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Reverse Vending Machine and Its Impacts on Quantity and Quality of Recycled PET Bottles in Thailand

Ronnachai Tiyarattanachai, Isana Kongsawatvoragul, and Isara Anantavrasilp*

International College, King Mongkut's Institute of Technology Lakrabang, Bangkok 10520, Thailand

Abstract

Polyethylene Terephthalate (PET) has been one of the most favorable beverage packaging materials worldwide. Most used PET bottles would become waste after their usage. In many countries such as Germany and the United States, Reverse Vending Machine (RVM) has been widely used to collect recyclable wastes including PET bottles from consumers as part of their recycling and reverse logistics programs. Such machine helps increase quantity and quality of recycled PET bottles. However, RVM is still relatively new in Thailand. Therefore, this study has been conducted to learn acceptance of the machine by consumers along with its impact on quantity and quality of recycled PET bottles. The study has found that approximately 21% more of PET bottles were collected when a RVM is installed in the study area compared to its Business as Usual (BAU) waste collection in the area, which relies solely on building janitors to collect waste. In terms of waste quality, PET bottles collected by the machine were well homogenous with minimal contents of other kinds of materials (e.g., residual contents, caps, and straws).

Keywords: Municipal solid waste, recycle, materials recovery facility, reverse logistics, reverse vending machine.

1. Introduction

Despite tremendous efforts spent by both private and government sectors in encouraging more recycling in Thailand, the recycling rate is still relatively low with only approximately 22% of its wastes being recycled compared to the US, where approximately 34% of its wastes are recycled [1].This is unfortunate because, with proper management on recycling activities, more wastes could have been used as raw materials for manufacturing and would result in the decrease of demands on virgin materials [2-3]. Returning usable materials into manufacturing processes is also part of reverse logistics [4].

Used polyethylene terephthalate (PET) bottles are probably ones of the most important recyclable wastes. PET plastic is the world most favorable beverage packaging material due to its excellent properties. PET is well-known for its unbreakability and low weight compared to glass bottles with the same capacity [5]. As reported by the Pollution Control Department (PCD) of Thailand, plastic is also one of the main Municipal Solid Wastes (MSWs) in the country [6].

*Corresponding author: E-mail: ktronnac@kmitl.ac.th

In Thailand, MSWs are usually collected and sent to Material Recovery Facilities (MRFs), where the wastes will be sorted and handled before being sold to manufacturers that can use them in their manufacturing processes [7]. Traditional waste collection in Thailand relies on private waste collectors. In the past, these waste buyers usually came in their three-wheeler vehicles called ‘Saleng’. Nowadays, pick-up truck is their common choice of vehicle for picking up wastes. Thai people have referred to these waste buyers as Saleng. Therefore, these waste buyers are hereafter referred to ‘Saleng’ in this paper. Poorly-sorted and non-sorted wastes will have to go through pre-manufacturing process at the MRFs [8].

In this step, waste quality, especially in terms of waste homogeneousness, is one of the most important concerns of the manufacturers [8]. There have been evidences indicating that poorly-sorted recycled plastics can lead to poor quality of raw materials [9].

Per the Association of Postconsumer Plastic Recyclers (APR), caps and labels are ones of the most important contaminants and shall be removed from recycled PET bottles. These components of containers are made of different kinds of non-PET materials and would cause problems to plastic reclaimers [10]. Unfortunately, the National Association for PET Container Resources (NAPCOR) reported that full-wrap shrink labels account for 3% and 6% by weight of recycled bottles collected in the US and Canada in 2011, respectively [11].

Therefore, reliable and efficient pre-process sorting methods play an important role in throughput and cost of recycling process. Reverse Vending Machine (RVM) is probably one of the solutions to be used to increase quantity and quality of recyclable wastes. RVM is a stand-alone machine with unmanned recycling equipment installed. In general, RVMs are designed to cash back money to users who deposit wastes at the machines. The first RVM was invented in 1972 by Tomra Company. It has been widely used in the US for recycling beverage containers, especially for the ones subject to the Bottle Bills. For example, under the bill, more than 16.5 billion beverage containers have been recycled per year in California [12].The RVM, however, is still relatively new in Thailand and has not been widely used yet [13].

This study provides experimental data regarding the impacts of the RVM on consumer behavior in terms of the changes in the amount of PET bottles disposed for recycling. The study also explores the benefits of RVM in improving quality of collected PET bottles. The results of the study can be used to support decision making for enhancement of recycling industry and reverse logistics in Thailand.

2. Methodology

The study intends to learn consumer behavior and the changes in quality of collected PET bottles when different kinds of waste collectors including 1) non-separate bins; 2) separate bins by types of recyclable wastes; and 3) RVM are provided. Details of study methodology are described below.

2.1 Study Area, Study Population and Sample Size

The study area was set to be the 55th Anniversary Building, King Mongkut’s Institute of Technology Ladkrabang (KMITL) and its vicinity. The building is the house of 3 academic units of KMITL, namely, the International College, the College of Nano Technology, and the College of Data Storage Innovation.

This study area was selected because it is part of an academic institution, in which its population tends to be well-educated. Referring to the theory of innovation diffusion, this study population is likely to accept such an innovation as the RVM more easily than other groups of people [14].

As presented in Table 1, there are a total of 574 people in the study area, which include 516 undergraduate and graduate students; 19 administrative staff (e.g., secretaries); and 39 academic staff (i.e., lecturers and researchers)

Table 1 Study Population Profile

Academic Units and Types of Population	International College	College of Nano Technology	College of Data Storage Innovation	Total
Students	270	167	79	516
Administrative Staff	6	4	9	19
Academic Staff	16	17	6	39

2.2 Data collection

The study focuses on the PET bottle wastes. It consists of 3 phases according to the types of containers provided including:

1) Phase I: Non-separate Bins
2) Phase II: Separate Bins for Recyclable Wastes
3) Phase III: Reverse Vending Machine

In each phase, the amounts of PET bottles were recorded along with other contaminants to learn the impacts and behavioral changes due to the types of waste collectors provided. Data were collected during 2-week period for each phase.

The purpose of Phase I is to collect baseline data of PET bottles collected in the study area prior to installation of separate bins and RVM. For Phase II and Phase III, separate bins for recyclable wastes including the ones designated for PET bottle collection and a RVM were installed to learn the impacts of the waste collectors on the quantity and quality of wastes collected. Details of data collection in each phase are summarized below:

2.2.1 Phase I: Non-separate Bins

Prior to the study, the wastes in the study area had been simply collected by the building's janitors. There was no separated waste bins installed. In the beginning of the study, we recorded the amount of wastes under this condition to serve as baseline data.

PET bottles and other wastes were collected daily in non-separate bins located all over the study area. No separate bins and RVM were installed in the area. The janitors usually sorted PET bottles from mixed wastes in non-separate bins and accumulated them into a considerable amount before selling them to Saleng. The selling price was generally lower than the market price.

Still, based on some personal conversations with the janitors, they were suggested by the waste buyers that PET bottles shall not be mixed with other kinds of wastes. Different colors of PET bottles shall be separated. Remaining contents shall be drained out and volume shall be reduced. The janitors generally reduce the volume by simply stepping on the bottles to flatten them. Failure in sorting and volume reduction would further reduce the selling price of PET bottles.

2.2.2 Phase II: Separate Bins for Recyclable Wastes

The objective of this phase of study is to learn the impact of provided separate bins for recyclable wastes on the amount of PET bottles collected. The results of this phase will also be used as another level of baseline data to later see the impacts of RVM on the amount of PET bottles collected, when a RVM is provided in addition to the separate bins for recyclable wastes.

Additionally, residual contents (liquid) and alien contents (e.g., straws, caps, and other materials) were recorded in this phase.

2.2.3 Phase III: Reverse Vending Machine

In this phase of the study, a RVM was installed at the ground floor of the study area. The RVM used for this study is named P'PET, one of the most advanced RVMs in Thailand invented by Thai innovator. Similar to Phase II of the study, quantities of residual and alien contents were recorded. Separate bins for recyclable wastes previously installed in Phase II of study were remained in their positions.

Since RVM is relatively new in Thailand including the study area. The study left some leap time to introduce and provide instructions for the use of machine to users in the study area for 2 weeks before initiating data collection of Phase III. This is to make certain that consumers are familiar with machine before data collection period.

3. The RVM

Our RVM, P'PET, is a machine that accepts PET bottles from the users and returns cash back to them. In other words, it buys the bottle from the users. It is designed to accept only clean, contaminants free, PET bottles. To detect the contaminant, P'PET is equipped with a barcode scanner and a high-sensitivity weight sensor to measure bottle weight. To deposit a bottle into the machine, the user must scan the bottle's barcode first. Using the barcode, the machine can determine whether the bottle is registered in the database and look up for its weight profile. Then, after the profile is loaded, the machine will open the bottle chamber where the user can deposit the bottle.Before the deposit, the user must separate the bottle cap from the bottle. Then he can put the bottle cap to the cap hole and the bottle to the bottle chamber.

After the deposit, the weight of the bottle is compared with bottle profiles database. If the weight of the given bottle matches the one in the database, the bottle will be accepted. If the bottle profile is not found in the database or the bottle weight does not match the stored profile, the machine will not accept the bottle. Once the bottles are successfully accepted, the machine will tear the bottles into small pieces and put them into storage chamber to be collected later. Then, it will cash out money to user. The amount of cash depends on bottle weights and market prices of recycled PET bottles. Figure 1 shows the P'PET machine.

The weight-profile checking prevents the user to put the bottle with contaminants (even bottle cap) into the machine. Indeed, the bottle profiles database must be updated constantly. Therefore, P'PET is also equipped with 2G/3G cellular and WiFi network adaptors allowing the RVM to periodically update its bottles database. Not only for the database update, the Internet connection also allows the RVM to send back the collected bottles and machine usage statistics back to the server. These statistics would further help improve the machine as well as providing an insight to user waste disposal behaviors.

Figure 1 P'PET RVM

4. Results and Discussion

Data collected in the study are presented in terms of quantity and quality of PET bottles collected.

4.1 Quantity of PET Bottles

As presented in Table 2, the average total weights of PET bottles collected during Phase I, Phase II, and Phase III of the study are 13.2, 12.3, and 16.6 kilograms per week (kg/wk), respectively. Overall, quantities of PET bottles collected during Phase III were increased by approximately 21% compared to Phase I and 26% compared to Phase II.

Figure 2 illustrates the amount of PET bottles collected in each phase categorized by collection device. Out of the average 12.3 kilograms of PET bottles collected during Phase II, 8.4 kilograms (68%) were collected from appropriate bins designated for PET bottles, while 3.9 kilograms (32%) were collected from other bins.

During Phase III, out of the average 16.6 kilograms of PET bottles collected per week, 10.0 kilograms (60%) were collected from PET bottle bins; 4.3 kilograms (26%) were collected from other bins; and 2.3 kilograms (14%) were collected from the RVM.

Table 2 Summary of Study Results

Phase	**Week 1**		**Week 2**		**Average**	
	Pc*	**Kg**	**Pc**	**Kg**	**Pc**	**Kg**
Phase 1 (17/2/13 - 2/3/13)						
PET bottles	-	14.1	-	12.2	-	13.2
Phase 2 (24/3/13 - 6/4/13)						
PET bottles in designated PET bins	378	7.4	439	9.3	409	8.4
PET bottles in non-designated PET bins	169	3.5	204	4.2	187	3.9
Caps	259	0.5	442	0.8	351	0.6
Labels	303	0.2	439	0.4	372	0.3
Other contaminants	-	7.1	-	7.1	-	7.1
***Phase 3 (21/4/13 - 18/5/13)**						
PET bottles in designated PET bins	539	12.2	141	2.7	455	10.0
PET bottles in non-designated PET bins	182	4.3	80	1.6	186	4.3
Caps	600	1.3	244	0.4	544	1.1
Labels	529	0.8	201	0.2	497	0.6
Other contaminants	-	9.4	-	10.7	-	16.4
PET bottles in RVM	127	3.5	46	1.1	86.5	2.3
Caps in RVM	142	0.2	86	0.2	114	0.2

*Pc = Piece

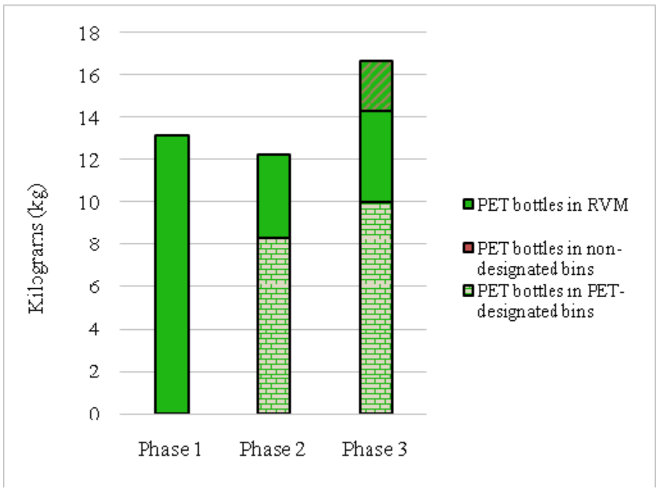

Figure 2 Comparison of PET bottles collected from different phases by types of waste collectors

The results show that, with the presence of RVM, more PET bottles were recycled. However, separate bins for recyclable wastes alone do not post positive impact in increasing quantity of recycled PET bottles. Approximately the same amounts of PET bottles were disposed into PET-designated bins and non-designated bins during both phases. The additional amount of PET bottles collected during Phase III was largely due to the presence of RVM.

Still, it should be noted that not all of the increased amount of PET bottles collected during Phase III went to RVM only, some additional amounts of PET bottles also went to PET bottle designated bins and other non-designated bins (Figure 2). This is because the RVM is equipped with weight sensor, which will reject PET bottles if their weights do not match the profile.

With this function, RVM is able to reject PET bottles with residual or alien contents. When PET bottles are rejected, users generally have two options as follows:

- Option 1 - users may drained out residual contents or removed alien contents including caps out of the bottles before depositing them into the machine again; or
- Option 2 - users may fail to resolve the rejection causes and dispose the bottles somewhere else.

Option 2 is likely to be the cause of the increased amount of PET bottles disposed in the PET bottle bins and other bins during Phase III. This is because RVM was still new to the users during the phase of the study. Users were likely not to know how to resolve the rejection issues.

The numbers of bottles accepted and rejected by the RVM are presented in Table 3.

Table 3 Summary of Botile Reject Rate

Day	Week 1		Week 2	
	Accepted	**Rejected**	**Accepted**	**Rejected**
1	28	46	18	32
2	30	22	3	7
3	13	9	0	15
4	22	44	7	7
5	6	0	15	19
6	13	34	3	10
7	15	43	0	10
Total	127	198	46	100

As presented in Table 3, the number of rejected bottles is in fact higher than the number of accepted bottles. There are a few implications of this information. First, the users may not be familiar with the use of RVM and fail to comply with bottle acceptance requirements (e.g., weight, free of residual contents and caps). Second, weight sensor of the machine may had been set too sensitive resulting in unnecessary rejections.

It should also be noted that the total amount of bottles attempted to be disposed at the machine came down from 325 bottles in Week 1 to 146 bottles in Week 2. Reliability of the machine could be responsible for this declining rate.

After the 1st week of data collection, the RVM was out order for about 1 week, before going to Week 2 of data collection. It was visually observed that some users brought their bottles and attempted to dispose them into the RVM. When they failed, the users may feel reluctant to come back to use the machine.

4.2 Quality of PET Bottles

During Phases II and III of the study, residual contents, straws, and other alien materials were also recorded as presented in Table I. Residual contents (liquid) were recorded at 7.1 kilograms and 16.42 kilograms in the bins designated for PET bottles during Phase II and Phase III of the study, respectively. These amounts account for 85% and 165% of the bottle weights recorded in the bins in Phase II and Phase III, respectively.

Residual contents in PET bottles deposited in the RVM were insignificant because of the weight detection sensor equipped with the machine, which would reject bottles with residual contents. The machine is also equipped with a slot for collecting removed caps from the recycled bottles. Due to weight sensor, users would be forced to remove them before depositing the bottles. Therefore, PET bottles collected by the machine are considered to be ‘clean’ and ‘homogenous’.

However, the machine was not able to segregate labels from recycled bottles neither by its mechanism nor forcing users to remove them. This is because label’s weight is too low. Setting weight detection low enough to detect label attached to recycled bottle would be too sensitive. Doing so would cause a lot of expected bottle rejections and may discourage users from recycling the bottles.

5. Conclusions

The study has been conducted to learn the impacts of RVM on consumer behavior in terms of the change in quantity and quality of recycled PET bottles. The results show that only placing separate bin for PET bottles along with other bins for recyclable wastes does not cause positive impacts on quantity and quality of recycled PET bottles. On the other hand, when the bins are accompanied with a RVM, approximately 26% of PET bottles were recycled more.

The RVM was also able to improve quality of recycled PET bottles due to its weight sensor and the fact that it only receives PET bottles. Homogeneousness of PET bottles was improved; bottles with caps, residual contents, and alien materials were completely rejected. However, the machine was not able to separate labels from recycled bottles.

Due to its functions and capability in improving quantity and quality of wastes, RVM should be used as part of reverse logistics process and recycle in Thailand.

The RVM used for the study, however, experienced some reliability issues. This is likely to be the cause of lower bottle depositions recorded in the 2nd week of data collection period in Phase III of the study. More bottles were rejected than the ones accepted by the machine.

6. Recommendations for the Design of RVM

Based on the experience with the use of the RVM in this study, recommendations for the design of the machine are as follows:

1) Texture sensing method should be considered to replace barcode scanning method to avoid rejection rate caused by unreadable barcode and unknown barcode.

2) To reduce volume of collected PET bottles, the machine should be equipped with compression mechanism instead of shredding mechanism. The shredding mechanism may jeopardize purity of collected wastes if different kinds of materials are not completely separated like the case of PET bottles and their labels.

3) There should be a designated slot in the machine for collecting bottle labels. Without it, users are unlikely to remove the labels before depositing the bottles into the machine.

4) There should be a clear instruction about how to dispose PET bottles into the machine posted at the machine. The instruction could either be attached to the side of the machine or graphically run on its screen. This is especially important for a new RVM market like Thailand where users are still not familiar with the use of the machine.

5) Reliability of the machine should be set as one of the top priority for improving the machine. This issue is very important for a new RVM market, where such machine has not been widely accepted. Unreliable machine might make users feel reluctant to accept this relatively new innovation in recycling process.

7. Recommendations for Future Studies

The following future studies are recommended.

1) Similar studies should be conducted with RVMs, which accept different kinds of wastes (e.g., can and glass). If repetitive results are obtained, companies and government agencies can be more confident in using and purchasing for the machines.

2) Some repetitive studies should be conducted with different group of study population. In real-world applications, there will be more variety of users in the market, who may or may not have the same behavior as found in this study.

3) There should be a study to conduct cost-effectiveness of the machine as opposed to traditional waste collection system (e.g., the use of Saleng and door-to-door pick-up truck waste collectors). This study would be beneficial for any potential buyer of the machine

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