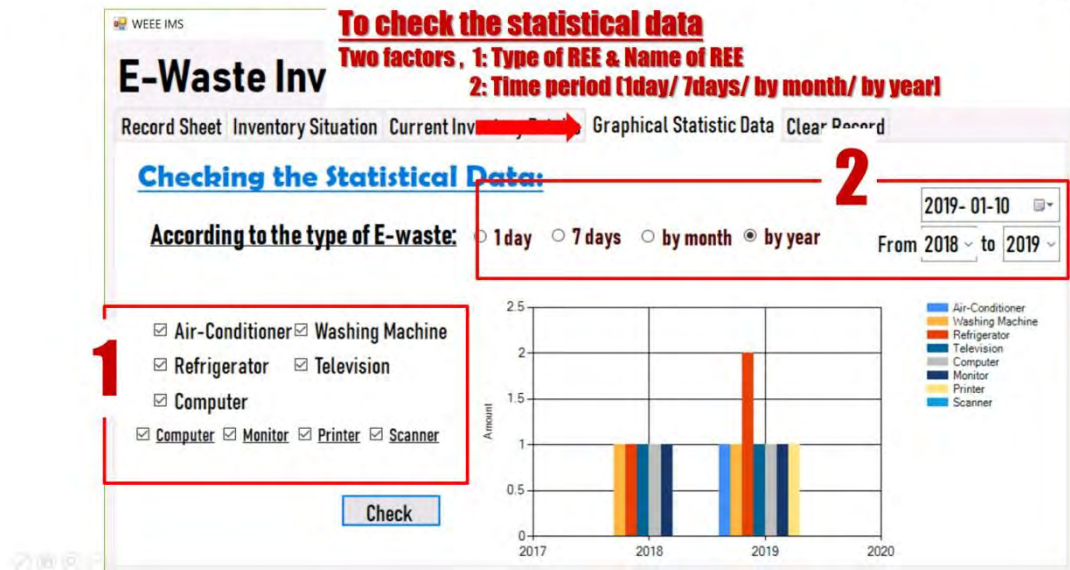
Figure 52 Step 4: System Design- Graphical Statistic Data (Manage)

Step 5: System Design- Clear Record (Stock-out)

For changing the status of the REEs when the REEs were sent to the recycler, there are two sections in Figure 53:

1: Read Tag Sections

2: The amount of REE in inventory

Figure 53 Step 5: System Design- Clear Record (Stock-out)

(h) System Highlights

(1) Instant monitoring of space utilization
   (i) Show the instant situation of REEs in inventory, e.g. rough position.
   (ii) Information flow between office and inventory.
It can reduce the repeated works and increase the internal process efficiency

(2) Structural database of collected REE
   (i) Save all data in details in database.
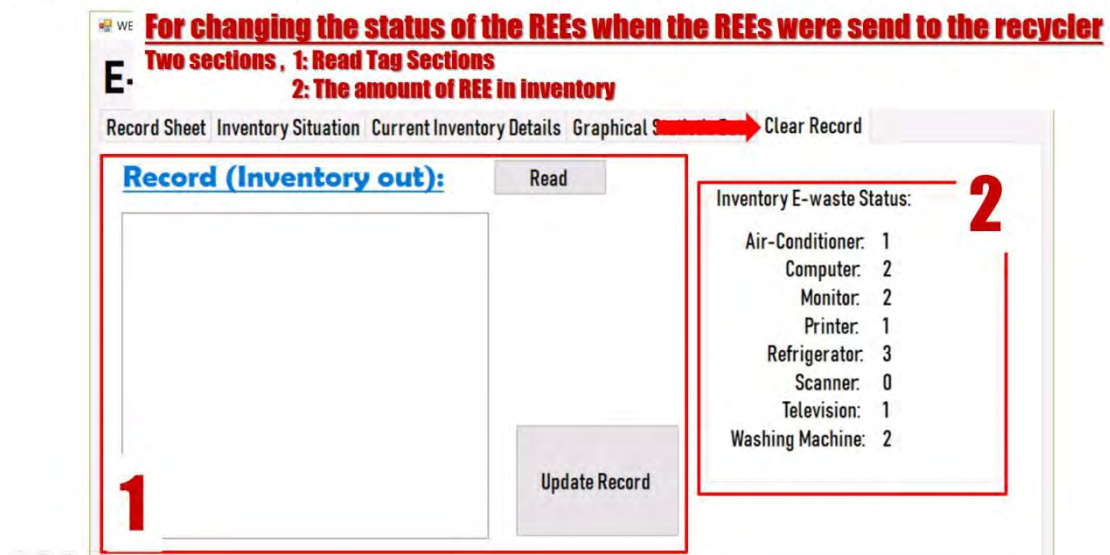   (ii) Keep all record for analyzing the collection trend.
It can provide more understandings to REEs in inventory, and the trends of REE collection.

(3) Instant update information to cloud database
   (i) Auto-update the inventory data from local to cloud.
   (ii) Checking the inventory situation at anytime and anywhere.
It can increase the management flexibility, Increase logistic flow efficiency when interacting recycler

(i) Potential Benefits

(a) Reduce human error and increase the efficiency (Figure 54)
For the Stock-in process before improvement, the REE data was recorded by hand/ by computer (e.g. Excel) for the required information.
1. Type of REE.
2. Name of REE.
3. Weight.

There was no error check. By using the system, human error can be reduced and the efficiency can be increased.
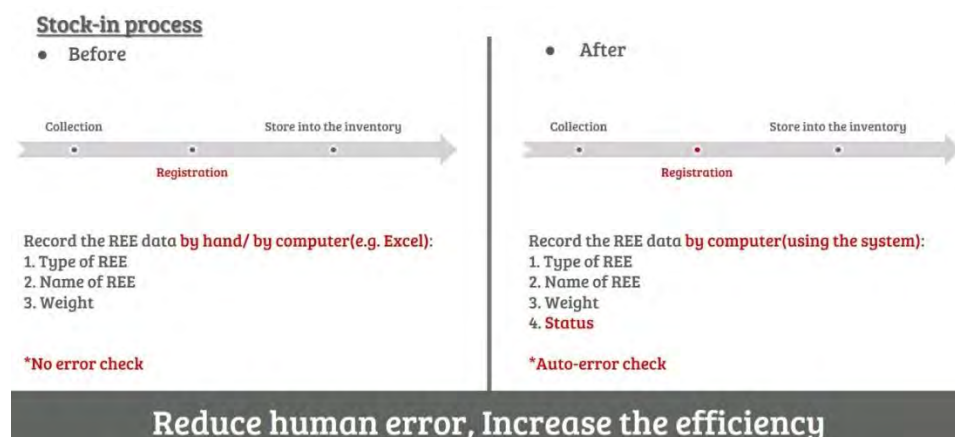
Figure 54 Potential Benefits: Reduce human error and increase the efficiency

(b) More systematic, Increase the management efficiency (Figure 55)

For the Stock-in process before improvement, the REE were put together. There was no specific position to place REE.

For the Stock-in process after improvement, different type of REE was divided. They have a specific position to place REE.

The placement of REE can be systematic and the management efficiency can be increased.
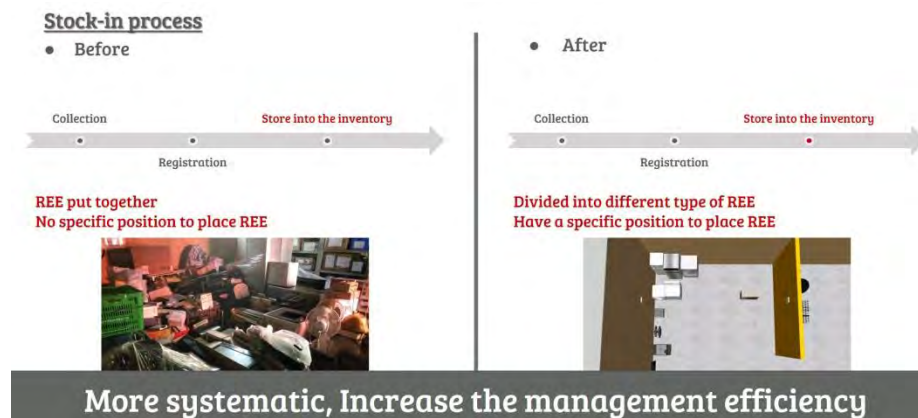
Figure 55 Potential Benefits: More systematic, Increase the management efficiency

(c) Increase space utilization (Figure 56)

For the Stock-out process before improvement, Recycler was called to collect only when the inventory was being full. For the Stock-out process after improvement, REEs can be collected more frequently. REEs are collected when collector comes or the inventory is being full. This can increase space utilization.
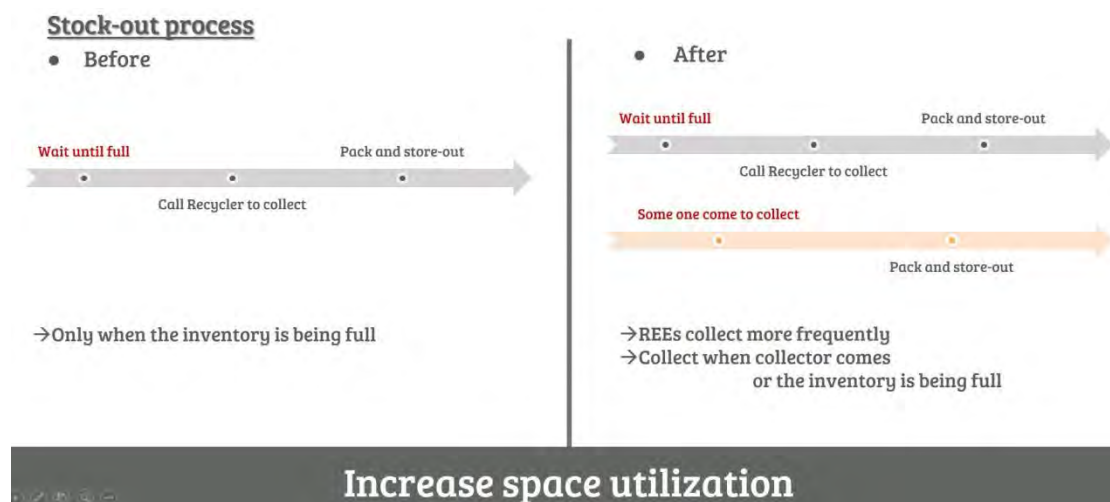
Figure 56 Potential Benefits: Increase space utilization

(d) Clear record and increase the management efficiency (Figure 57)

For the Stock-out process before improvement, there was no record for stock-out. It was hard to get back collection data to analyse. For the Stock-out process after improvement, they have record for stock-out. It is easy to get collection data to analyse. This can help to have a clear record and increase the management efficiency.

Figure 57 Potential Benefits: Clear record and increase the management efficiency

Chapter 4 - Transportation Route Planning System for REE collection

Solution integration

One of the challenging issues in e-waste recycling is Cost Effectiveness since it is not a high profit business. Usually, e-waste collectors will seek at low cost recycling approaches, i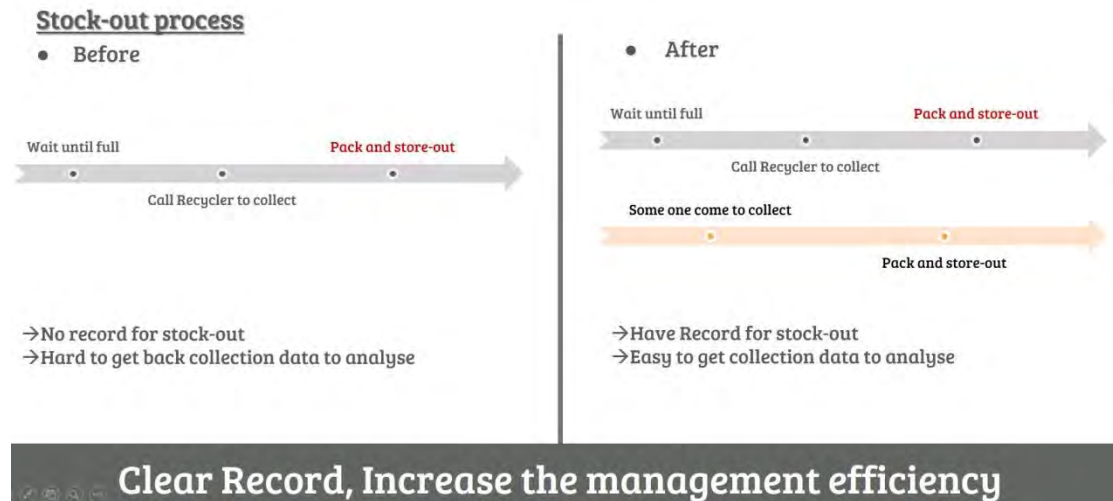n order to increase profit. Transportation route planning is a way to reduce collectors' expenditure in e-waste collection.

4.1 Transportation route planning

Regarding the transportation route planning in Figure 58, there are 3 e-waste collection approaches with different scenarios are mentioned. They facilitates collectors in e-waste storage. On the other hand, a good transportation planning could effectively help collectors in cutting cost and increase efficiency. Besides, it also increase e-waste collection flow efficiency.

A route planning system would be designed for and introduced to the 3 scenarios in order to optimize the collection flow.

Household Collection   Private Housing Estate Disposal   Community Green Station

Figure 58 Transportation route planning

Why Route Planning is good for e-waste collection

Usually, e-waste collectors plan transportation route by non-systematic judgement. In fact, they need a route planning system to help them in a more systematic approach.

Advantages of Non-Systematic

1. Much slower
2. Route may not be optimized
3. Result in longer time for e-waste collection
4. Increase expenditure in fuels

Disadvantages of Non-Systematic
1. Fast for transportation decision
2. Optimize driving distance
3. Shorten time for e-waste collection
4. Reduce expenditure in fuels

4.2 Compare non-systematic route planning and systematic route planning

In the systematic approach, it figures out the shortest route of 11 locations, in just within a few seconds. Human will spend a lot of time on calculation to find this optimized route out. For the Distance of the route found by systematic approach, it is 66.7km. For the Distance of the route found by non-systematic approach, it is 71.7km that is about 5km longer than that of the distance by systematic approach.

4.2.1 How to do?

Information from the 3 scenarios in route planning
A Route planning system effectively helps recyclers in cutting cost. The required information includes: (a) Full address and District, (b) E-waste Category, (c) Collection Signal, (d) Weight (Optional).

4.2.2 Cross-application of route planning system

Refer to Figure 59, Each of the 3 approach share their database and relevant information to public.
E-waste source can be from:
(a) Household Collection
(b) Private Housing Estate Disposal
(c) Community Green Station

Cross-application of route planning system

Each of the 3 approach share their database and relevant information to public.

E-waste source from:

(a) Household Collection

(b) Private Housing Estate Disposal

(c) Community Green Station
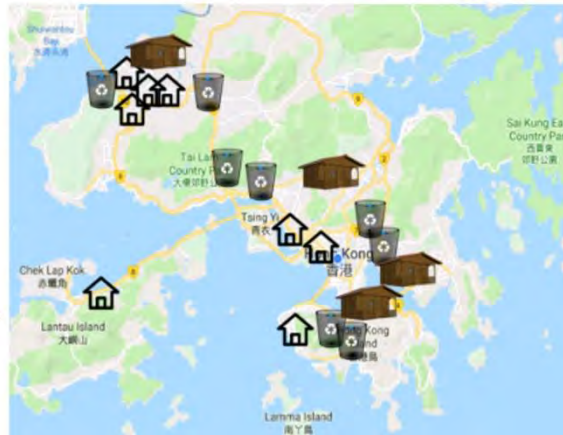
Figure 59 E-waste source

Route Planning Approach can be divided into "Self-develop" and "Online Tools in the market". The captured images for the "Self-develop route planning system demo" and "Online tools demo" are shown in Figure 60 and Figure 61 respectively.
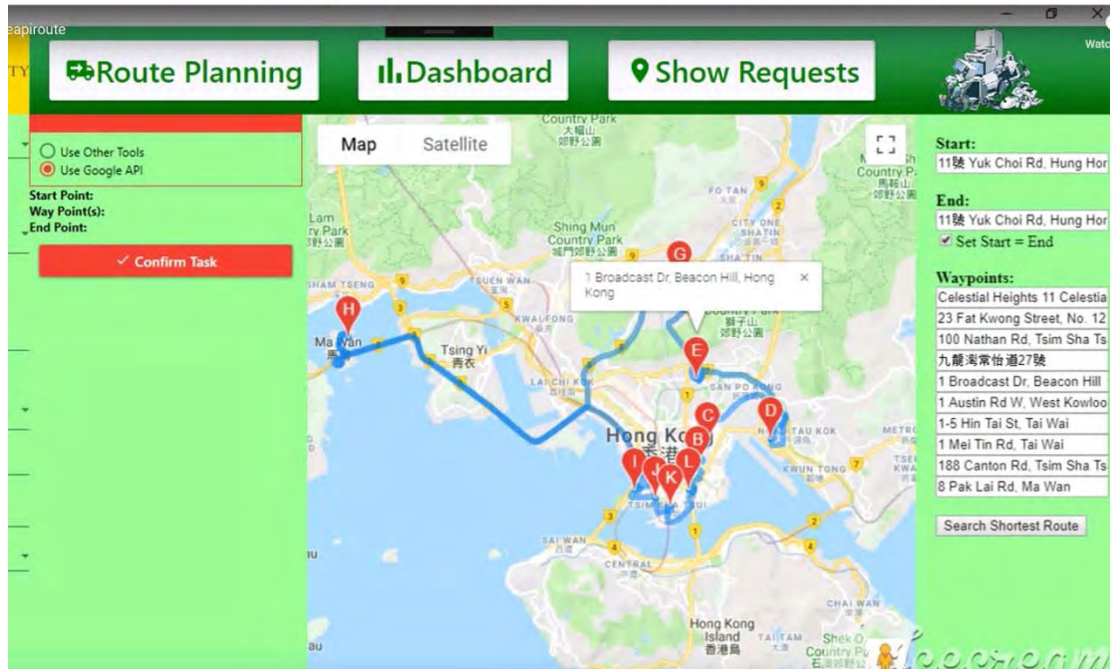
Self-develop route planning systm demo

Figure 60 Captured image for the "Self-develop route planning system demo"

Online tools demo
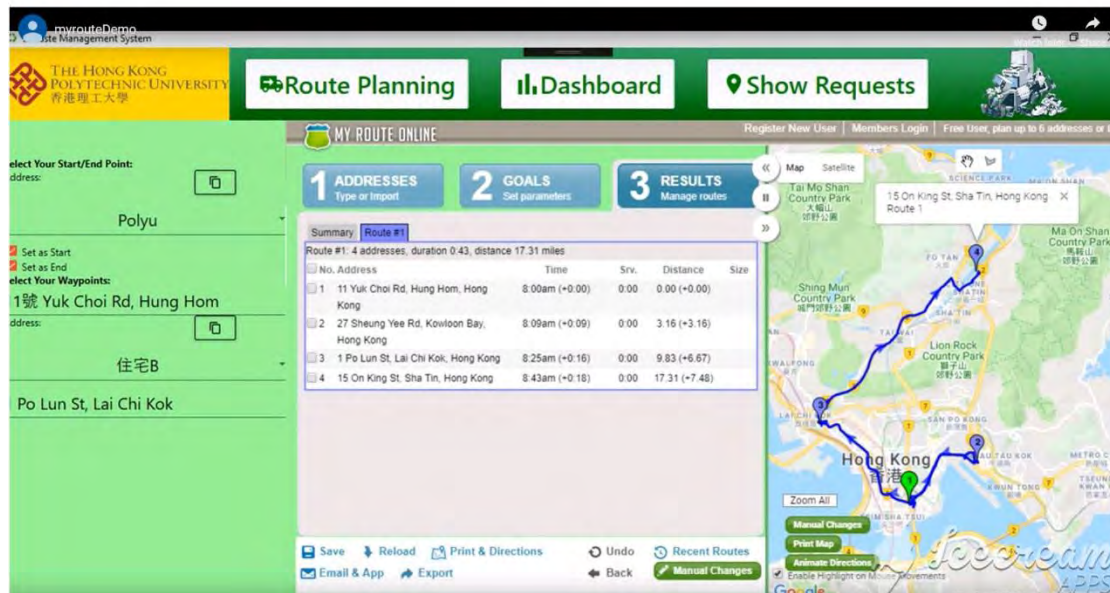
Figure 61 Captured image for the "Online tools demo"

4.3 Which one should you choose?

There are two cases to consider. Case 1: If your company has developers / programmers, go for self-develop approach. Case 2: If your company doesn't have any developers / programmers, go for online tools in the market.

A comparison of the concerns (e.g. cost, result generating performance, any tailor-made function, any maintenance required, ease of management) between Self-developed System against Online Tools is shown in Table 3.

Table 3 Comparison between Self-developed system against Online Tools

Self-developed system vs Online Tools

Concerns	Self-developed system	Online Tools
Cost	Normally, it is free of charge	Charged by monthly subscription
Result generating Performance	Faster	Slower
Any tailor-make function?	Can be customized	Usually fixed
Any maintenance required?	Yes	No
Ease of management	Harder	Easier

Apart from systematic route planning, some additional functions **may also help in** e-waste collection.

For Additional function 1: E-waste Collection Point Visualization, it can be referred to Figure 62. The benefits of visualizing the collection points are:

1. To have rough understanding on the distribution of e-waste collection service request.
2. To visualize e-waste by category. It facilitates e-waste collectors to target on specific e-waste.
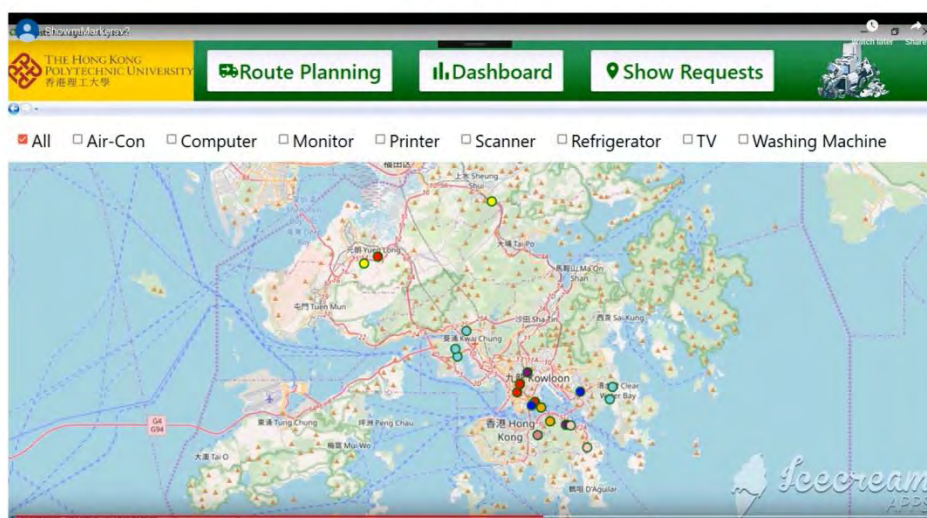
Figure 62 Additional function 1: E-waste Collection Point Visualization

For additional function 2: Historical Data Shown On Dashboard, it can be referred to Figure 63.

The benefits of using Dashboard are:

1. To provide a rapid understanding on the e-waste collection trend in the past
2. To have a strategy change on e-waste collection and recycling

There are two examples. For the first example, Computer occupied 40 % of the total e-waste collected. In this way, more computer dismantling specialists should be trained and e-waste processing rate should be increased. For the second example, Yau Tsim Wong and Tuen Mun districts have highest e-waste collection service request. Accordingly, a dismantling center should be set up and Mobile Collection Point should be arranged there.

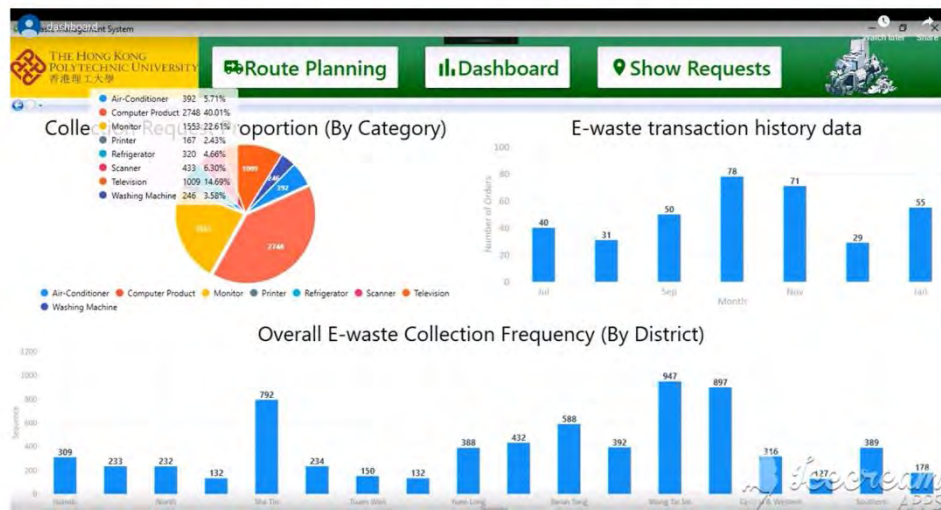# Additional function 2: Historical Data Shown On Dashboard

Figure 63 Additional function 2: Historical Data Shown On Dashboard

Chapter 5 - Expected Outcomes

5.1 Expected outcomes of Automatic booking system

Expected outcomes of Automatic booking system can be referred to Table 4.

The possible changes and their industrial impact are listed as follows:
Change 1: Generate an optimal solution for consumers and recyclers
Industrial impact: This can (a) reduce the human error on scheduling, (b) have a better scheduling and (c) have a Cost effective solution.

Change 2: Transparency on scheduled tasks
Industrial impact: This can help to have a better planning on transportation

Change 3: Opportunities for other 7 recyclers and Community Green Station
Industrial impact: This can help to ease the pressure from the collection process of Alba

Table 4 Expected outcomes of Automatic booking system

What would be change	Industrial Impact
Generate the optimal solution for consumers and recyclers	• Reduce the human error on scheduling • Better scheduling • Cost effective
Transparency on scheduled tasks	Better planning on transportation
Opportunities for other 7 recyclers and Community Green Station	Ease the pressure from the collection process of Alba

5.2 Expected outcomes of REE collection in private housing estate

Expected outcomes of REE collection in private housing estate can be referred to Table 5. The possible changes and their industrial impact are listed as follows:

Change 1: Provide a place to store monitors and Design a system to check filling status
Industrial impact: This can enable REE collection in housing estates.

Change 2: Enable Medium-sized recyclers to collect REE from housing estates
Industrial impact: This can help to open up business opportunities to SME recyclers to collect REE from housing estates.

Table 5 Expected outcomes of **REE collection in private housing estate**

What would be change	Industrial Impact
Provide a place to store monitors	Enable REE collection in housing estates
Design a system to check filling status	
Enable Medium-sized recyclers to collect REE from housing estates	Open up business opportunities to SME recyclers to collect REE from housing estates

5.3 Expected outcomes of REE Inventory Management system

Expected outcomes of REE Inventory Management system can be referred to Table 6.

The possible changes and their industrial impact are listed as follows:
Change 1: Increase efficiency in REE inventory management system
Industrial impact: This can (a) Reduce human error, (b) Save human resources, and (c) Save cost.

Change 2: Provide a structural database to analyze the REE disposal pattern in a particular district

Industrial impact: This can help to have a better planning for REE collection in Hong Kong.

Change 3: Link to route planning system
Industrial impact: This can help to increase REE logistics flow efficiency.

Table 6 Expected outcomes of REE Inventory Management system

What would be change	Industrial Impact
Increase efficiency in REE inventory management system	• Reduce human error • Save human resources • Save cost
Provide a structural database to analyze the REE disposal pattern in a particular district	Better planning for REE collection in HK
Link to route planning system	Increase REE logistics flow efficiency

5.4 Expected outcomes of Route Planning System

Expected outcomes of Route Planning System can be referred to Table 7.

The possible changes and their industrial impact are listed as follows:
Change 1: Lower the transportation cost.
Industrial impact: This can make SME recyclers more willing to collect e-waste from household and from housing estates.

Change 2: Increase e-waste distribution transparency
Industrial impact: This can help to facilitate recyclers to find e-wastes from an integrated platform and hence improve e-waste processing rate per day.

Change 3: Provide useful information
Industrial impact: This can help to enable cooperation between recyclers (e.g. labor division, work division) and Facilitate recyclers in strategy planning.

Table 7 Expected outcomes of Route Planning System

What would be change	Industrial Impact
Lower the transportation cost	Make SME recyclers more willing to collect e-waste from household and from housing estates
Increase e-waste distribution transparency	Facilitate recyclers to find e-wastes from an integrated platform and hence improve e-waste processing rate per day
Provide useful information	Enable cooperation between recyclers (e.g. labor division, work division) Facilitate recyclers in strategy planning

Appendix

A1. RFID technology background

As shown in Table A1, RFID Technology can be classified into 3 major categories: (a) Low Frequency, (b) High Frequency, (c) Ultra-high Frequency. For (a) Low Frequency, the RFID uses a frequency of around 120-135 KHz for the application of single read. It has short reading distance and slower reading speed. For (b) High Frequency, the RFID uses a frequency of around 13.56 MHz for the application of multi read. It has small bulks and short reading distance. For (c) Ultra-high Frequency, the RFID uses a frequency of around 860-930 MHz for the application of multi read. It has long reading distance and faster data transfer rate. It is suitable for most applications.

Table A1 RFID Technology

Low Frequency	High Frequency	Ultra-high Frequency
120-135 KHz Single read Short reading Distance Slower reading speed	13.56 MHz Multi read Small bulks Short reading distance	860-930 Mhz Multi read Long reading dstance Faster data transfer rate Suitable for most applications

As shown in Table A2, RFID Tags can also be classified into 3 major categories: (a) Active, (b) Semi-active, (c) Passive. For (a) Active, the RFID tag has longer reading distance and its cost is very expensive. The power source belongs to internal-battery powered. The RFID tags have the advantages that they are able to initiate communications and they have higher data bandwidth. The disadvantages of the RFID tags include (i) Tag must be replaced when battery dies, and (ii) Tag is usually bulky in size. For (b) Semi-active, the RFID tag has moderate reading distance and its cost is expensive. The power source belongs to internal-battery powered. The RFID tags have the advantages similar to the active tag. They are able to initiate communications and they have higher data bandwidth. The disadvantages of the semi-active tags, similar to the active tag, include (i) Tag must be replaced when battery dies, and (ii) Tag is usually bulky in size. For (c) Passive, the tag has shorter reading distance and its cost is low. The power source relies on reader. The RFID tags have the advantages such as longer lasting and more resistant to harsh environment. The disadvantage of the passive tags is the problem of difficult reading through metal or liquid.

Table A2 RFID Tags

	Active	Semi-active	Passive
Reading distance	Longer	Moderate	Shorter
Cost	Very Expensive	Expensive	Low
Power Source	Internal-battery powered	Internal-battery powered	Relies on reader
Advantages	Able to initiate communications Highes data bandwidth	(simiar to active tag)	Longer lasting More resistant to harsh environment
Disavantages	Tag must be replaced when battery dies Bulky in size	(simiar to active tag)	Difficult reading through metal or liquid

A2. Cost Effectiveness Of Google Directions

Google Directions API is generally used to visualize routes in google map. If you manage your monthly request well, basically you don't need to pay money while enjoying the service. Refer to Figure A1, the initial credits in the first year and US$200 monthly credit will be given and they are equivalent to free usage in the Google Directions API.
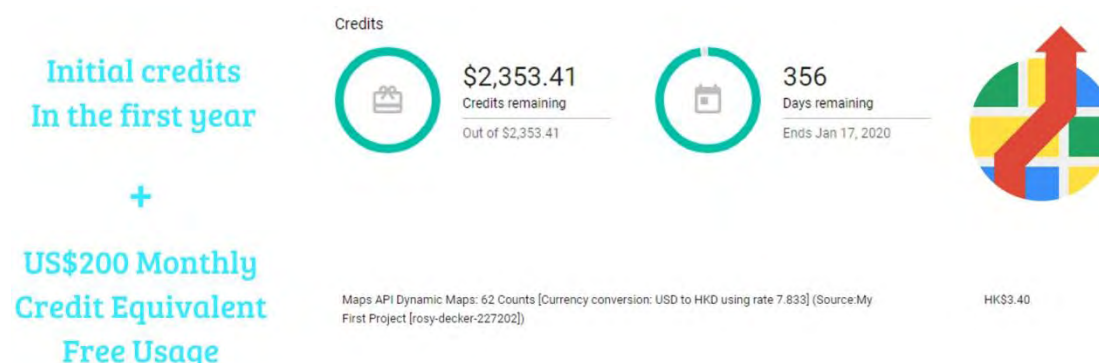

Figure A1 Google Directions API

A3. Cost Of Cloud Database

It is summarized as follows:
1. Storage of cloud database is not expensive
2. The most cost charged by cloud database is from data usage and cloud server performance.
3. Cloud Database plays an important role in IoT.
4. It brings a lot of convenience but may also increase variable cost in e-waste collection.

A4. RFID interference

The experimental results on RFID interference for different devices (e.g. MacBook Pro, Lenovo laptop, Power bank) are shown in Figure A2. The results show that both MacBook Pro and Lenovo laptop have negative response on RFID interference and they have zero meter in the maximum reading distance. In contrast, the power bank has positive response on RFID interference and it has 0.9 meter in the maximum reading distance. The graph in Figure A2 shows a plot of the passing rate against the reading distance at an angle of 90 degrees for the power bank. The maximum reading distance when the tags are not attached to any objects is 2 meters. If the tag is directly attached to e-waste, the reading reliability would drop significantly.
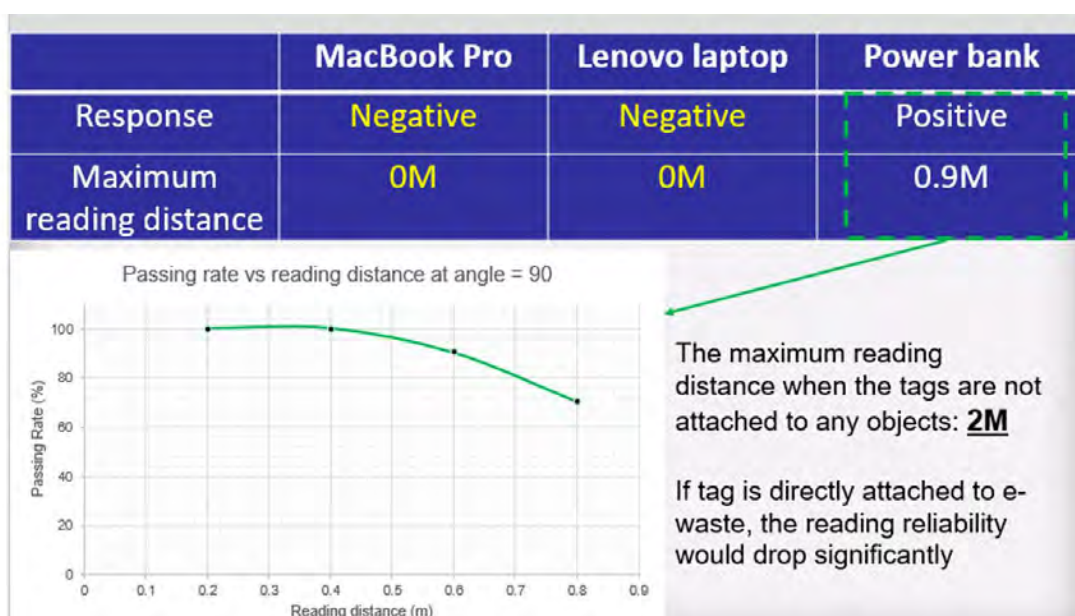

Figure A2 RFID interference (Experiment results)

A5. Possible solutions on RFID interference

The relationship between Bolster thickness and maximum reading distance is shown in Figure A3. In order to reduce the RFID interference, it is suggested to increase the distance between the tag and the metallic surface as far as possible. Also, a non-metallic bolster with a suggested thickness greater than or equal to 2cm between the tag and E-waste should be added.
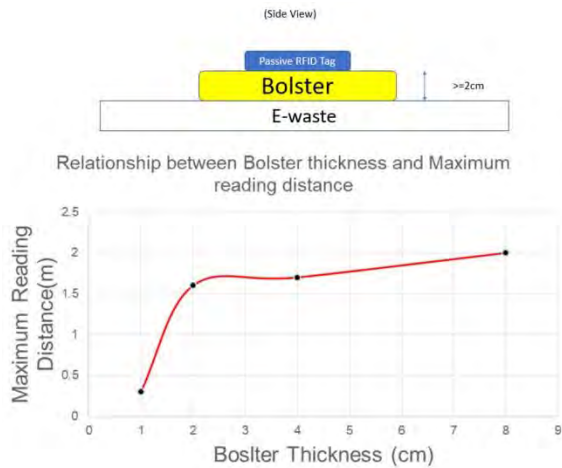
Figure A3 Relationship between Bolster thickness and maximum reading distance

A6. Ultra-high frequency (UHF) RFID Handheld Reader

There are two types of UHF RFID Handheld Readers. One type (in Figure A4) is Mobile-based, working with NFC and has an Android platform. It is applicable to RFID, Barcode and QR Code and the specification is as follows:

a) Range: >1-2M
b) Frequency: >10 tags per second
c) Independent Power
d) Communication: WIFI, Bluetooth, GPRS, GPS

The estimated price of the reader is around $1500-2500.

Figure A4 UHF RFID Handheld Reader (Mobile-based)

The other type (Figure A5) of UHF RFID Handheld Readers is for industrial use. It is applicable to RFID, Barcode and QR Code and the specification is as follows:

a) Range: >5M
b) Frequency: >50 tags per second
c) Independent Power
d) Communication: WIFI, Bluetooth, GPRS, GPS

The estimated price of the reader is around $4000-6000, which is about 2 times higher than that of the mobile-based reader.

Figure A5 UHF RFID Handheld Reader (Industrial use)

Contact information

PCB Technology Centre

Address: Room DE003, PCB Technology Centre

Department of Industrial and Systems Engineering

The Hong Kong Polytechnic University

Hung Hom, Kowloon, Hong Kong

Tel: (852) 2766 6615

Fax: (852) 2362 9787

Website: http://pcbtc-hkpu.org/

For enquiry

Contact Persons	Telephone	Email
Prof. YUNG Kam Chuen, Winco	2766 6599	wincokc.yung@polyu.edu.hk