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# ADVANCED REVERSE LOGISTICS FOR THE DISPOSED SMALL AND MEDIUM END-OF-LIFE CONSUMER ELECTRONICS WITH THE ADOPTION OF IOT

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Abstract. *In order to respond to the matter of global warming, the EPR (Extended Producer Responsibility) regulation is continuously expanding its mandatory products of small and medium (S&M) end-of-life (EOL) consumer electronics in Korea. However, the current state of the reverse logistics for the collection of disposed S&M EOL products is still at the beginning stage. This study applies IoT (Internet of Things) technology for identifying the conditions of collection box to deciding the appropriate time for collection and to managing the weights of collected EOL products until they are delivered and recycled properly. Actual field data and interview are applied for designing and experimenting the reverse logistics activities under the current situation and proposing new situations with IoT technology. Results are verified that application of IoT technology can reduce the number of transportations needed for collecting the same amount of EOL product disposed. Application of the proposed IoT technology in this field is expected to improve the level of the reverse logistic activities and its efficiency.*
**Keywords:** Reverse logistics, S&M EOL consumer electronics, IoT, EPR

1. **Introduction.** According to Statistics Korea, the ratio for single-person household to national household is over 30% (30.4%) in 2020 [1]. This domestic situation is providing more sales of necessary and supportive small and medium (S&M) consumer electronics, and eventually increasing disposals of the end-of-life (EOL) products. Therefore, the Korean government has initiated the regulation of EPR (Extended Producer Responsibility) since 2003, which extends the responsibility of producers not only performing after-service but also collecting and recycling when their products are disposed at the EOL stage [2]. Furthermore, the Korean Ministry of Environment (MoE) established the annual goal of recycling amount of EOL consumer electronics and increasing it every year. Also, this regulation expands the range of mandatory products of recycling continuously for strengthening the role of EPR as shown in Table 1 [3].

Consumer electronics can be classified as large (TV, refrigerator, washer, etc.) and small and medium (electric fan, computer, audio, humidifier, etc.) products based on the criteria of volume. In this research, the problems of reverse logistics for the disposed S&M EOL consumer electronics are identified while IoT (Internet of Things) technology is applied to solving the current problems.

IoT technology can be defined as the technology of sending and receiving real-time data by attaching appropriate sensors to the objects [4]. The applicability and challenges of IoT are reviewed and suggested that "IoT applications cover almost all aspects of human life and make the connectivity possible at anytime, anywhere and to anything in the future" [5]. Among recent studies related to IoT, sustainable energy and environment, smart city,

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Table 1. National mandatory products of recycling under the EPR regulation

| Year | Number of mandatory products of recycling | Mandatory consumer electronics of recycling |
|---|---|---|
| 2003 | 5 | TV, Refrigerator, Washer, Air conditioner, Personal computer |
| 2005 | 7 | Audio, Mobile phone (Including existing 5 products) |
| 2006 | 10 | Printer, Copy machine, Fax machine (Including existing 7 products) |
| 2014 | 27 | Slot machine, Electric purifier, Softener machine, Electric oven, Microwave oven, Humidifier, Garbage disposer, Mixer, Electric fan, Electric bidet, Air purifier, Vacuum, Electric heater, Electric rice cooker, Electric iron, Video player, Tableware drying machine (Including existing 10 products) |
| 2020 | 49 | Dehumidifier, Navigator, Scanner, Beam projector, Router, Toaster, Electric kettle, Sawing machine, Electric water heater, Electric fri-fan, Running machine, Hair drier, Foot bath machine, Monitoring camera, Food drying machine, Baking machine, Electric massager, Game machine, Frier, Coffee maker, Medical bath machine, Dryer (Including existing 27 products) |
| 2023 | 50 | Sun light panel (Including existing 49 products) |

E-health and transportation and low carbon products [6], and smart environment monitoring system [7] are suggested as interesting possible areas contributed by the potential power of IoT.

IoT technologies are already applied at many industries such as service, agriculture, construction, manufacturing, and logistics domestically and provide various valuable effects [8-16]. Table 2 summarizes some of IoT technologies applied at several industries already.

Several IoT technologies are already applied to collection boxes for collecting disposed cans, plastic bottles, glass bottles, milk packs, and food wastes for further appropriate recycling operations (see Table 3).

Chapter 2 analyzes the problems of current reverse logistic activities for collecting and moving the disposed S&M EOL products, and specific IoT technology which can improve the existing problems of reverse logistics for disposed S&M EOL products is proposed. The expected effects of applying IoT in this filed are analyzed at Chapter 3 and the related results and future research topics are summarized at Chapter 4.

## 2. Reverse Logistics for Disposed S&M EOL Products.

2.1. **Current problems.** Most large consumer electronics, such as TV and refrigerator, are quickly collected because of the inconvenience with large size and volume when they are disposed at EOL stage. Therefore, proper reverse logistic activities necessary for collecting and recycling operations are already established and running well in Korea currently [17,18].

On the other hand, the reverse logistic activities for disposed S&M EOL consumer electronics are still in the beginning stages. Currently, the cases of disposing and collecting the S&M EOL products at outside of residency can be classified as following two cases.

(i) In the areas with no collection boxes: EOL products are disposed outside by paying a fee, which then a contracted collection company with the local government picks them up under the pre-fixed time interval basis.
(ii) In the areas with collection boxes: EOL products are disposed at the collection box (see Figure 1) without paying a fee, which then a contracted private collection company picks them up under the pre-fixed time interval basis.

Table 2. IoT technologies and effects applied at different industries

| Industry | Applied areas | Applied IoT technology | Effects |
|---|---|---|---|
| Service | Restaurant, delivery, customer A/S | Kiosk, unmanned store, health service | 0.05% revenue increasing when 1% increasing of IoT using rate |
| Agriculture | Smart agriculture (farm, garden, etc.) | Humidity and temperature sensor, pressure sensor | Optimizing labor and resource usage, connection of crops with animals |
| Construction | Disaster forecasting algorithm and monitoring system, safety management at construction site, on-site heavy loading analysis | Data mining, decision tree, mixed neural network, circular neural network, heavy loading identification | Prevention of construction accident, recognizing situation of workers' danger and prevention in advance, minimizing accidents of workers' injuries |
| Manufacturing | Smart factory (robotics, operations, quality control, etc.) | Cyber physics system, robotics, 3D printing, cyber security | Efficiency of manufactu-ring, intelligent data collection and control, protection from cyber crimes |
| Logistics | Smart logistics (home delivery, port, railroads, etc.) | Smart control center, IoT sensor, SenseAware | Efficient inventory management, improving quality control, optimizing transportation layout, delivery by unmanned driving |

Table 3. IoT technologies applied domestically at the collection box

| Name | Disposed products | Applied technology |
|---|---|---|
| Superbin Basic | Can, plastic bottle | AI sensing, deep learning |
| Superbin Original | Can, plastic bottle | AI sensing, deep learning |
| Super Green PF-PVM | Plastic bottle | IoT AI, Return AI |
| Compressing garbage box with solar light power energy | Plastic bottle | Solar light power energy |
| TORMA T11 | Glass bottle | Bar-code identification |
| Today's separating collection | Milk pack | IoT AI |
| Unmanned food waste collecting box | Food waste | RFID |

When S&M EOL products are disposed at outside a residency (case i), the disposed EOL products may be stolen by an unauthorized private company who illegally dismantles products. So, Korea Electronics Recycling Corporative (KERC), which is the agency performing the EPR for manufacturers, will operate the free collection boxes at several higher population density areas (case ii) [3]. Whenever any S&M EOL products are ready


Figure 1. Collection box for disposing S&M EOL consumer electronics

for disposal, they can be loaded into the collection box by opening the door located at the top side. Then, disposed EOL products are collected and delivered to the recycling facility where appropriate recycling operations are provided. Therefore, the role and responsibility of reverse logistics are highly guaranteed.

Unfortunately, however, current reverse logistic activities of case ii, which collects the disposed S&M EOL products from the collection boxes only under the pre-fixed time interval basis without considering the actual conditions of the collection box, are having the following problems.

(i) Collections are performed without enough disposed products in the collection box (see Figure 2).
(ii) When amount of disposed products is over the capacity of the collection box, some of them are dumped outside and these products can be stolen by illegally dismantling companies (see Figure 3).

Figure 2. Not enough amount of disposals

Figure 3. Disposals at outside of collection box

2.2. **Suggestions for improvement.** A collection box which is currently used for the collection of S&M EOL products cannot identify how many EOL products are being disposed inside. In this study, IoT technology is applied for sensing the conditions (weight and volume) of each collection box by attaching sensors inside of the collection box (see Figure 4).

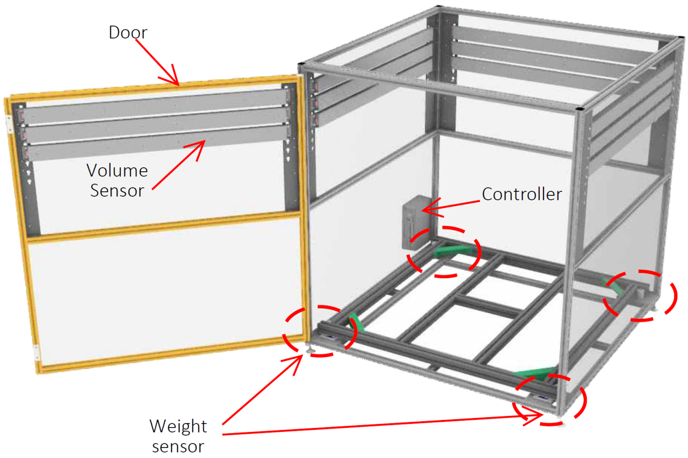


Figure 4. Sample of collection box with attaching sensors

The application of IoT technology measuring the volume and weight of the disposed products can provide the appropriate collection time required for each collection box. Therefore, the collection activities can be scheduled efficiently and overall transportation cost and amount of $CO_2$ emission can be reduced. Furthermore, the weight sensors attached to the collection box can provide actual weight of disposed products at the time of collection so the chance of leakage during the reverse logistics can be eliminated.

## 3. Analysis of Effects.

**3.1. Input data.** Currently 7,002 collection boxes for disposing S&M EOL consumer electronics have been dispatched throughout the 54 local provinces where population densities are higher than most in Korea. In order to analyze the effects of IoT technology application to the collection box, actual field data obtained from Incheon province during a 9-month (January to September, 2022) period are observed in this study (see Table 4). Unfortunately, however, detailed data needed for this study was not available from the actual field. Therefore, some data was collected by interviewing with field operators.

The reverse logistics with the current 770 collection boxes dispatched in Incheon province is operating regularly based on a pre-fixed time interval because the condition of each collection box cannot be identified at all. The analysis of actual field data and interviews revealed that an average of three vehicles operated per day for collecting an average 30.24 kg of disposed S&M EOL products per collection box. Also, annual total cost of operating one vehicle is estimated as $50,000 per year.

**3.2. Experimentations.** Current collection box used in the field is applied as experimental collection box in this study (see Figure 5 and Figure 6). Initial experimentations are performed to identify when the experimental collection box is occupied with average weight (30.24 kg) of S&M EOL products. Also, we are observing to see what happens to the experimental collection box collects more weights than 30.24 kg. The following are procedures of the experimentations.

(i) Same size of current collection box is applied as experimental collection box.
(ii) Total of 28 different types and sizes of S&M products are selected and a random number is assigned to each product.
(iii) Randomly selected S&M product is assumed as EOL product and disposed at the experimental collection box.
(iv) Sensors are located at four different heights; at 1/3 height (25 cm), 1/2 height (37.5 cm), 3/5 height (45 cm), and 2/3 height (50 cm) of the collection box. Then, weight

Table 4. Data applied for representing collections of disposed S&M EOL products

| | Name | Data (unit) | Collection method |
|---|---|---|---|
| (1) | Total 9 months collection weights | 1,016,162 (kg) | Actual field data |
| (2) | Total collection vehicles used for 9 months | 721 (vehicles) | Actual field data |
| (3) | Total operation days of collections for 9 months | 320 (days) | Actual field data |
| (4) | Average collection vehicles operating per day | 3 (vehicles/day) | Field interview |
| (5) | Average operation hours per day | 5 (hours/day) | Field interview |
| (6) | Average boxes collected per vehicle per hour | 7 (boxes/hour) | Field interview |
| (7) | Average annual operating cost per collection vehicle | 50,000 (dollars/year) | Field interview |
| (8) | Average number of collection boxes collected daily | 105 (boxes/day) | (4)×(5)×(6) |
| (9) | Average weight of S&M EOL products collected per collection vehicle | 1,409 (kg/vehicle) | (1)/(2) |
| (10) | Average total weight of S&M EOL products collected per day | 3,176 (kg/day) | (1)/(3) |
| (11) | Average weight of S&M EOL products collected per collection box | 30.24 (kg/box) | (10)/(8) |

Figure 5. Actual collection box

Figure 6. Experimental collection box

is measured when the volume of disposed products reaches at each height of the collection box.

(v) 30 experimentations are performed per four different heights. Therefore, a total of 120 experimental results are obtained.

Among 28 different weights (volume) of S&M products applied in the experimentations, the largest one is the microwave oven with 13.7 kg (32,430 cm$^3$) and the smallest one is a car phone installer with 0.2 kg (432 cm$^3$). The average volume is 12,166.86 cm$^3$ and standard deviation is 9,211.36 cm$^3$ and the average weight is 3.3 kg and standard deviation is 3.0 kg. The cases of experimentations are summarized in Table 5. When comparing the average weights of collected EOL products per collection box with four cases, it is

Table 5. Cases of experimentations

| Case | Height of sensors locating at collection box (cm) (total 75 cm) | Average weight of collected EOL products per collection box (kg) | Average number of disposed products per collection (product) |
|---|---|---|---|
| Case 1 | 1/3 Height (25.0 cm) | 21.55 (kg) | 8 (products) |
| Case 2 | 1/2 Height (37.5 cm) | 38.52 (kg) | 12 (products) |
| Case 3 | 3/5 Height (45.0 cm) | 51.44 (kg) | 15 (products) |
| Case 4 | 2/3 Height (50.0 cm) | 56.23 (kg) | 16 (products) |
| Total average | | 41.94 (kg) | 12.75 (products) |

Table 6. Expected effects by applying IoT technology

| Height of sensors locating at collection box (cm) (total 75 cm) | (12) Average weight of collected EOL products per collection (kg) | (13) Total number of collection boxes collected per day (box) | (14) Average number of collection boxes collected daily per vehicle (box) | (15) Rate of reduced number of collection boxes collected daily per vehicle (%) | (16) Total annual reduction of operating cost per vehicle ($) |
|---|---|---|---|---|---|
| No sensors | 30.24 (Current) | 105 | 35 | 0 | 0 |
| 1/2 Height (37.5 cm) | 38.52 (Improvement #1) | 82.45 | 27.48 | 21.49 | 10,745 |
| 3/5 Height (45.0 cm) | 51.44 (Improvement #2) | 61.74 | 20.58 | 41.20 | 20,600 |
| 2/3 Height (50.0 cm) | 56.23 (Improvement #3) | 56.48 | 18.83 | 46.20 | 23,100 |
| Applied equation | | (10)/(12) | (13)/3 | ([35-(14)]/35) × 100 | \$50,000 ×(15)/100 |

identified that three cases (cases 2, 3, 4) can collect more average weights of disposed products than current situation (30.24 kg).

3.3. **Expected effects by applying IoT technology.** Current average weight (30.24 kg) of S&M EOL products collected per collection box obtained from actual field data was tested. The data results found that the volume of disposed EOL products did not quite reach the halfway mark of the collection box (total 75 cm) at the time of collection. This is the evidence that current reverse logistics for collecting disposed S&M EOL products from collection boxes based on pre-fixed time interval is not efficient at all.

The experiments which increase the average weight of collections by applying IoT technology are summarized in Table 6. When sensors are located at three different heights (cases 2, 3, 4), which provides heavier average weight of collection, it is identified that the number of collection boxes collected daily per vehicle can be reduced accordingly. Also, the total operating cost for reverse logistic can be reduced accordingly.

4. **Conclusions.** The Korean government has taken care of increasing disposed EOL consumer electronics with the regulation of EPR by expanding number of mandatory products and strengthening the government's goal of recycling rate every year. However, the disposed S&M EOL products at collection boxes are collected with pre-fixed time interval basis without considering the conditions of collection boxes currently. Also, the exact weight of collection at each collection box cannot be identified and could allow for leaking to occur from the collection point to final delivery at the recycling facility.

This study analyzes the effects of adopting the IoT technology for solving the current problems of reverse logistics. Current field data and interview are applied for identifying the average collection weight of disposed S&M EOL products per collection box and the heights reached within the collection box are measured with same size experiment collection box. It was found that the average collection weight (30.24 kg) of disposal per collection box does not reach the halfway height of the collection box and this reveals that current collection activities of S&M EOL products from collection boxes are not operated efficiently.

Experiments are performed with locating IoT sensors at three different heights within the collection box where the average collection weight is heavier than the current average of 30.24 kg. Results showed that by applying the IoT sensors to the collection boxes we can reduce the number of daily collections up to 46.2% per vehicle. Results also showed that a maximum of 23,100 dollars of annual operating cost for reverse logistics per vehicle can be reduced when IoT sensors are located at the 2/3 height of the collection box which provided an average weight of collected EOL products per collection box as 56.23 kg.

Future studies should further explore how the application of IoT technology with the current reverse logistics of collecting disposed S&M EOL consumer electronics from collection boxes can also reduce the total amount of $CO_2$ emissions produced.

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